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"Gheorghe Asachi" Technical University of Iasi, Romania

GEOGRAPHIC INFORMATION SYSTEM BASED APPROACH FOR THE INVESTIGATION OF GROUNDWATER NITROGEN POLLUTION NEAR A CLOSED OLD LANDFILL SITE IN BEIJING, CHINA

Jun Wu[1], Weidong Zhao[2], Jian Lu[3]*, Song Jin[4], Jiaquan Wang[2], Jiazhong Qian[2]

[1]*Qinghai Institute of Salt Lakes, Chinese Academy of Sciences, Xining, Qinghai 810008, PR China*
[2]*School of Resources and Environmental Engineering, Hefei University of Technology, Hefei, Anhui Province 230009, PR China*
[3]*Key Laboratory of Coastal Environmental Processes and Ecological Remediation, Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai, Shandong 264003, PR China*
[4]*Department of Civil & Architectural Engineering, University of Wyoming, Laramie, WY 82801, USA*

Abstract

Groundwater pollution investigation near old and closed landfill sites is increasingly attracting more attention. Nitrogen compounds, especially those leached from the landfill area, are often regarded as a main pollution source for the groundwater. This study investigated the nitrogen pollution in the groundwater near a closed old landfill area of Beijing, China. The field investigation showed that the nitrate-polluted groundwater was determined as Class VI (refers to bad quality) at the detection rate of over 70% in three out of seven wells. The detection rates of nitrate-polluted groundwater of Class V (refers to bad quality) were more than 50% in four out of seven wells. Geographic information system (GIS) was employed to evaluate the groundwater contamination and investigate the spatial-temporal distributions of the nitrogen pollutants in the shallow groundwater. Elevated concentration of ammonium was observed during May and September when the weather was fairly warm and precipitation was plenty. Extreme concentrations of ammonium were only observed in the area near the well W26, which is adjacent to an old landfill. Nitrate pollution was determined to be severe in the study area based on the detected nitrate concentrations. During winter (November 2007 to January 2008), the nitrate contamination became more severe.

Key words: ammonium, geographic information system, groundwater, nitrate

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1. Introduction

Groundwater has been considered as an important and sensitive water source due to its low susceptibility to contamination in comparison to surface water, and its large storage capacity (USEPA, 1985). Therefore, groundwater has become a research hotspot all over the world (Di Palma et al., 2015; Muntean and Mihăiescu, 2016; Wen et al., 2018). Groundwater near landfill areas is considered the most vulnerable due to the potential invasion of leachate (Fatta et al., 1999; Rusu et al., 2017). A wide range of compounds have been recognized as groundwater contaminants, including nitrogen species, heavy metals, phenols, pesticides, and microorganisms (Juhler and Felding, 2003; Kaçaroğlu and Günay, 1997; Relić et al., 2010; van Maanen et al., 2001). Nitrate is one of the main nitrogeneous contaminants that commonly occur in groundwater. Excessive nitrate in drinking water has been linked to blue baby syndrome, abortions in women, and increased risk of non-Hodgkin's lymphoma (Sparks, 2003).

Waste disposal facilities usually affect the surrounding environmental quality, especially for the groundwater and surface water due to the leachate (North et al., 2004; Yusof et al., 2009). Recently,

* Author to whom all correspondence should be addressed: e-mail: jlu@yic.ac.cn; Phone: +86 5352109278; Fax: +86 5352109000

groundwater contamination in landfill areas has been attracting more attentions (Albaiges et al., 1986; Jensen et al., 1999; Rapti-Caputo and Vaccaro, 2006). Landfill is the main solid waste disposal method in the world, especially in developing countries. For example, more than 56.6% of the municipal solid waste in China was placed in landfills in 2010. Although synthetic liner including HPDE film has been applied in many landfill sites to prevent the discharge of landfill leachate into groundwater, many old or closed landfill sites in China used engineered clay as the preventive liner for landfills. The prime concern is whether the engineered clay layer can maintain integrity and impermeability over the landfill lifespan. Worst of all, many old landfill sites had no leachate collection treatment systems at all. In those landfill sites, leachate is alomost free to egress the waste directly into the groundwater (Wikipedia, 2014). As a typical contaminant, nitrogen compounds were frequently detected in groundwater within the landfill areas (Heaton et al., 2005; Murray et al., 1981).

Geographic information system (GIS) is an effective tool for characterizing spatial distribution of contamination (Popescu et al., 2015; Praharaj et al., 2002; Sweeney, 1999). Specifically, GIS is good at showing the relationship between spatially variable soil, groundwater, and contaminant conditions. As in a few of many example applications, Ahn and Chon (1999) investigated the groundwater contamination and established the spatial relationship between groundwater constituents and pollution sources using GIS. Kistemann et al. (2008) used GIS tool to evaluate groundwater contamination with vinyl chloride and precursor volatile organic compounds. GIS techniques were also applied for assessing local groundwater contamination risk (Ducci, 1999; Wen et al., 2009).

In this study, the distribution of main contaminants in the groundwater underneath an old landfill site was assessed by using the GIS tool. The goal was to obtain an overall profile of nitrogen pollution in the areal groundwater near this landfill.

2. Material and methods

2.1. Study area

The study area is located at 39°47′32.21″ N to 39° 48′43.31″ N latitude and 116°16′12.10″ E to 116°17′31.35″ E longitude (Fig. 1). Near Well 26, the landfill that was built in 1950s lies in urban area but not in agricultural area. The main contents of this landfill were municipal solid wastes. There was no other major additional nitrogen source in this area. Moreover, there was no sewage treatment plant or septic tank system in this area. The climate in this study area is characterized by sand stormy and windy spring (March, April and May), hot and humid summer (June, July and August), mild autumn (September and October), and cold winter (from November to February) (Pang et al., 2009). The average annual precipitation is about 626 mm (Xu and Han, 2009), and about 80% of the annual precipitation happens in summer. The annual mean temperature is around 12 °C (Xu and Han, 2009). In July and August, ambient temperature can exceed 40 °C. The coldest month is January, with the lowest temperature below -20 °C.

2.2. Chemical analysis

Water samples were collected from the wells that were located by mobile Global Positioning System (GPS) kit on day 21 of each month during 2007-2008. Two wells including W3 (located within the landfill) and W12 (adjacent to the landfill) were chosen to study the possible impact of landfill leachate on groundwater quality. Only nitrogen compounds were monitored in other wells. Concentration of physiochemical parameters including pH, ammonium, nitrate, sulfate, chloride, heavy metals (Cd, Cr, Cu, Fe, Ni, Pb and Zn), and the microbiological parameters (total coliform (TC) and fecal coliform (FC)) were analyzed in the groundwater samples. Landfill leachate was collected in July 2007 to analyze the typical concentrations of nitrogen compounds. All analyses were performed according to standard methods (APHA-AWWA-WPCF, 1999).

2.3. GIS analysis and data evaluation

The obtained data of the nitrogen contaminants were displayed by using ARCVIEW 3.0a and ARCVIEW SPATIAL ANALYST 1.1a. The spatial positions of seven wells were determined using a GPS. Inverse distance weighted (IDW) interpolation was applied to develop the digital terrain model (DTM) for the target pollutants. The contamination assessment was performed according to the criteria of Quality Standard for Groundwater of China (GB/T 14848-93). Quality classes I, II, III, IV, and V refer to the groundwater quality categorization. The water quality decreases from I to V. Classes I and II refer to “good quality” while Classes IV and V refer to “bad quality”.

3. Results and discussion

3.1. Water quality pre-investigation

The results showed that the main contaminants in the groundwater were nitrogen compounds. This is consistent with reports that nitrogen pollution of the groundwater near landfill site has been frequently observed (Heaton et al., 2005; Murray et al., 1981). The concentrations of nitrate in these water samples were much higher than the maximum contaminant level (MCL) of 10 mg L^{-1} specified in the U.S. EPA groundwater (Sparks, 2003), suggesting high risk to human health. However, nitrate concentrations of most of water samples fell within the criteria for groundwater with Class IV. According to the Chinese groundwater quality criteria, groundwater of Class IV or V is categorized as “low quality water” while Class level I, II, and III indicate relatively high quality.

Although high heavy metal or phenol concentrations were frequently observed in groundwater nearby landfills (Demirel, 2007; Mor et al., 2006), low level heavy metals and pesticides were detected in this study, as summarized in Table 1. We presumed the lower contents of metals and pesticides were attributed to the convent of the landfill under study, which was mainly filled with municipal solid waste rather than chemical or industrial wastes.

The elevated concentrations of NO_3^--N and NH_4^+-N in the groundwater showed that groundwater quality was being significantly affected by the landfill leachate percolation. The concentration of NH_4^+-N in the landfill leachate reached 1290 mg L^{-1} and NO_3^--N was detected at a lower concentration of 1.42 mg L^{-1} (Table 2).

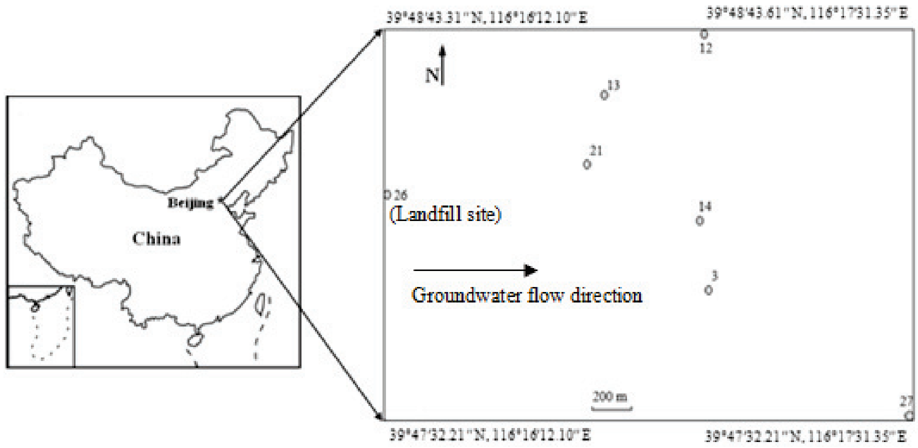

Fig. 1. Map showing the study area and the location of sampling points. Well W26 lies within the old landfill site area

Table 1. Characteristics of the groundwater (samples collected in March 2008)

Parameter	***Well number***		***Groundwater quality criteria***[a]				
	3	12	I[b]	II[b]	III[b]	IV[b]	V[b]
pH	7.3	7.8		6.5-8.5		5.5-6.5, 8.5-9	<5.5, >9
Total hardness (mg L^{-1})	836	617	≤150	≤300	≤450	≤550	>550
TDS (mg L^{-1})	1522	1160	≤300	≤500	≤1000	≤2000	>2000
COD_{Mn} (mg L^{-1})	1.9	1.0	≤1.0	≤2.0	≤3.0	≤10	>10
Phenols (mg L^{-1})	<0.002	<0.002	≤0.001	≤0.001	≤0.002	≤0.01	>0.01
NO_3^--N (mg L^{-1})	29.3	45.7	≤2.0	≤5.0	≤20	≤30	>30
NO_2^--N (mg L^{-1})	<0.003	<0.003	≤0.001	≤0.01	≤0.02	≤0.1	>0.1
NH_4^+-N (mg L^{-1})	0.07	0.06	≤0.02	≤0.02	≤0.2	≤0.5	>0.5
Sulfate (mg L^{-1})	310	280	≤50	≤150	≤250	≤350	>350
Chloride (mg L^{-1})	338	230	≤50	≤150	≤250	≤350	>350
F (mg L^{-1})	0.78	0.86	≤1.0	≤1.0	≤1.0	≤2.0	>2.0
Fe (mg L^{-1})	<0.03	<0.03	≤0.1	≤0.2	≤0.3	≤1.5	>1.5
Mn (mg L^{-1})	<0.01	<0.01	≤0.05	≤0.05	≤0.1	≤1.0	>1.0
As (mg L^{-1})	0.0012	0.0016	≤0.005	≤0.01	≤0.05	≤0.05	>0.05
Hg (mg L^{-1})	0.00005	0.00008	≤0.00005	≤0.0005	≤0.001	≤0.001	>0.001
Se (mg L^{-1})	<0.0003	0.0004	≤0.01	≤0.01	≤0.01	≤0.1	>0.1
Cu (mg L^{-1})	<0.008	<0.008	≤0.01	≤0.05	≤1.0	≤1.5	>1.5
Zn (mg L^{-1})	0.007	<0.002	≤0.05	≤0.5	≤1.0	≤5.0	>5.0
Pb (mg L^{-1})	<0.009	<0.009	≤0.005	≤0.01	≤0.05	≤0.1	>0.1
Cd (mg L^{-1})	<0.005	<0.005	≤0.0001	≤0.001	≤0.01	≤0.01	>0.01
Hexavalent chrome (mg L^{-1})	<0.004	<0.004	≤0.005	≤0.01	≤0.05	≤0.1	>0.1
Cyanide (mg L^{-1})	<0.004	<0.004	≤0.001	≤0.01	≤0.05	≤0.1	>0.1
Hexachlorobenzene (μg L^{-1})	<0.15	<0.15	≤0.005	≤0.05	≤5.0	≤5.0	>5.0
DDT (μg L^{-1})	<0.48	<0.48	ND[c]	≤0.005	≤1.0	≤1.0	>1.0
Total bacterial count (mL^{-1})	7	5	≤3.0	≤3.0	≤3.0	≤100	>100
Coliforms (L^{-1})	0	10	≤100	≤100	≤100	≤1000	>1000

[a] *Criteria of the groundwater quality of China (GB/T 14848-93)*

[b] *I, II, III, IV, and V refer to the quality grade. The water quality decreases gradually from I to V. I and II refer to the good while IV and V refers to the bad*

[c] *ND = no detection*

Table 2. Characteristics of the landfill leachate

Parameter	*Concentration*	*Parameter*	*Concentration*
pH	8.4	NO_3^--N	1.42 (mg L^{-1})
NH_4^+-N	1290 (mg L^{-1})	NO_2^--N	0.06 (mg L^{-1})
Cd	0.04 (mg L^{-1})	Pb	0.30 (mg L^{-1})

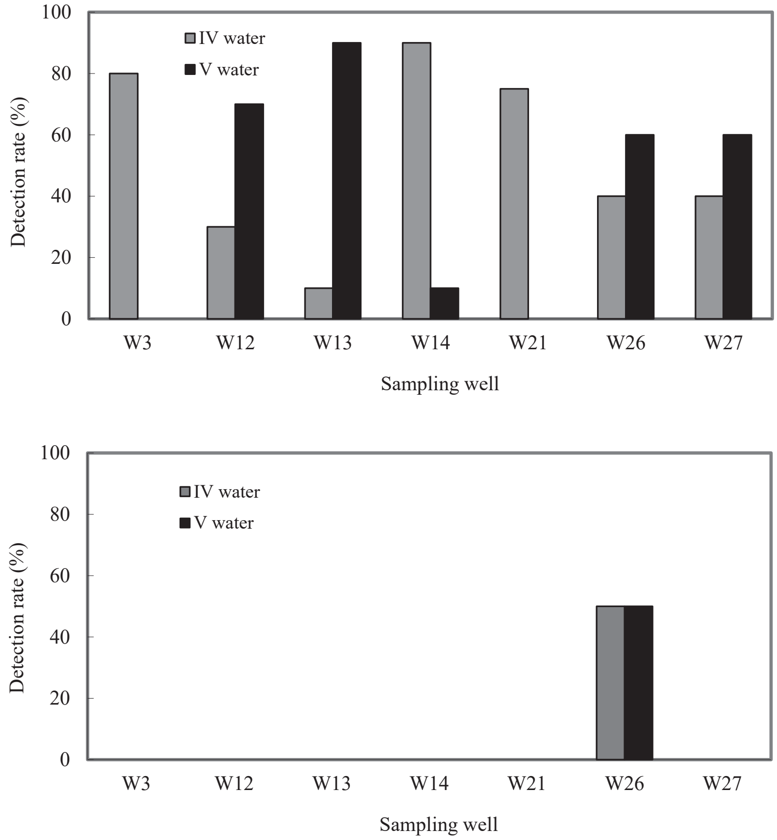

Fig. 2. Detection rates of elevated nitrate (A) and ammonium (B).
The water quality classification was determined based on the concentrations of nitrate or ammonium

Higher NH_4^+-N level in the landfill leachate suggested that landfill was a main nitrogen pollution source for the groundwater near this site. This result agrees with other studies in which landfills mainly release ammonium in the groundwater (Heaton et al., 2005; Murray et al., 1981). The ammonium was usually oxidized to nitrate in the groundwater in the extended area.

3.2. Detection rate of elevated nitrogen levels in the groundwater near the landfill

Elevated concentrations of nitrate were observed at high detection rates in all groundwater samples, while high concentrations of ammonium were mostly detected in groundwater samples collected from W26 during 2007-2008 (Fig. 2). For groundwater collected from wells W3, W14, and W21, the detection rate of nitrate-impacted groundwater of Class VI was > 70%. More severe nitrate contamination was detected in groundwater from wells W12, W13, W26, and W27. The detection rate of nitrate-impacted groundwater of Class V was > 50%. These results suggested that the groundwater near the landfill had been heavily contaminated by nitrogen compounds.

3.3. The spatial-temporal distribution of nitrogen contaminants in the shallow groundwater

Concentrations of NH_4^--N and NO_3^--N in the groundwater were analyzed from samples collected during a period of one year (2007-08). The spatial distribution of the mean and annual NH_4^--N and NO_3^--N concentrations of the groundwater were presented in the water quality maps (Figs. 3-4). As shown in these maps, heavy contamination of ammonium near W26 was observed while the nitrate contamination appeared to be slight in the research area at the beginning (May 2007), but gradually worsened from July to September (2007). The ammonium contamination remained to be high during the same period.

During winter (November 2007 to January 2008), the nitrate concentration increased, but ammonium concentration sharply decreased. However, ammonium concentration rebounded when spring (2008) came again.

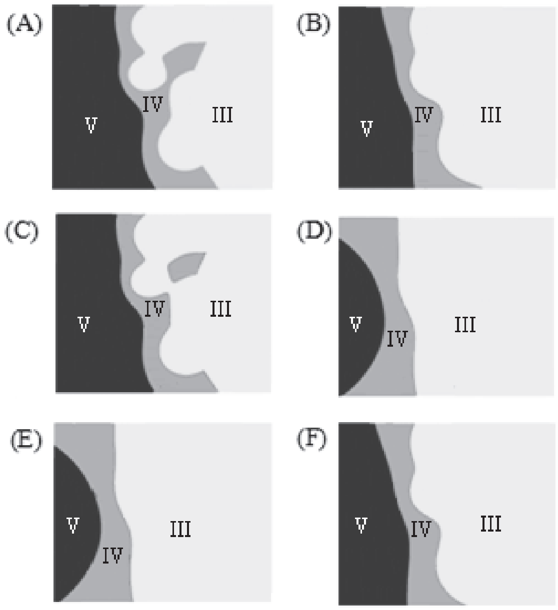

Fig. 3. Profiles of ammonium during 05/2007 (A), 07/2007 (B), 09/2007 (C), 11/2007 (D), 01/2008 (E), and 03/2008 (F). The water quality classification (III-V) was determined based on the concentrations of ammonium. Water samples were collect on day 21 of each month

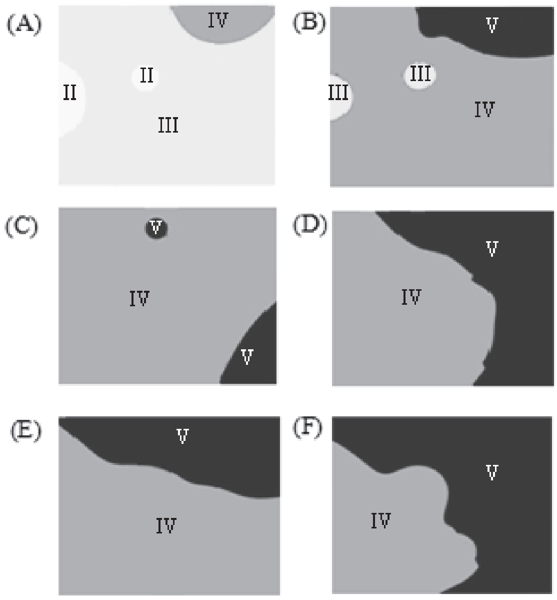

Fig. 4. Profiles of nitrate in 05/2007 (A), 07/2007 (B), 09/2007 (C), 11/2007 (D), 01/2008 (E), and 03/2008 (F). The water quality classification (III-V) was determined based on the concentrations of nitrate. Water samples were collect on day 21 of each month

During this study, the heavy contamination of ammonium was observed during the mild and humid months of May through September. Abundant precipitation during this period presumably helped leach organic nitrogen out of the landfill into the nearby aquifer. Degradation processes resulted in ammonium, which would eventually transform into nitrate and migrate outward from the landfill site. Nitrate is relatively stable in groundwater containing adequate dissolved oxygen (Freeze and Cherry, 1979). Due to its high solubility of nitrate and lesser sorption to soil matrix, nitrate in the groundwater dispersed quickly and formed a plume ahead of ammonium. For the same mobility of nitrate, its concentration would decrease rapidly during the wet season (Kaçaroğlu and Günay, 1997). Oxidation of ammonium to nitrate could explain its profile during this study.

GIS is an effective tool to analyze distribution of contaminants (Praharaj et al., 2002; Sweeney, 1999). The spatial and temporal distribution of nitrogen contaminants in the shallow groundwater in this study was well summarized through GIS based approaches, suggesting that GIS is good at showing the relationship between spatially or temporal variable groundwater and nitrogen contaminant conditions. According to the previous study, GIS tool has been successfully applied in the groundwater contamination assessment (Ducci, 1999; Kistemann et al., 2008; Wen et al., 2009). The heavy pollution area with high potential risk in this study has also been demonstrated clearly using the GIS tool.

3.4. Maps of nitrogen concentrations in the impacted groundwater

GIS has been successfully used to establish spatial relationship between the groundwater constituents and the pollution sources (Ahn and Chon, 1999). To further analyze the influence of the landfill as the source of the nitrogen impact on the groundwater, the concentration profiles of the nitrogen contaminants during the wet and dry seasons were presented by GIS water quality maps (Figs. 5-6). The results showed higher ammonium concentrations in the area near W26. The map suggested that well W26 lied at the source of nitrogen release, the landfill. This was confirmed by the field investigation. The ammonium concentration of groundwater collected from well W26 was 6.46 mg L^{-1}, exceeding the concentration for Class V groundwater. The concentrations of ammonium decreased while nitrate increased along the distance away from well W26. This could be attributed to the oxidization of ammonium into nitrate during its transportation in groundwater (Heaton et al., 2005; Murray et al., 1981), and the subsequent dilution of nitrate by surface water that percolated down during the wet season. In contrast, during the dry season, concentrations of ammonium and nitrate remained to be high for the same reason. The data clearly indicated that the groundwater was being impacted by the leachate from the old landfill.

With the temporal monitoring data, the spatial concentration distribution maps of nitrogen pollutants can be produced by GIS, which can be used to predict nitrogen pollutant fate. The fundamental pollution information provided should prove the pollution trend and potential pollution source. The information obtained by GIS could be useful for selection of pollution control strategies.

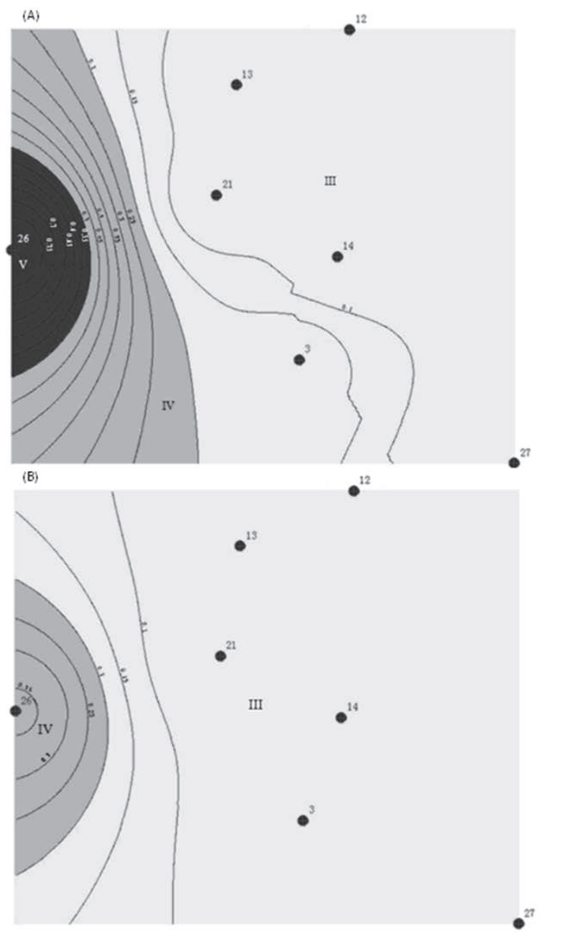

Fig. 5. Profile of ammonium concentrations during the wet and dry seasons. (A) Water samples were collected in August 2007; (B) Water samples were collected in December 2007. The water quality classification was based on the concentrations of ammonium

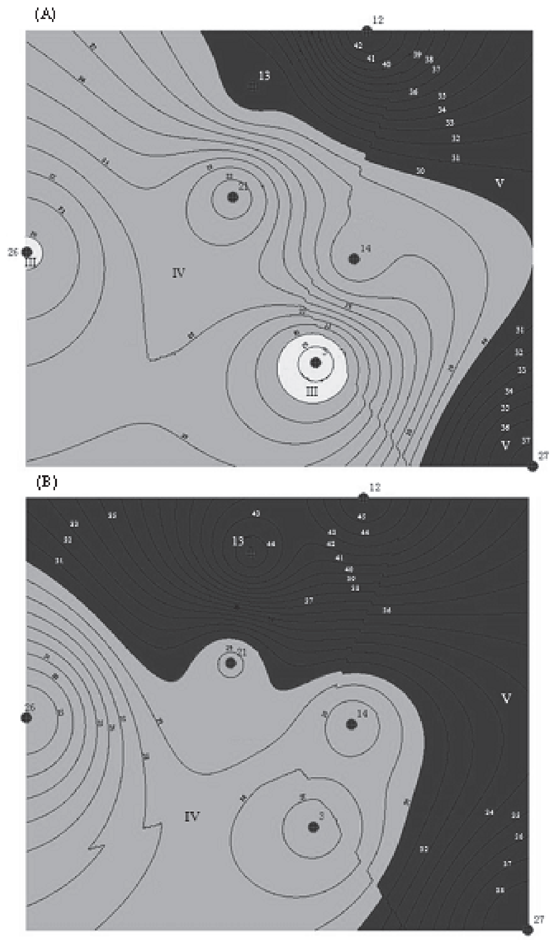

Fig. 6. Profile of nitrate concentrations during the wet and dry seasons. (A) Water samples were collected in August 2007; (B) Water samples were collected in December 2007. The water quality classification was based on the concentrations of nitrate

4. Conclusions

By feeding data from groundwater sampling near an old landfill into the GIS, we demonstrated that the adjacent area was contaminated by nitrogen constituents, especially nitrate. The detection rates of nitrate-impacted groundwater of Class VI quality were > 70% in groundwater samples collected from three out of seven wells. The detection rates of nitrate-impacted groundwater of Class V quality were > 50% in groundwater collected from four out of seven wells. Elevated amount of ammonium was detected in groundwater collected from well W26. The heavy contamination of ammonium was observed from May to September when the weather was fairly warm and precipitation was plenty. High ammonium pollution could only be observed in the area near W26. The nitrate apparently dispersed faster and formed a plume well ahead of ammonium in an extended area from the landfill. The use of GIS helped summarize the analytical data obtained from the groundwater sampling near the closed landfill. The information depicted by the GIS has significant environmental implications in terms of assessment of the local environment and selection of proper remedies for controlling landfill leachate and treating the contaminated groundwater in the area.

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