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Groundwater Nitrate Contamination and Driving Forces from Intensive Cropland in the North China Plain

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Abstract High nitrate in groundwater is a serious problem especially in highly active agricultural areas. In this paper, the concentration and spatial distribution of groundwater nitrate in cropland area in the North China Plain were assessed by statistical and geostatistical techniques. Nitrate concentration in groundwater reached a maximum of 526.58 mg/L, and 47.2%, 21.33% and 11.13% of samples had levels in excess of nitrate safety threshold concentration (50 mg/L) in shallow, middle-deep and deep groundwater, respectively. And NO_3^- content significantly decreased with groundwater depth. Groundwater nitrate concentrations under vegetable area are significantly higher than ones under grain and orchard. And there are great differences in spatial distribution of nitrate in the North China Plain and pollution hotspot areas are mainly in Shandong Province. Based on both multiple regressions combined with principal component analysis (PCA), significant variables for nitrate variation in three types of ground water were found: population per unit area, percentage of vegetable area, percentage of grain crop area, livestock per unit area, annual precipitation and annual mean temperature for shallow groundwater; population per unit area and percentage of vegetable area for middle-deep groundwater; percentage of vegetable area, percentage of grain crop area and livestock per unit area for deep groundwater.

Key words Groundwater, Nitrate contamination, Spatial variation, Principal component analysis, Regression analysis

1 Introduction

Groundwater is an important natural resource that provides drinking water supplies for nearly half the population in China and in the whole world as well[1-3]. But this natural resource is susceptible to contamination by various human activities, such as industry, municipal discharges and excessive use of fertilizer in croplands[4-5]. Nitrate occurs naturally in the environment, but its contents in groundwater commonly exceed natural levels, which may produce potential hazards to human health, such as birth defects, digestive cancers and leading to increase in the occurrence of an impairment of immune-system[6-8].

The agriculture-derived nitrate pollution has been an environmental issue in world[9]. Higher concentrations in shallow groundwater in intensive agricultural regions are generally believed to come from agricultural activities[10]. Efforts have been made to understand how factors (*e. g.* redox conditions, soil properties, iron, dissolved oxygen concentrations and so on) affect the final nitrate concentration in the groundwater[11-13]. However, it is difficult to alter these factors for mitigating nitrate pollution, such as dissolved oxygen concentrations[14-15]. Therefore, it is important to analyze the driving forces on nitrate leaching sources that can help regulate groundwater nitrate contamination. Numerous studies have demonstrated irrigation and fertilizer applications in agriculture as the sole reason for the elevated nitrate concentration in groundwater[16-18]. Furthermore, swine manure application also has impacted nitrate concentration in subsurface drainage water, for excess swine manure as nitrogen supplement resulting in greater soil nitrate residual without increasing yield and therefore possible buildup of excessive nitrate amounts in the root zone causing increased NO_3^- leaching to the groundwater[19-21]. Relationships between groundwater quality and agricultural practices will ultimately develop good cultivation for implementation by farmers and other land users for long term sustainability of our production systems. Additionally, it is also important to understand other factors related to groundwater contamination, such as climate variables[22].

The North China Plain is the most intensive agricultural regions, called as "China's granary"[23]. Monitoring and understanding trends in groundwater nitrate concentration in this area are necessary and important for determining the effect of agricultural practices on groundwater quality. In 1996, Zhang Weili *et al.*[24] found nitrate pollution in groundwater caused by agriculture in the North China Plain. Then, many districts have been reported with groundwater nitrate contamination[25-27]. Zhao Tongke *et al.*[28] conducted the survey of groundwater nitrate pollution in seven provinces in the North China[28]. However, research on the

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spatial distribution and influencing factors of nitrate pollution in this area are inadequate. Therefore, this study aimed at the analysis of nitrate pollution situation and probable factors in different groundwater depth, in order to develop suitable agricultural practices to mitigate the groundwater nitrate pollution to a greater extent.

2 Material and methods

2.1 Overview of study area The study area (Fig. 1) is a three-province and two-municipality area in the North China Plain, including Hebei Province, Henan Province, Shandong Province, Beijing City and Tianjin City. The area is approximately 514 126 km^2, with longitude from 110°22′ E to 122°42′ E and latitude from 31°23′ N to 42°39′ N, of which 347 741 km^2 is used for cropland[29] (Fig. 1). The mainly grown crops are wheat, maize, greenhouse vegetables, cotton and fruit, of which the wheat-maize rotation, vegetables and orchards account for multitude cultivated area. The temperate, semi-moist, and continental climate in the study area is influenced by the monsoon, with 400 – 800 mm of annual precipitation, mainly between June and September. The mean temperature is 8 – 14℃, and the annual accumulated temperature (>0℃) is 3 200 – 4 500℃[23].

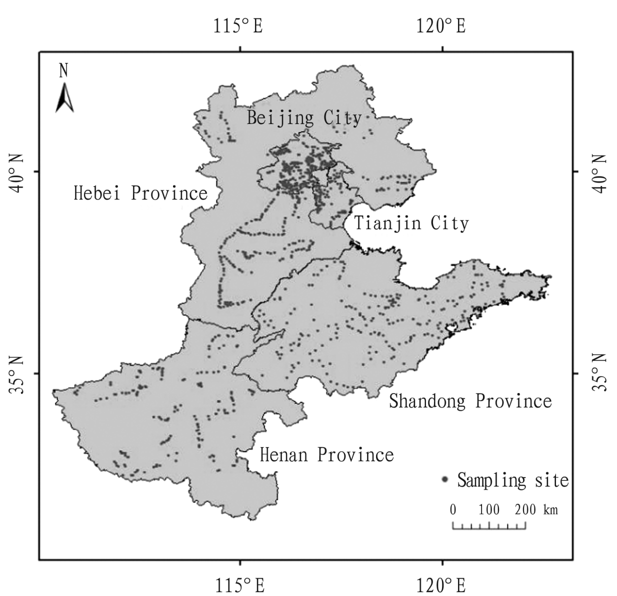


Fig. 1 Location of sampling wells in intensive cropland in the region of North China

2.2 Sampling and data collection About 1 111 groundwater samples were collected in 2002, including 343 in Beijing, 105 in Tianjin, 239 in Hebei province, 206 in Henan and 218 in Shandong (Fig. 1). The sampling was conducted in May (before rainy season) and October (after rainy season) for every site, and mainly involving intensive cropland, and grain crop, vegetable crop and orchard. Samples were collected in polyethylene bottles after pumping the wells for about 30 min. The pumping ensured that collected water samples did not come from the water in the storage within the wells. The polyethylene bottles were first rinsed with the water samples to be collected to reduce the probability of contamination. All samples were transported in an ice-cooled cabin to the laboratory and they were stored in a cooler until analysis. Nitrate concentrations of water samples were analyzed in the laboratory using a colorimetric method with an UV-VIS spectrophotometer[30].

During sampling, basic information about well location, groundwater depth, planting pattern and surrounding land-use were collected. According to depth, sampling wells were divided into three types, shallow (0 – 30 m), middle-deep (30 – 100 m) and deep (>100 m). Additionally, ten possible variables including per capita agricultural production, livestock per unit area, percentage of grain crop area, percentage of vegetable area, percentage of orchard area, amount of nitrogen fertilizer per unit area, percentage of effective irrigation area, population per unit area and two climate variables (annual mean temperature and precipitation), were assembled at the municipal level from statistical data and literatures[29, 31].

2.3 Statistical and geostatistical analyses Analyzed with the Shapiro-Wilk test, data regarding NO_3^- concentration were not normally distributed. Then, the nonparametric Mann-Whitney U test or Kruskal-Wallis test was used to compare differences of nitrate concentration among well depth, sampling seasons (before and after rainy season) and cropland uses.

Geostatistical analyses were performed to determine the spatial extent of groundwater nitrate contamination, which were subjected to three stages of analysis: the first involved determining the type of distribution using histogram views and Voronoi maps; the second stage represented fitting the best representative semivariogram model; and the final stage involved the constructing the spatial distribution maps for some variable based on kriging interpolation techniques. We used GS+ software[32] to model experimental semivariograms and ArcGIS Geostatistical Analyst (ESRI version 10.0) to conduct kriging and to map kriging predicted values of nitrate.

Principal component analysis (PCA) was used in this study to transform a number of predictive variables into a small number of artificial variables known as principal components (PC) with a variation reduction technique. The table of rotated principal components loadings was used for confirmation of PC. The ordination diagram also presents the PCA result, in which all of the variables are represented by arrows. A smaller angle between arrows represents a higher correlation between variables, arrow direction represents positive or negative correlation, and arrows length corresponds to variance contribution to PC. The significant factors and the regression model for nitrate variation were then completed by stepwise regression with stepwise Akaike's Information Criterion (AIC). In analysis, square-root transformation was applied to all data to transform non-normal data to a data set that is reasonably normal. All statistical analyses were conducted using R software (version 3.0.3).

3 Results

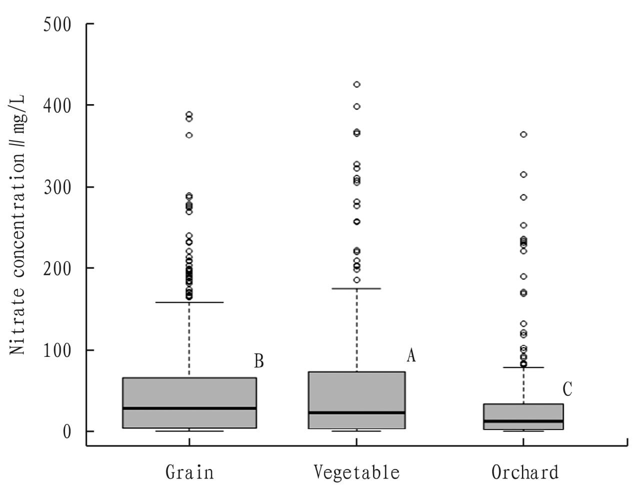
3.1 Occurrence of nitrate in groundwater Data regarding NO_3^- contents were statistically analyzed (Table 1). Nitrate concentrations collected before rainy season (in May) reached a maximum value of 417.59 mg/L with a median value of 36.39 mg/L. Correspondingly, nitrate concentration after rainy season (in October) reached a maximum value of 526.58 mg/L with a median value of 42.64 mg/L, significantly higher than those in May with the Mann-Whitney U test ($P < 0.05$). The non-parametric test also showed there are significant differences in nitrate concentration among grain, vegetable and orchard cropland with a 1% significance level (Fig. 2). The highest content of NO_3^- was under vegetable area, followed by grain and orchard areas.

Nitrate content decreased with groundwater depth, and there are statistically significant differences among shallow, middle-deep and deep wells, analyzed with Kruskal-Wallis test ($P < 0.05$). In addition, coefficients of variations (CV) were very high in deep well, showing larger variability of NO_3^-.

In Fig. 3, the results of groundwater analysis for NO_3^- concentration are shown with frequency distribution. The distribution of NO_3^- content is positively skewed in shallow, middle-deep and deep wells. In shallow wells, 34.45% of the samples (154) showed low NO_3^- concentrations (< 20 mg/L), NO_3^- concentrations in 18.34% of the samples (82) were in the range of 20 – 50 mg/L, and 47.2% of the samples had levels in excess of the 50 mg/L NO_3^-. Concentration of NO_3^- in 23.71% of the samples was above 100 mg/L. In middle-deep wells, 50.34% of the samples (221) showed low NO_3^- concentrations (< 20 mg/L); NO_3^- concentrations in 25.97% of the samples (114) were in the range of 20 – 50 mg/L, and 23.69% of the samples had levels in excess of the 50 mg/L NO_3^-. Concentration of NO_3^- in 10.25% of the samples was above 100 mg/L. Furthermore, NO_3^- concentrations in deep wells were lower than shallow and middle-deep wells. Among the samples, 12.89% of them (29) had levels in excess of the 50 mg/L NO_3^-, and concentration of NO_3^- in 3.56% of them (8) was above 100 mg/L.

Table 1 Nitrate concentration in water supply wells: descriptive statistical analysis mg/L

Month	Number of samples	Depth type	Min	1st Qu.	Median	Mean	3rd Qu.	Max	CV // %
May	447	Shallow	0.000 4	9.21	36.39	63.10	82.48	417.59	124
	439	Middle-deep	0.000 4	3.58	18.63	37.14	45.98	354.27	146
	225	Deep	0.000 4	0.58	2.94	18.16	18.93	499.58	238
October	447	Shallow	0.000 4	8.04	42.64	73.99	113.90	526.58	118
	439	Middle-deep	0.000 4	3.78	18.43	41.08	44.52	402.63	157
	225	Deep	0.000 4	0.38	3.22	23.01	24.68	466.40	214



Note: Different letters on the top of boxes represent a significant difference between different cropland use types ($P < 0.05$).

Fig. 2 Comparisons of measured groundwater nitrate concentration among different cropland use types in three depths of wells in study area.

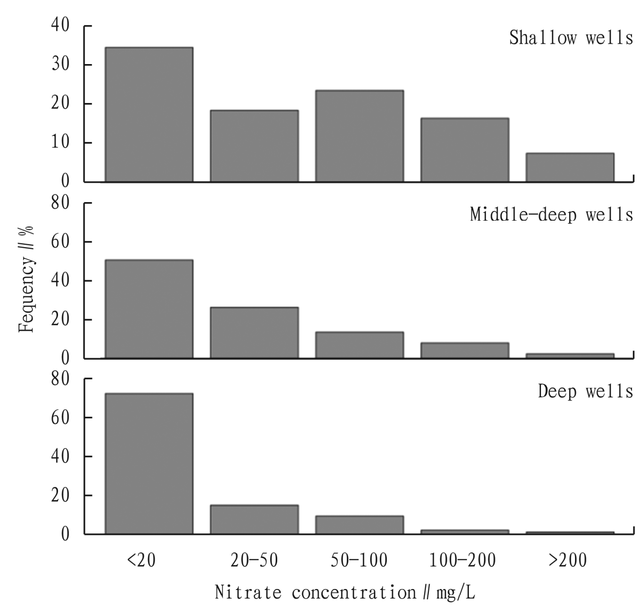


Fig. 3 Frequency distribution for nitrate concentration in groundwater samples from the study area

3.2 Geospatial variation of nitrate concentration Spatial statistics were able to estimate the distribution of nitrate contamination in the study area. The computed model parameters are presented in Table 2. The spatial semivariogram may be affected by intrinsic (physical, chemical, and biological characteristics of hydraulic and geographic conditions) and/or extrinsic (agricultural management practices, such as fertilization, irrigation and animal wastes) factors and can be classified into three categories according to a nugget-to-sill ratio (%), with a ratio of < 25% indicating a strong spatial dependence, a ratio of 25% – 75% indicating a moderate spatial dependence and a ratio of > 75% indicating a weak spatial dependence[33]. In this study, it is noteworthy that the ratios of nugget-to-sill for NO_3^- in middle-deep and deep wells are less than 25%, which showed a spatial dependence and might be completely attributed to intrinsic factors. In addition, the ratio of nugget-to-sill for NO_3^- in shallow wells is 32%, showing a moderate spatial dependence, which might be determined by extrinsic factors and intrinsic factors.

Validation analysis was performed to evaluate the accuracy of the interpolation of the ordinary Kriging. The residual sum of squares (RSS) and the correlation coefficient (r^2) were then used to evaluate the performance of the interpolation. Ideally, RSS should be as small as possible, and r^2 should be close to 1. The result of validation showed that the RSS ranged from 0.096 to 0.421 and r^2 ranged from 0.229 to 0.341, indicating an accuracy of predictions.

Spatial distribution of nitrate concentrations was shown in Fig.4. The location and areal coverage of six different NO_3^- concentration classes were different in shallow, middle-deep and deep wells. The safety threshold interval (< 50 mg/L) generally decreased, while the interval of 50 – 100 mg/L increased in shallow wells. In deep wells, the higher interval of 100 – 200 mg/L generally decreased. Kriging prediction maps indicate that higher nitrate concentration mainly encountered in Shandong Province from shallow to deep wells. Yantai, Weifang, Rizhao, Linyi, Zaozhuang and Zibo districts have been hotspot areas for nitrate contamination. Geographical variations for nitrate in Henan province are noteworthy. For example, nitrate concentrations in shallow wells were high in Pingdingshan, Xuchang and Luohe districts; while in middle-deep wells nitrate concentrations were high in Qiyuan and Jiaozuo districts. Such high intra-provincial variations were also remarkable in Hebei province. Zhangjiakou, Qinhuangdao and Chengde districts are heavily polluted by nitrate. These heavily contaminated areas should be monitored specifically and apply appropriate alternative management practices to protect aquifers against degradation.

Table 2 Model parameters for semivariograms of logit-transformed NO_3^- concentration in shallow, middle-deep and deep wells

Depth	Model	Nugget	Sill	Nugget/Sill	Range//m	r^2	RSS
Shallow	Spherical	0.220	0.683	0.32	81 000	0.30	0.179
Middle-deep	Exponential	0.086	0.606	0.14	93 000	0.30	0.096
Deep	Spherical	0.072	1.013	0.07	92 000	0.34	0.421

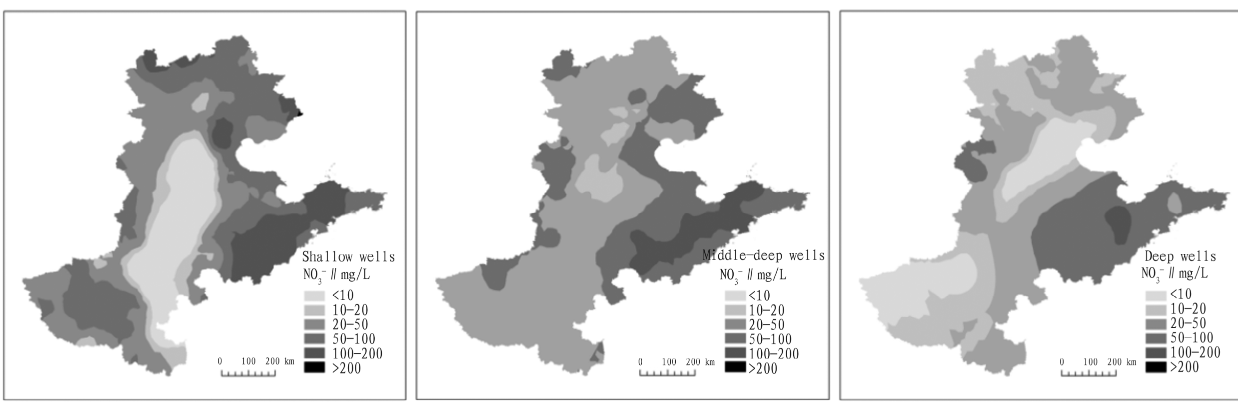


Fig.4 Spatial pattern of estimated groundwater nitrate concentration in shallow, middle-deep and deep wells in the study area

3.3 Analysis on influencing factors Principal component analysis (PCA) of ten variables probably affecting variation of groundwater nitrate in shallow, middle-deep and deep wells was conducted. A data matrix (Table 3) extracts the dominant patterns in terms of a complementary set of score and loading plots. The pattern in three types of wells was different for the principal components. PCA in shallow wells showed the first four PCs explained 76% of the total variance. Among these PCs, the first PCs (PC1) explained 27% of total variance, on which 3 factors, population per unit area (POPp), percentage of vegetable area (VGp) and percentage of grain crop area (GNp) have high loading. The second PCs (PC2), accounting for approximately 19% of the total variation, was loaded heavily with per capita agricultural production (Agdp). The third PCs (PC3) and the forth PCs (PC4) accounted for 15% and 14% of the total variance, with high loading of livestock per unit area (LS), annual precipitation (Pre) and annual mean temperature (TM), respectively. In middle-deep wells, the first two PCs explained 54% of the total variance. PC1 explains 28% of total variance and it loaded heavily on population per unit area (POPp) and percentage of vegetable area (VGp). PC2, accounting for approximately 25% of the total variation, was loaded heavily with high percentage of orchard area (Fup). Additionally, in deep wells, the first four PCs explained 85% of the total variance. PC1 explained 24% of total variance, on which 3 factors, TM, POPp and percentage of irrigation area (IRp) have high loading. PC2, accounting for approximately 18% of the total variation, was loaded heavily with GNp and VGp. PC3, accounting for approximately 22% of the total variation, was loaded heavily with Pre and Fgdp. And PC4 accounted for 18% of the total variation, with high loading on LS.

A multiple stepwise regression analysis of the principal components was then used to determine independent variables that are significant for the variation of the transformed nitrate concentration. With Akaike's Information Criterion, significant PCs were selected as predictor variables. Regression results for shallow well analysis showed PC1, PC3 and PC4 are significant variables for variance of NO_3^-. In regression equation, the interception is 11.78 and coefficients of PC1, PC3 and PC4 are 0.365 2, –0.746 7 and 0.384 3, respectively. Regression for middle-deep well analysis showed PC1 is significant variables for variance of NO_3^-, and in regression equation, the interception is 11.80 and coefficient of PC1 is 0.387 7. While for deep wells, regression showed PC2 and PC4 are significant variables for variance of NO_3^-, and in regression equation, the interception is 9.90 and coefficients of PC2 and PC4 are 0.146 9 and 0.443 1, respectively. Combined with principal analysis and stepwise regression results, effective factors for variation of NO_3^- in three types of wells are concluded: population per unit area, percentage of vegetable area, percentage of grain crop area, livestock per unit area, annual precipitation and annual mean temperature for shallow groundwater; population per unit area and percentage of vegetable area for middle-deep groundwater; and percentage of vegetable area, percentage of grain crop area and livestock per unit area for deep groundwater.

Table 3 Rotated principal components loadings of ten variables in shallow, middle-deep and deep wells

Variables	Shallow well				Middle-deep well		Deep well			
	PC1	PC2	PC3	PC4	PC1	PC2	PC1	PC2	PC3	PC4
Agdp	0.23	0.89	0.09	−0.11	−0.02	−0.68	−0.41	−0.22	0.80	0.22
GNp	0.80	0.07	−0.17	0	0.76	−0.32	0.20	0.86	−0.02	−0.25
VGp	0.82	0.1	−0.01	0.22	0.82	−0.12	0.20	0.84	0.08	0.29
Fup	0.36	0.54	−0.33	−0.16	0.22	−0.75	0.09	−0.63	0.69	0.04
Pre	−0.15	−0.18	0.30	0.81	0.11	0.68	−0.11	−0.25	−0.87	0.19
TM	0.29	−0.05	−0.19	0.83	0.50	0.17	0.87	0.13	0.14	−0.21
POPp	0.88	−0.05	0.08	−0.04	0.83	−0.13	0.76	0.06	−0.06	0.51
LS	−0.19	0.02	0.90	0.02	−0.16	0.62	−0.04	0.02	0.06	0.95
NGp	0.42	−0.35	0.64	0.04	0.56	0.53	0.46	−0.08	−0.49	0.60
IRp	0.38	−0.77	0.18	0.05	0.49	0.48	0.75	0.32	−0.30	0.13
SS loading	2.74	1.86	1.53	1.44	2.84	2.55	2.37	2.07	2.23	1.83
Proportion Var	0.27	0.19	0.15	0.14	0.28	0.25	0.24	0.21	0.22	0.18
Cumulative Var	0.27	0.46	0.61	0.76	0.28	0.54	0.24	0.67	0.46	0.85
Proportion Explained	0.36	0.25	0.20	0.19	0.53	0.47	0.28	0.24	0.26	0.22
Cumulative Proportion	0.36	0.61	0.81	1.00	0.53	1.00	0.28	0.78	0.54	1.00

Note: Agdp, the gross agricultural production per capita; GNp, percentage of grain crop area; VGp, percentage of vegetable area; Fup, percentage of orchard area; Pre, annual precipitation; TM, annual mean temperature; POPp, unit-area population; LS, unit-area livestock quantity; NGp, unit-area nitrogen fertilizer; IRp, percentage of irrigation area.

4 Discussions

According to WHO, 47.2%, 21.33% and 11.13% of the groundwater samples have been in excess of nitrate safety threshold concentration (50 mg/L) in shallow, middle-deep and deep wells, which shows nitrate pollution of groundwater in the North China Plain cannot be ignored. Long-term groundwater quality monitoring studies are needed and will provide the critically needed data on changes in ground water quality with different land use management programs and to understand if good agriculture practices are effective in protecting groundwater.

The difference of nitrate concentration before and after the rainy season is consistent with many reports, indicating that large amounts of precipitation can cause rapid infiltration (3.8 – 5.8 mm/min); accordingly, the contamination or excess fertilizer/manure application might have entered the groundwater via heavy rainfall after the rainy season (from June to August)[34]. CV of nitrate was all beyond 100% in three types of wells. Higher CV means large variation among sampling sites. In deep groundwater, nitrate standard deviation is lower than that in shallow and the middle-deep groundwater, and mean nitrate contents also lower sharply, which leads to a larger CV in deep groundwater.

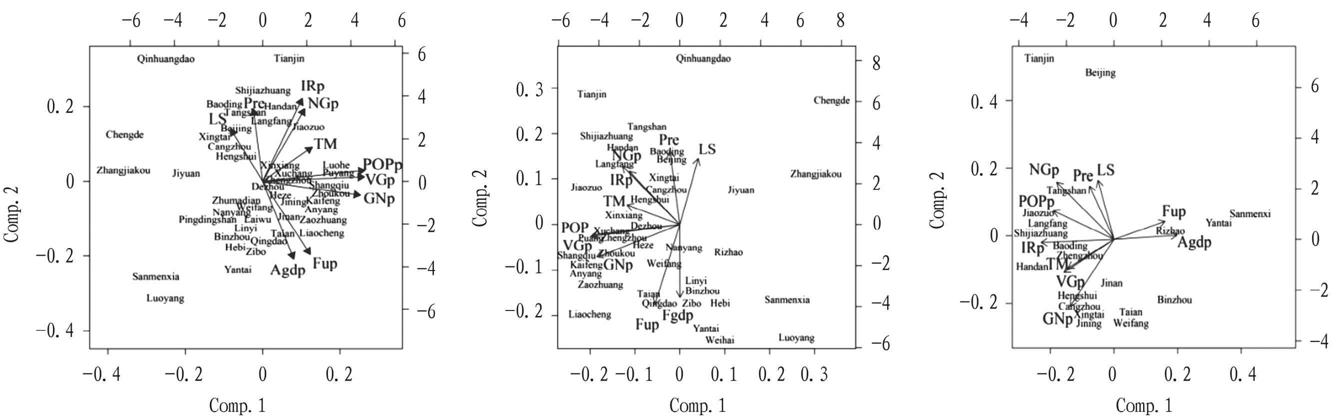
Difference of groundwater nitrate contamination under cropland use rooted in agriculture management practices such as cropping pattern, fertilizer application and irrigation way[35]. Many reports showed excessive nitrate in groundwater is closely related to vegetation planting, for its higher loads of nitrogen[24, 28, 36–37], which is no exception in this research. Space distribution of nitrate in Fig. 3 shows areas in the central and eastern parts of Shandong Province have high nitrate concentration, where vegetable grow widespreadly. Results of multivariate statistical analysis also showed the variable of percentage of vegetable area is significant factor for variation of groundwater nitrate in three types of groundwater. Fig. 5 with the first two PC in three types of wells showed many cities, such as Liaocheng, Taian and Zaozhuang in Shandong Province, Kaifeng, Luohe, Shangqiu and Puyang in Henan Province have high ratio of vegetable cultivation area. Especially in shallow wells, the variable of percentage of vegetable area is the main influencing factor for nitrate spatial distribution. The number of significant variables for nitrate variation in shallow groundwater is higher than than that in middle-deep and deep wells, indicating groundwater in shallow wells is more easily affected by the outside.

Besides vegetation variable, percentage of grain crop area is also a significant variable for variation of groundwater nitrate in shallow and deep wells. Zhao Tongke *et al.*[28] found groundwater nitrate concentration is higher under orchard area than in grain crop area. However, groundwater nitrate concentration in orchards is lowest in this study, which is not consistent with some reports; for example, Pasten Zapata *et al.*[38] reported that vegetable agriculture and orchards showed higher and highly variable NO_3^- concentrations.

The variable of livestock per unit area is a significant variable for variation of groundwater nitrate in shallow and deep wells. Previous reports showed animal wastes are considered as highly concentrated pollutants that may reach the water table[39-40]. For sites with similar aquifer features and groundwater depth, contamination must exist in some sites located closely to a septic tank[41]. Pasten-Zapata *et al.* [38] also concluded that livestock activities within a 1 000-m radius contributed significantly to NO_3^- in shallow ground water in Mexico.

Gu Baojing *et al.* [42] reported that amount of nitrate leakage to groundwater was significantly related to population density. This variable also has high loading on the principal components of PCA in shallow and middle-deep wells in this study. Regions in this study are the relative centralization of urban construction and population, and there are significantly differences among cities. Additionally, the effects of natural factors (annual mean temperature and precipitation) on groundwater nitrate variation were different in many reports[41-42]. In this study, variables of TM and Pre significantly affect nitrate content in shallow water, but have little impact in middle-deep and deep wells after multivariate statistics.

It is noteworthy that amount of nitrogen fertilizer per unit area is not included in regression equation for nitrate concentration. Hu Kelin *et al.* [43] reported groundwater pollution by NO_3^- leaching occurred in the North China Plain due to the use of wastewater for irrigation and excessive application of fertilizers. Especially in shallow groundwater systems, frequent and excessive use of fertilizers resulted in a significant nitrate pollution[44]. During the last two decades, groundwater contaminations from extensive fertilizer applications have been reported in many studies[43-47]. Nevertheless, variables about nitrogen fertilizer and crop areas were based on unit area in this study, and there is no significant difference among districts[48], which probably provide the reasons for having no significant difference among districts.



Note: Agdp, the gross agricultural production per capita; LS, unit-area livestock quantity; GNp, percentage of grain crop area; VGp, percentage of vegetable area; Fup, percentage of orchard area; NGp, unit-area nitrogen fertilizer; IRp, percentage of irrigation area; POPp, unit-area population, TM, annual mean temperature; Pre, precipitation.

Fig. 5 Principal component analysis (PCA) of variables for groundwater nitrate

5 Conclusions

High NO_3^- in groundwater and surface water is a serious problem especially in highly intensive agricultural areas, worldwide. In this work, nitrate concentration in groundwater reached a maximum of 526.58 mg/L, and 47.2%, 21.33% and 11.13% of samples had levels in excess of nitrate safety threshold concentration (50 mg/L) in shallow, middle-deep and deep groundwater, respectively, which shows nitrate pollution of groundwater in the North China Plain cannot be ignored. Additionally, nitrate content decreased with increasing groundwater depth ($P<0.05$), and nitrate concentration under vegetable area is higher than that under grain and orchard areas ($P<0.05$). The median nitrate concentrations in October (after rainy season) were higher than those in May (before rainy season). The kriging map of groundwater nitrate shows that groundwater nitrate has a strong spatial variability. Many districts, such as Yantai, Weifang, Rizhao, Linyi, Zaozhuang and Zibo in Shandong Province, and Pingdingshan, Xuchang and Luohe in Henan Province, and Zhangjiakou, Qinhuangdao and Chengde in Hebei Province are heavily contaminated with nitrate.

Based on both multiple regressions combined with principal component analysis (PCA), significant variables for nitrate variation in three types of ground water were found: population per unit area, percentage of vegetable area, percentage of grain crop area, livestock per unit area, annual precipitation and annual mean temperature for shallow groundwater; population per unit area and percentage of vegetable area for middle-deep groundwater; percentage of vegetable area, percentage of grain crop area and livestock per unit area for deep groundwater.

Nitrate contamination in groundwater should be considered in developing and implementing strategies for rural developments. Measures must be taken to alleviate nitrogen pollution, such as changing the cropping pattern, adjusting the irrigation and fertilization programs and applying limited water application and split application of nitrogen fertilizers and reducing pollution from livestock and wastewater discharge. Results in present study may have important implications for regions with similar climate, topography, agriculture model and urbanization in China.

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technological support for disaster emergency response.

5.4 Enhancing structure adjustment of economy, industry and land use responding to climate change risk It should adjust economic structure, decline resource type of economy, and improve technology and population-intensive type of economy, especially economic proportion in non-coastal areas. When development of the first and second industries have reached a certain scale, it should improve proportion of the service sector as quick as possible, especially proportion of tourism service industry. Urban land use in metropolitan areas should be greatly decreased, while proportion of land use in central cities and towns should be improved. It should restrict utilization ratio of cultivated land in desert oasis area and development of agricultural farmland in hilly areas, vigorously develop eco-service industry, and obviously improve proportion of ecological land and water use.

5.5 Establishing integrated disaster reduction forum and alliance of "the Belt and Road Initiative", and including it in the high-end forum summit meeting of "the Belt and Road Initiative" Countries and regions of "the Belt and Road Initiative" are affected by "Asia water tower" to different degrees and typhoon in mid-latitudes of the northern hemisphere or coastal areas of the Western Pacific Ocean. They bear or face influence of the same natural disaster chain, namely earthquake disaster chain and typhoon disaster chain. Once a catastrophe occurs, it will affect many countries in the region. Therefore, it should establish "integrated disaster reduction alliance" under the support of Asian Infrastructure Investment Bank and "BRICS National Bank", and it should be included in China-led international organizations and forum summits, such as SCO, China-Africa Cooperation Forum. By issuing "catastrophe lottery" and establishing "disaster fund of the Belt and Road Initiative", catastrophe is responded, and comprehensive disaster prevention and mitigation ability is improved in an all-round way.

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