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Using geographic information system (GIS) and remote sensing (RS) in zoning nitrate concentration in the groundwater of Birjand, Iran

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Original Article

Abstract

Previous studies have shown that the presence of nitrate in drinking water can cause several diseases especially in the infants, such as cancer and blue baby. The Environmental Protection Agency (EPA) has since adopted the 50 mg/l standard as the maximum contaminant level (MCL) for nitrate for regulated public water systems. This study aimed to evaluate the concentration of nitrate in the drinking water wells of Birjand, Iran, using inverse distance weighting (IDW) model and also using remote sensing (ENVI software) for studying the vegetation area. In this study, the average annual nitrate level in 2015 was measured from 19 wells around Birjand that were used as rural water supplies. For the zoning of nitrate concentration in the groundwater of Birjand, we used Arc GIS software by using IDW interpolation methods, and for studying the vegetation area and its effect on the groundwater quality we used Landsat Archive image (L4-5 TM sensor) and ENVI 4.7 software. The mean concentration of nitrate was 25.89 ± 12.33 mg/l in the groundwater. Nitrate concentration was more than the standard range (50 mg/l) according to the National Standard of Iran (No. 1053) in one well in the studied zone. Based on the information obtained from remote sensing, agricultural activities were an effective factor in increasing the concentrations of nitrate in the groundwater of the studied area.
KEYWORDS: Water, Nitrates, Geographic information systems, Remote sensing technology

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Introduction

Nitrate can appear in bodies of water as a pollutant in high concentration levels. If nitrate concentration exceeds the standard level in drinking water, it can cause diseases such as cancer and methemoglobinia.[1] It has been suggested that nitrate ingestion is associated with an increased risk of stomach cancer, possibly through endogenous nitrosamine formation.[2] Fan and Steinberg conducted a research about health implications of nitrate and nitrite in drinking water. In their study, animal experimental data showed reproductive toxicity associated with exposure to high levels of nitrate or nitrite, which are not likely to be encountered

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with in drinking water.[3] van Maanen et al. studied thyroid function in populations for which the drinking water was polluted with different levels of nitrate. Results showed development of thyroid hypertrophy in the population that consumed water with high concentrations of nitrate.[4] Therefore, new methods are being used for monitoring water networks today.[5] Natural and anthropogenic sources can increase nitrate in the ground water. One of the anthropogenic sources is agricultural activity. Nitrate fertilizers use in agricultural activity and a poor drainage can cause ground water pollution.[5]

Geographic information system (GIS) and remote sensing are effective tools for water quality monitoring, mapping and modeling.[6] GIS is an appropriate system to investigate the quality of ground water and spatial variability for monitoring water resources. It is considered as a new and powerful technology for zoning, analysis, anticipation and explanation of the data.[7] In the ArcGIS software, one of the spatial analysis methods is inverse distance weighting (IDW); the effective factor in this model is the distance fort weighting.[8,9] IDW method is relatively fast and easy to compute and straight forward to interpret. Its general idea is based on the fact that the attribute value of an unsampled point is the weighted average of known values within the neighborhood, and the weights are inversely related to the distances between the prediction location and the sampled locations. At the moment, many studies use this method to study the spatial change of quality and quantity properties of groundwater.[10-12] Fallahzadeh et al.[13] conducted a study and used GIS for zoning of nitrite and nitrate concentration in drinking water wells in Yazd, Iran. They analyzed nitrate and nitrite concentration rate via Arc GIS software using Kriging and IDW interpolation methods. Basnyat et al.[14] examined a method to determine nitrate pollution within a given basin based on basin characteristics. Their study was based on the hypothesis that some basin characteristics such as land use/land cover, slope, and soil attributes can affect the quality of water by regulating sediment and chemical concentration. They used geographic information system (GIS) and remote sensing (RS) as analysis tools.[14] Lake et al.[15] used GIS to identify all areas of groundwater prone to nitrate pollution. They used many factors in their research such as the quality of water leaving the root zone of a piece of land, soil information, presence of low-permeability superficial (drift) material, and aquifer properties. Lee et al.[16] used GIS to develop statistical models for groundwater quality assessment in urban areas.

This research aimed to consider the contamination of groundwater resources of Birjand, Iran, with nitrate using IDW methods, and also to investigate the causes of pollution using remote sensing techniques.

Materials and Methods

The research area involved Birjand, from the north to the south of the city at the longitude of 58.50E to 59.40E and latitude of 32.71N to 33.70N (Figure 1).

The data of nitrate in 2015 (three sampling periods per year, 1 sample on the first day of the year, every 4 months) were obtained from Birjand water and wastewater company, which were related to 19 wells in the studied area. In this study, Arc GIS software (IDW method) was utilized in order to spatially analyze nitrate concentration data in the groundwater of the city of Birjand. For studying the vegetation area, we used Landsat Archive image (L4-5 TM sensor, taken from http://earthexplorer.usgs.gov/) with bands' combination and maps' extraction with the ENVI software (version, 4.7, Research Systems Inc, Boulder, Co, USA). ENVI is software used to process and analyze geospatial imagery. It is commonly used by remote sensing professionals and image analysts. ENVI is used as a spectral tool for geometric correction, terrain analysis and radar analysis, with raster and vector GIS capabilities, and provides extensive support for images from a wide variety of sources.

Figure 1. The location of study area in Birjand, South Khorasan province

Results and Discussion

In this study, nitrate concentration of the groundwater was measured and analyzed in 19 wells of Birjand. Statistical descriptions related to nitrate concentrations in this study are displayed in table 1.

According to Iran's standard for drinking water (No. 1053), nitrate concentration should be less than 50 mg/l. In this study, we used one-sample Student's t-test as the statistical test for comparing data with the standard. The results showed significant difference from the standard ($P < 0.05$) except in place 18. In one of the studied wells, nitrate concentration rate was more than the maximum allowable amount according to Iran's standard (No. 1053), and in other cases, nitrate concentration was within the standard range. Figure 2 shows zoning of nitrate concentration in the groundwater of studied area.

As pointed before, for extraction of vegetation map we used Landsat Archive image (L4-5 TM sensor). For this purpose, we used ENVI 4.7 software capacities for bands' combination. For producing RBG color images, we used combination band in ENVI software as follow: band 4 as red, band 3 as green, and band 2 as blue. A combination of these bands showed the vegetation area. The produced image is shown in figure 3.

Table 1. The statistical description of nitrate in the wells of Birjand

Wells number	NO_3 concentration in 1st sampling (mg/l)	NO_3 concentration in 2nd sampling (mg/l)	NO_3 concentration in 3rd sampling (mg/l)	Average NO_3 in 3 seasons (mg/l)	Standard deviation	Mean difference	P
1	13.00	23.09	19.60	18.56	5.12	-31.43	0.009
2	9.74	17.00	17.50	14.75	4.34	-35.25	0.005
3	26.30	38.15	35.80	33.42	6.27	-16.58	0.045
4	13.70	20.00	19.20	17.63	3.43	-32.36	0.004
5	16.60	17.40	17.90	17.30	0.66	-32.70	< 0.001
6	17.60	18.40	19.90	18.63	1.17	-31.36	< 0.001
7	53.97	54.85	55.25	54.69	0.65	4.69	0.006
8	28.93	29.76	29.91	29.53	0.53	-20.46	< 0.001
9	27.09	26.96	27.40	27.15	0.23	-22.85	< 0.001
10	35.00	36.20	37.30	36.17	1.15	-13.83	0.002
11	38.43	38.60	39.78	38.94	0.74	-11.06	0.001
12	15.70	16.60	17.85	16.72	1.08	-33.28	< 0.001
13	6.55	6.85	7.54	6.98	0.51	-43.02	< 0.001
14	11.02	19.20	20.60	16.94	5.17	-33.06	0.008
15	16.79	17.30	17.80	17.30	0.51	-32.70	< 0.001
16	22.85	23.10	24.36	23.44	0.81	-26.56	< 0.001
17	29.05	31.00	30.00	30.02	0.98	-19.98	0.001
18	41.00	54.33	54.00	49.78	7.60	-0.22	0.964
19	23.00	23.15	25.80	23.98	1.58	-26.01	0.001

NO_3: Nitrate

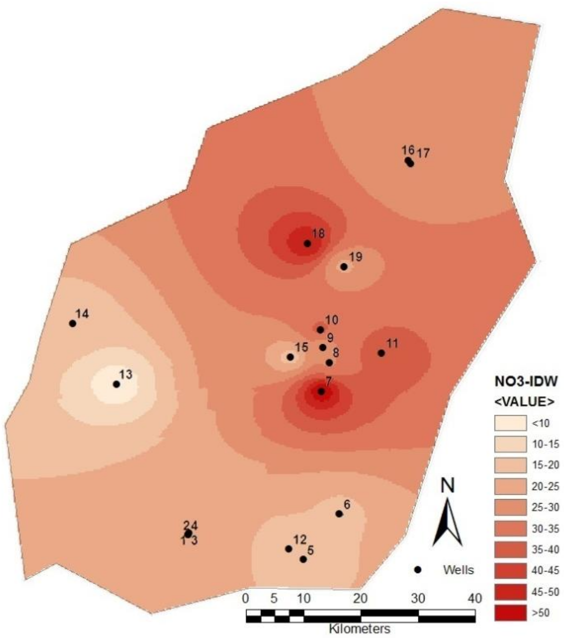

Figure 2. Zoning Nitrate concentration in Birjand wells using inverse distance weighting (IDW) methods

In this figure, the vegetation area is displayed in red. For further diagnosis of vegetation area, we used unsupervised classification capacity of ENVI software; then, the extracted image was transferred to ArcGis software in the Geo Tiff format. In the ArcGis software, we turned off all layers except the vegetation layer. Figure 4 is the final image produced from vegetation area in the ArcGis software.

According to the extracted maps using remote sensing techniques, the vegetation around the wells with higher concentrations and value variation of nitrate had a further development. The picture extracted from remote sensing technique showed that wells located in the high expanded vegetation area had more seasonal variation in nitrate concentration. Most of the vegetation in this area included agricultural activities; thus, widespread use of chemical fertilizers within the seasonal period is one of the reasons for groundwater pollution by nitrate. Zhang et al.[17] concluded that the most important factor in groundwater pollution is agricultural fertilizing. Fertilizer application is expected to double or even triple within the next 30 years in their area, worsening the problem of nitrogen fertilizer-related pollution. Nas and Berktay[18] evaluated the nitrate data and used ArcView GIS 3.2 for this purpose.

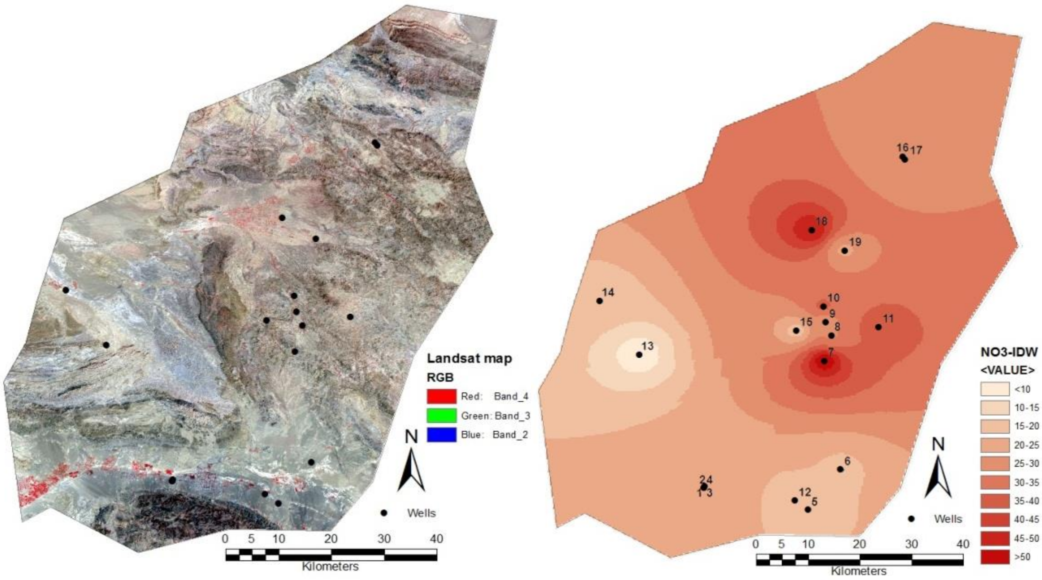

Figure 3. RBG color image using combination of bands 4 (red), 3 (green) and 2 (blue)

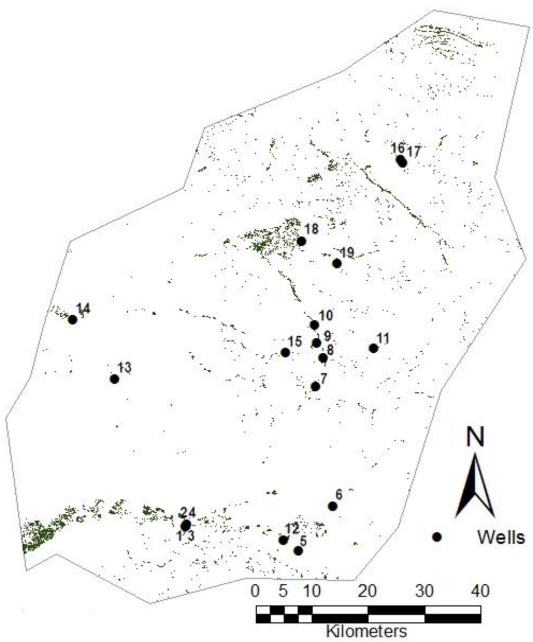

Figure 4. Final image of vegetation area produced by ArcGis

Results showed that the distribution of nitrate concentrations was not correlated with the well depth in the study area. Lasserre et al.[19] conducted a research and tested a GIS-model on a 20 km^2 area particularly vulnerable to agricultural nitrate pollution. Results showed that the simulated nitrate concentrations were in good agreement with the measured values. Thilagavathi and Subramani[6] used GIS and remote sensing to investigate and monitor groundwater quality in the Chalk Hill region. Water quality index (WQI) was calculated, and it revealed groundwater pollution in the study area. Therefore, it is necessary to recommend appropriate methods for improving water quality in polluted areas. In the groundwater, the presence of nitrate, nitrite, and phosphate above the permissible limit is not conducive to the drinking purpose.[16]

Conclusion

According to the results, IDW method is an appropriate method for estimating nitrate content in the groundwater. In the studied zone, nitrate concentration was in the standard range according to the National Standard of Iran (No. 1053), except in one case. It is recommended that we use appropriate agricultural methods such as improving the drainage of agricultural land for reducing groundwater contamination in a long-term period.

Conflict of Interests

Authors have no conflict of interests.

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