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Groundwater quality and nitrate pollution modeling: an integrated study of contour mapping and geographic information system

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ABSTRACT

In this study, the water quality of 50 wells in Rumeshgan, which is in western Iran, was evaluated using a water quality index and a nitrate pollution index (NPI). Final obtained results were delineated by geographic information system contour mapping. Different ordinary kriging models (spherical, exponential, Gaussian, circular, and linear) were used to forecast the groundwater quality index (GWQI) and the NPI of un-sampled points in the studied area. Results showed that about 50% of the studied wells had excellent water quality (GWQI < 50), 40% had good water quality (50 ≦ GWQI < 100), while only 10% were determined to be in the poor or very poor category (100 ≦ GWQI). Three wells had significant pollution, and they are located in the southwest part of the study area. The linear model (with a root-mean-square error of 1.07) was chosen as the best-fit model. The contour maps show that the spatial distribution of groundwater quality can also be used approximately to estimate suitable locations for new wells containing minimum harmful contaminants.

Keywords: Groundwater quality index; Nitrate pollution index; Well; GIS

1. Introduction

Clean drinking water is a fundamental necessity for human health [1] because more than 80% of human diseases are due to contaminated water [2]. Water quality is very important for people because it is directly linked with human welfare [3,4]. As groundwater is less susceptible to pollution and contamination than surface water, it is one of the most widely used sources of drinking water [4]. The quality of groundwater can deteriorate due to overharvesting and overuse of fertilizers, storage tanks, septic systems, uncontrolled hazardous waste, landfills, chemicals, soil composition, time that the water remains within an aquifer, road salts, and atmospheric contaminants [3–5]. One of most common and frequently introduced contaminants in groundwater is nitrate

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[6–8]. Nitrate in groundwater may be caused by point sources such as sewage disposal systems and domestic animal facilities, as well as non-point sources such as fertilizers, decomposing plants, parks, golf courses, lawns, atmospheric deposition, and gardens, or naturally occurring sources of nitrogen [4,9–11]. Many studies have shown that nitrate is present in groundwater throughout the world, and the problem is growing [12–14]. Nitrate is in a class of chemicals that has potential health risks. The Environmental Protection Agency (EPA) has set 10 mg/L (NO_3^--N) as the maximum contaminant level for nitrate-nitrogen in drinking water [15], and the World Health Organization (WHO) has determined that 50 mg/L is the maximum acceptable nitrate concentration in drinking water [16]. It is known that human activity causes the nitrate content in groundwater to exceed 20 mg/L [17]. Colorectal cancer, methemoglobinemia in infants, and non-Hodgkin's lymphoma (NHL) can result from chronic exposure to high levels of nitrate in drinking water [17–19]. If the organic or inorganic concentration of nitrate in drinking water is at a higher than acceptable level, it may cause adverse health effects in people of all ages. Therefore, it is very important to evaluate water quality to ensure that the water is healthy for a particular use, such as drinking, recreation, irrigation, or supporting fish [18]. An efficient way to evaluate water quality is use of water quality indices, which represent the combined influence of all studied parameters. The index is basically a mathematical means of calculating a single value from multiple test results.

A geographic information system (GIS) has been applied by Anbazhagan and Nair to show the spatial difference between geochemical elements in Panvel Basin, Maharashtra [20]. Many other studies used a GIS to represent water quality results, especially for groundwater quality assessment [21–24]. The present study has been conducted to study chemical composition and biological quality of Rumeshgan county well water to suitability as a source of drinking water and represent the obtained results by applying nitrate pollution index (NPI), groundwater quality index (GWQI), and a GIS to represent the spatial distribution of groundwater quality.

2. Materials and methods

This study utilized groundwater quality data collected from 50 water wells of Rumeshgan county. Water samples in each location were collected by various project partners and transported to the analytical laboratories in accordance with the standard operating procedure developed by the project team.

2.1. Hydrogeology of study area and sample collection

The city of Rumeshgan is located in the Lorestan province in western Iran. The Lorestan province is part of the Zagros folded belt. The Lorestan province like with basin of Zagros has massive sedimentary property (with the Paleozoic era to the Quaternary period). Rumeshgan county is located at latitude and longitude coordinates of 33˚16´07.0´´N and 47˚34´19.9´´E, respectively, and it has mountainous and temperate climatic conditions. The usual precipitation for studied area is 544 mm/y and average air temperature is 17.1˚C. Based on field observation and available data, groundwater is the only available water supply in the Rumeshgan. It is a rural area and most of its residents participate in agriculture and animal husbandry. Within the city are the villages of Bazvandi, Rumiani, Rashnudeh, Lalonde, Rahmanabad, and Aqajan. Formation types for the studied area are limestone, conglomerate, sandstone, siltstone, dolomite, gypsum, marne, and salt in different regions. In addition, alluvial deposits of sand, gravel, silt, and clay are the present type. According to well owners, water well depths in studied area ranged from 17 to 48 m. Deepest and lowest depth there are in southeast and northwest, respectively. In other hand, from southeast toward northwest of Rumeshgan county, the well depth decreases.

The water samples were collected from wells between June 2014 and December 2014. Samples were collected in acid washed polypropylene containers with 4 L capacity. To perform microbiological tests glass or plastic, sterilized containers (not completely fill container) were used and transferred to laboratory in <6 h. To ensure there is no field interference with obtained results, we took field transfer blank and trip blanks, too. Based on field study, there were 881 active wells. Using following equation and proportional method, we selected 50 wells to study. Budget limitation was the major limitation in widening sample size.

$$n_0 = \frac{Z^2_{1-\frac{\alpha}{2}} pq}{d^2}$$

$$n = \frac{n_0}{\left(1 + \frac{n_0}{N}\right)}$$

where p = 0.5, d = 0.1, and α = 0.05. Sampling was conducted on all days of the studying period (except public holidays) at various days and times. A total of 50 samples were collected at random times and places.

2.2. Sample analysis

The physicochemical parameters are analyzed in the laboratories. pH and conductivity were analyzed at the time of sampling. Hardness (total hardness and non-carbonate hardness, magnesium hardness, and calcium hardness) carbon dioxide (CO_2), chloride (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}) cations, and bicarbonate (HCO_3^-) by titration method, nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{2-}) by spectrophotometry method, sulfate (SO_4^{2-}) by turbidimetry, sodium (Na^+), potassium (K^+) by flame photometry method, and total dissolved solids (TDSs) by samples evaporating method, were measured according to the standard methods for water and wastewater examination [25]. In addition, the biological quality of the obtained samples based on a concentration of total coliform bacteria was reported as the most probable number per 100 mL (MPN/100 mL of sample), and an IMVIC (indole, methyl red, Voges–Proskauer, and citrate) test was carried out according to standard methods for water and wastewater examination (multiple tube fermentation technique sections 9,221-B, E, F) [25]. All laboratory analyses were performed within standard times as they are recommended by [25]. To determine whether the water was suitable for drinking, a comparison was made using the drinking water quality standards presented in Table 1. In addition, a GIS, the GWQI, and the NPI were used to represent the obtained results. In the GIS representation, contour maps were prepared using the ESRI ArcView 3.0 software program for various physicochemical parameters with an inverse concentration to clustering and an interpolation technique [21]. First, the collected well data were input to build up the spatial database. Geographic longitude/latitude coordinates were converted to metric coordinates using the Universal Transverse Mercator (UTM) projection. The database includes the well number, location (coordinates), and the concentration in mg/L of the studied parameters mentioned above. We used SURFER to grid the data and create the contour plot. The SURFER plots were then exported to a shape file and added to ArcView.

2.3. Nitrate pollution index

A single-parameter water quality index called the NPI has been used to measure the nitrate pollution in the studied wells. Using this index, it was proposed that nitrate pollution in the groundwater is due to human activity. The following relation was used to calculate the NPI [26]:

$$\mathrm{NPI} = \frac{C_s - \mathrm{HAV}}{\mathrm{HAV}} \tag{1}$$

where C_s is the concentration of nitrate in the sample, and HAV is the threshold value of the anthropogenic source (human-affected value), taken as 20 mg/L. Based on the obtained values for the NPI, water quality was classified into five categories (see Table 1).

2.4. Groundwater quality index

Groundwater quality was evaluated using the WQI, which can represent the quality as a result of different water quality parameters in combination together. It has been used by [27] previously, which is following:

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{SI}_i \tag{2}$$

At first, the sub index (SI) was determined for each parameter of the WQI using the following relation:

$$\mathrm{SI}_i = W_i \times q_i \tag{3}$$

To obtain the SI, it is necessary to calculate the relative weight (W_i) and quality rating scale (q_i). W_i is determined based on the importance of the target parameter in comparison with others for specific use, and q_i is obtained by dividing of the parameter concentration

Table 1
Values and categories of GWQI and NPI

Parameters	IR standard value	Wi	GWQI value	Water quality	NPI value	NPI interpretation
pH	6.5–8.5	0.1818	<50	Excellent	<0	Clean (unpolluted)
Total hardness	300	0.0909				
Calcium	75	0.0909	50–100	Good	0–1	Light pollution
Magnesium	30	0.0909				
Chloride	250	0.1363	100–200	Poor	1–2	Moderate pollution
TDS	500	0.1818			2–3	Significant pollution
Nitrate	45	0.2272	200–300	Very poor	>3	Very significant pollution

in each water sample by its respective standard according to the guidelines laid down, and the result multiplied by 100:

$$q_i = (C_i - C_{io})/(S_i - C_{io}) \times 100 \quad (4)$$

In Eq. (4), C_i denotes the concentration of each chemical parameter in each water sample in mg/L, C_{io} is the ideal value of the parameter in pure water, and S_i is the Iranian (IR) drinking water standard for each chemical parameter in mg/L [27].

2.5. Assessment of the spatial distribution of the GWQI and the NPI using semivariogram models

To determine the GWQI and NPI values for a specific site, and to predict the data trend, the ordinary kriging method can use either semivariograms or covariances. Semivariogram buildup can be determined by plotting the semivariance (i.e. determining the spatial distribution among points of the studied area) against the lag distance (distance between each adjacent points), which is used to calculate spatial dependence between samples. Theoretical models such as spherical, exponential, Gaussian, circular, and linear plateau models are used to forecast un-sampled stations in the studied area. In this study, the akaike information criterion (AIC), the Bayesian information criterion (BIC), root-mean-square error (RMSE), and the sum of errors (observed and estimated values) (SSE) [where n is the number of two sums (errors)] have been used as output model values. Comparison between the used model and the actual distribution was done with the AIC. If the AIC or the BIC are used to compare two or more models, the one that is preferable has the lowest AIC or BIC. The RMSE evaluates how much of the variability in the actual values is explained by the model. The smallest value of RMSE shows the best-fit one.

3. Results and discussion

The statistics of the water quality parameters and contour maps based on all wells has represented in Table 2 and Fig. 1, respectively, and water sample chemistry has been tested by a piper diagram.

Based on obtained result by the piper diagram, water samples are high in calcium plus magnesium (Ca^{2+} + Mg^{2+}) and chloride plus sulfate (Cl^- + SO_4^{2-}), resulting in an area of permanent hardness [28].

The electrical conductivity (EC) values ranged from 1,026 to 1,992 μS/cm; the highest and lowest values there were for wells nos. 46 and 11, respectively. Water temperature, type, and concentration of ions extant in the water affect the EC value. On the other hand, the EC can reveal the general quality of the effective parameters for groundwater.

Dissolution of some contaminants, such as hydrocarbons, in groundwater can result in increasing water resistance and EC reduction [29]. Organic matter decomposition may lead to the presence of organic acids and bio-surfactants in groundwater that are polar compounds and result in EC enhancement [30,31]. None of the observed groundwater data had EC values greater than the IR MCL limit (2,000 μS/cm), while 62% had values more than IR MDL (1,500 μS/cm). The TDSs containing inorganic and organic substances in ionized or colloidal form in the water can illustrate groundwater salinity as well as EC. None of the observed groundwater data has a TDS value greater than the IR limit. The TDS values vary from 615.6 to 1,195.2 mg/L with a mean of 926.8 ± 162 mg/L, which is not greater than the Iranian standard. Atekwana et al. [29] showed that hydrocarbon degradation in a polluted area can lead to an increase in TDSs because of hydrocarbon degradation byproducts and superior minerals. However, increasing levels of TDSs in a study area can be used as an indicator of soil or groundwater contamination as result of land using or other contaminant source, but we did not study this aspect in present study. Therefore, the groundwater of the Rumeshgan region is not contaminated based on TDS results. Obtained results show that the pH values ranged in 7, which indicates that the groundwater had neither an alkaline nor an acidic nature. The mean value of pH is within the Iranian standards. Since chemical material can change pH, it can be an important indicator for water contamination by chemical substances. The obtained results showed that the mean concentration of CO_2 in the water samples was 39.9 ± 41.5 mg/L. Macpherson [32] had reported that following CO_2 injection in a well, the values of pH, alkalinity, and EC changed rapidly. In addition, increased CO_2 injection led to an increase in Ca, Mg, Fe, Mn, and BTEX in the groundwater samples [32]. Pumping equipment, casting, and pipe corrosion; loss of pumping volume as a result of carbonate precipitation; gas-lift; and cavitation are negative effects of too much CO_2 in groundwater. In this study, CO_2 had a significant relation with SO_4^{2-}, calcium hardness, TH, magnesium hardness, EC, TDS, NO_2^-, Cl^-, Mg^{2+}, Ca^{2+}, and MPN (p < 0.05). It tell us the mentioned parameters level may be under influence of CO_2 concentration and it can be used to develop a model, but it need more studies.

The sulfate (SO_4^-), chloride (Cl^-), and phosphate (PO_4^{2-}) anions were lower than the IR standard for all wells, while the NO_3^- concentration was higher than

Table 2
Descriptive analysis of parameters in the studied wells

Parameters	Min	Max	Mean	Std. deviation	IR standards	
					MCL[a]	MDL[b]
SO_4^{2-} (mg/L)	0.253	3.12	1.06	0.6	400	200
PO_4^{2-} (mg/L)	0.000008	0.000234	0.000063	0.000049	1.5	–
pH	7	7	7	0.00	6.5–8.5	6.5–8.5
Calcium hardness (mg/L $CaCO_3$)	30	510	193.8	130.9	–	–
NCH (mg/L $CaCO_3$)	0.00	500	234	113.6	–	–
TH (mg/L $CaCO_3$)	230	850	467.4	144.3	500	350
Magnesium hardness (mg/L $CaCO_3$)	18	595	257.4	162.4	–	–
HCO_3^- (mg/L)	235	351	273	20.7	–	–
CO_2 (mg/L)	0.00	169.8	39.9	41.5	–	–
EC (μS/cm)	1,026	1,992	1,544	271	2,000	1,500
TDS (mg/L)	615.6	1,195	926.8	164	1,500	500
NO_2^- (mg/L)	0.002	5.4	0.14	0.75	0.3	0.1
NO_3^- (mg/L)	0.025	67	12.4	18.5	45	45
Cl^- (mg/L)	0.2	15	4.74	4.78	400	200
Mg^{2+} (mg/L)	4.32	142.8	61.77	38.99	150	50
Ca^{2+} (mg/L)	12	204	77.52	52.39	250	75
Na^+ (mg/L)	9	92	51	23.6	200	200
K^+ (mg/L)	0.00	5.2	4.1	1.9	–	–
MPN/100 mL	3	1,100	117.3	233.76	0	0
WQI	21.4	121.6	58.1	29.09	–	–
NPI	−0.99	2.35	−0.38	0.93	–	–

[a]Maximum contaminant level.
[b]Maximum desirable level.

the IR standard for 8% of the wells, and NO_2^- was higher than the IR standard value for only one well. About 32% of the studied wells had a total hardness higher than the IR standard, and wells nos. 17 and 4 had the lowest and highest value, respectively. The concentration of Mg^{2+} was higher than the IR MCL value in 68% of the studied wells, while no well had a Ca^{2+} concentration higher than the IR standard. Aquifer and soil composition can enter Mg^{2+} in groundwater as a result of ion exchange [33]. Conducting a study to reveal the effect of soil composition and geology influence on ground water chemistry can be useful in interpreting cation and anion content of the studied well water. A study with the aim in future is recommended. Generally, calcium and magnesium maintain a state of equilibrium in most waters. MPN/100 mL was used as a microbiological indicator. Results showed that all wells have microbiological contamination even not pathogenic one. Wells nos. 2 and 5 had the highest MPN value, while well no. 48 had the lowest (1,100 MPN/100 mL vs. 3 MPN/100 mL). The maximum permissible value of total coliforms in drinking water is 0 per 100 mL (MPN = 0). Total and fecal contamination of groundwater can be due to manmade activity in the region of the well and environmental factors such as the specifications of watershed, weather condition, and land management measures [28]. The source of pollution and well contamination by coliforms may be separate, i.e. it may enter the well through pores in the surrounding soil or through a cracked drum/casing and move through the water flow to other wells. Rumeshgan is a county where husbandry one of the main activities, and this can affect the biological quality of the groundwater for the reasons mentioned above. In addition, use of manure may be a reason to obtain the result [1].

An IMVIC test was used to identify the presence of bacteria species in the studied wells. The test result has been presented in Table 3, which shows that 13 bacteria species were detected. *Klebsiella oxytoca* and *Bacillus coagulans* were the most and least prevalent bacteria species in the studied wells (positive in 18 tests vs. 1 test), respectively. *K. oxytoca* is a Gram-negative, i.e. a species of coliforms that has been identified as a pathogen. On rare occasions, *K. pneumoniae* and *K. oxytoca* may cause serious infections, such as destructive pneumonia. Lehtola et al. [34] identified *K. oxytoca* as one of the coliform species that can grow in pipe biofilms. *K. oxytoca* has already been isolated from the chlorination tank of the effluent wastewater treatment plant [35]. Podschun et al. [36] investigated the occurrence of different *Klebsiella* spp. in aquatic environments. Based on their results, 123 *Klebsiella* strains were isolated in 53% of the samples, the most common species being *Klebsiella pneumonia* and *K. oxytoca*. At environmental view, *Klebsiella pneumonia* can do heterotrophic nitrification and aerobic denitrification in aquatic environment [34]. Furthermore, *K. oxytoca* is a micro-organism that fixes nitrogen [34]. Thus, high level of nitrate at some well water may be linked to *Klebsiella pneumonia* and *K. oxytoca* presence. *B. coagulans* is a lactic-acid-forming and facultative anaerobic bacterium of the *Bacillus* genus. The main features of *B. coagulans* are acid and heat resistance and easy culture [37]. *B. coagulans* was isolated from the industrial wastewater drainage and selected for its

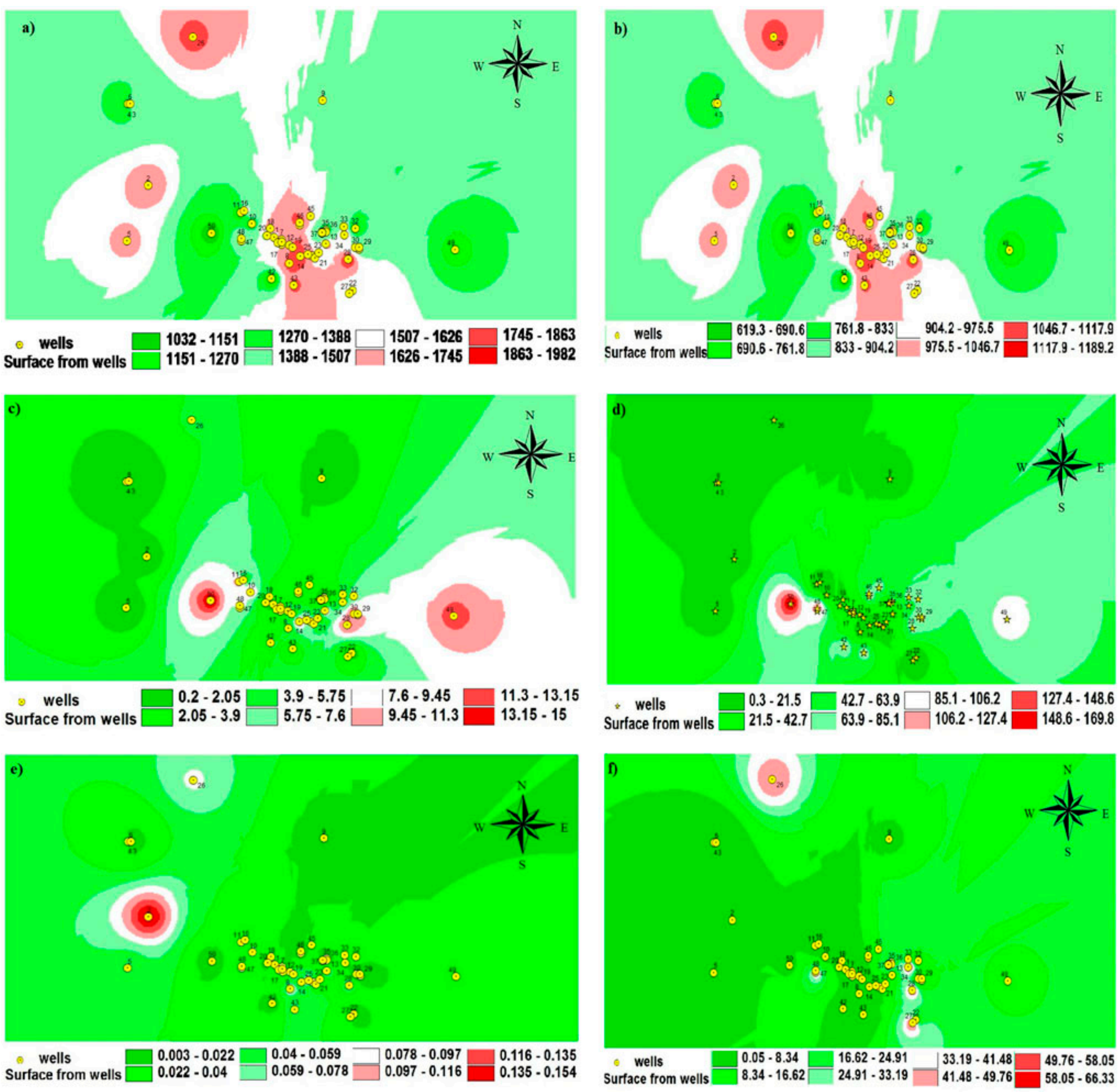

Fig. 1. Contour map of studied parameters based on the data of 50 wells: (a) water conductivity, (b) TDS, (c) Cl^-, (d) CO_2, (e) nitrite (NO_2^-), (f) nitrate (NO_3^-), (g) total hardness, (h) non-carbonate hardness, (i) calcium hardness, (j) magnesium hardness, (k) total MPN/100 mL, and (l) sulfate (SO_4^{2-}).

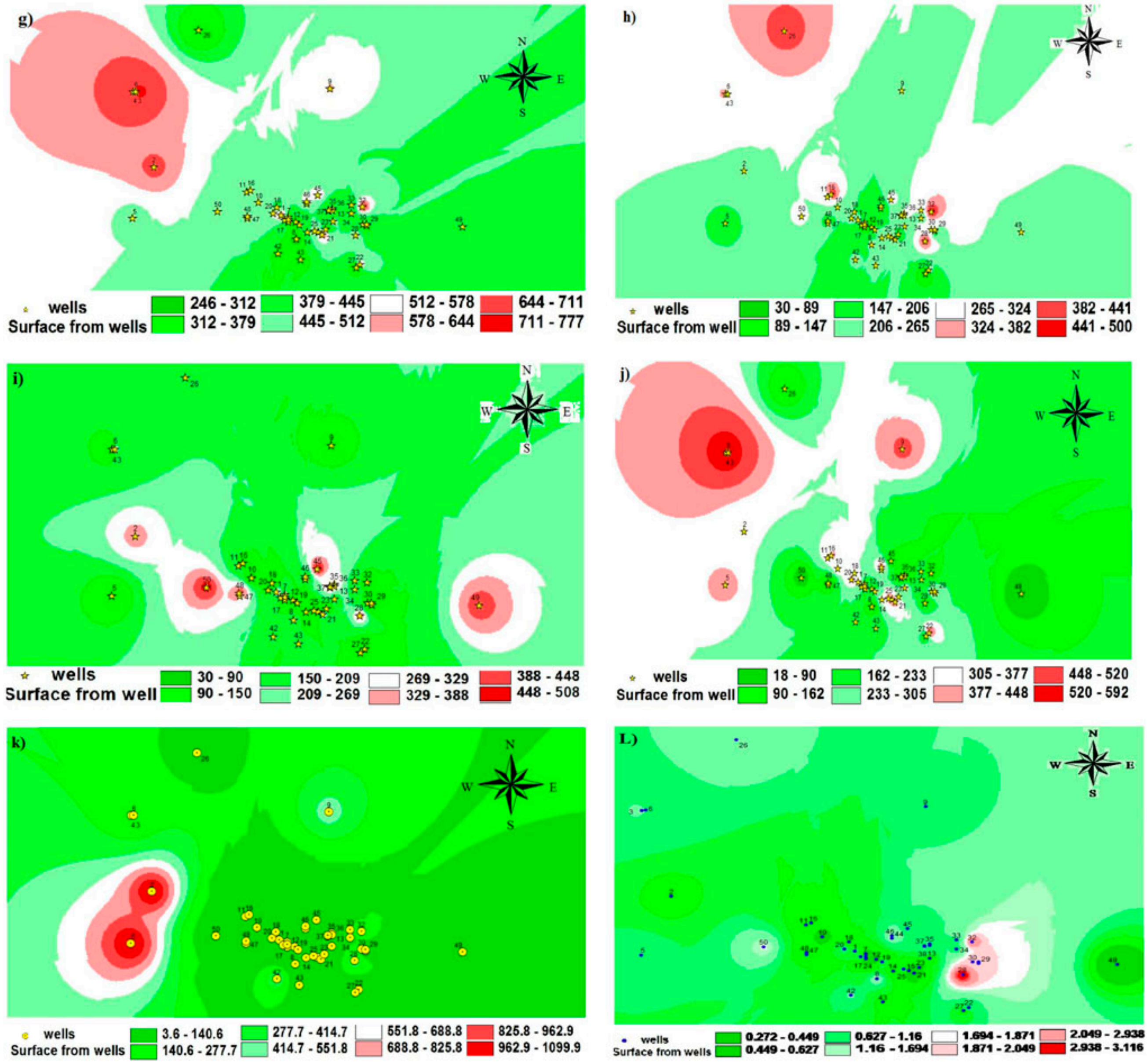

Fig. 1. (*Continued*).

antimicrobial activity against Gram-positive and Gram-negative bacteria, as well as yeast strains [37]. *B. coagulans* has been introduced as a probiotic micro-organism, as a food ingredient [38]. When taken orally, it has also shown beneficial effects on the intestinal environment, stool frequency and characteristics, and dermal attributes in animals and humans [38]. It seems that the presence of *B. coagulans* in the studied groundwater is not considered as a pathogenic bacterium. In a study done [39], nitrogen from aromatic ring of pyridine had been reduced to ammonia and subsequently heterotrophically to nitrite and nitrate by *B. coagulans*. In other word, this micro-organism can be a cause of nitrate increasing in groundwater because of high identified at well waters.

The overall quality of the water and the NPI for each well are shown in Fig. 2 (they were determined using a GIS). The highest and lowest GWQI values were obtained for wells nos. 45 and 3 (121.26 vs. 21.43). About 50% of the studied wells there are in the excellent water quality category (WQI < 50), 40% of them place in the good water quality category, while only 10% there are in the poor or very poor category.

Table 3
MIVIC results for studied wells

Well no.	IMVIC
1	*C. koseri/diversus*, A typical *Enterobacter cloacae*
2	*C. koseri/diversus*, A typical *Enterobacter cloacae*
3	*K. oxytoca*
4	*K. oxytoca*
5	*Proteus mirabilis*, *Citrobacter freundeii*, *S. paratyphi B*, *Klebsiella ozaenae*, Citrobacter, Arizona, Erwinia, *Klebsiella pneumuniae*
6	*P. agglomerans*
7	*K. oxytoca*
8	*C. koseri/diversus*, A typical *Enterobacter cloacae*
9	*P. agglomerans*
10	*C. koseri/diversus*, A typical *Enterobacter cloacae*
11	*C. koseri/diversus*, A typical *Enterobacter cloacae*
12	*K. oxytoca*
13	*P. agglomerans*
14	*C. koseri/diversus*, A typical *Enterobacter cloacae*
15	*K. oxytoca*
16	*P. agglomerans*
17	*P. agglomerans*
18	*K. oxytoca*
19	*Citrobacter freundeii*, *Proteus mirabilis*, *S. paratyphi B*. *Klebsiella ozaenae*, Citrobacter, Arizona, Erwinia, *Klebsiella pneumuniae*
20	*C. koseri/diversus*, A typical *Enterobacter cloacae*
21	*C. koseri/diversus*, A typical *Enterobacter cloacae*
22	*P. agglomerans*
23	*K. oxytoca*
24	*K. oxytoca*
25	*K. oxytoca*
26	*Citrobacter freundeii*, *Proteus mirabilis*, *S. paratyphi B*, *Klebsiella ozaenae*, Citrobacter, Arizona, Erwinia
27	*Bacillus coagulans*
28	*Citrobacter freundeii*, *Proteus mirabilis*, *S. paratyphi B*, *Klebsiella ozaenae*, Citrobacter, Arizona, Erwinia, *Klebsiella pneumuniae*
29	*Citrobacter freundeii*, *Proteus mirabilis*, *S. paratyphi B*, *Klebsiella ozaenae*, *Citrobacter*, Arizona, Erwinia, *Klebsiella pneumuniae*
30	*P. agglomerans*
31	*K. oxytoca*
32	*C. koseri/diversus*, A typical *Enterobacter cloacae*
33	*C. koseri/diversus*, A typical *Enterobacter cloacae*
34	*C. koseri/diversus*, A typical *Enterobacter cloacae*
35	*P. agglomerans*
36	*Citrobacter freundeii*, *Proteus mirabilis*, *S. paratyphi B*, *Klebsiella ozaenae*, Citrobacter, Arizona, Erwinia, *Klebsiella pneumuniae*
37	*K. oxytoca*
38	*C. koseri/diversus*, A typical *Enterobacter cloacae*
39	*K. oxytoca*
40	*K. oxytoca*
41	*K. oxytoca*
42	*Citrobacter freundeii, Proteus mirabilis, S. paratyphi B, Klebsiella ozaenae, Citrobacter, Arizona, Erwinia, Klebsiella pneumuniae*
43	*C. koseri/diversus*, A typical *Enterobacter cloacae*
44	*Citrobacter freundeii, Proteus mirabilis, S. paratyphi B, Klebsiella ozaenae, Citrobacter, Arizona, Erwinia, Klebsiella pneumuniae*

(*Continued*)

Table 3 (*Continued*)

Well no.	IMVIC
45	*P. agglomerans*
46	*K. oxytoca*
47	*K. oxytoca*
48	*K. oxytoca*
49	*P. agglomerans*
50	*K. oxytoca*

The GWQI value is 58.1 ± 29.09, which is generally in the good water quality category.

Based on the NPI and the nitrate concentration, wells were grouped into three classifications (lower than 20 mg/L, 20–50 mg/L, and greater than 50 mg/L). About 82% of the samples had a nitrate concentration that lowered the threshold value of the anthropogenic source or the human-affected value. In addition, the characteristics of the aquifer can be important to interpret the results [40], but it is not discussed here. We recommended to use the aquifer characteristics in future studies. More than 10% of the sampled sites had a nitrate concentration of more than 20 mg/L and less than 50 mg/L, while 8% of the sampled sites had a nitrate concentration of more than 50 mg/L. Similar to the above-mentioned nitrate, 82% of the wells were placed in the unpolluted category. Only three wells had significant pollution (they are located in the southwest part of the study area). The correlation coefficient (r) is computed and the correlation matrix is shown in Table 4.

A positive r corresponds to an increasing monotonic trend, while a negative r corresponds to a decreasing monotonic trend between two water quality parameters. A high correlation coefficient (near 1 or −1) means there is a good relationship between two variables, and a value near 0 means there is no relation between them. In the study area, significance correlations are found between the WQI with Ca^{2+}, CO_2, NO_3^-, Mg^{2+}, and magnesium hardness ($p < 0.05$), and the NPI with Ca^{2+}, CO_2, NO_3^-, Mg^{2+}, and magnesium hardness ($p < 0.05$). In this study, the semivariogram models (circular, spherical, exponential, Gaussian, and linear) were checked for the GWQI and NPI data-set.

As presented in Table 5, the AIC and BIC values for all used models except the exponential model (AIC = 428.07) fitted for the GWQI and the NPI semivariogram are very close, which shows a close action of the models, while RSME values are close together for

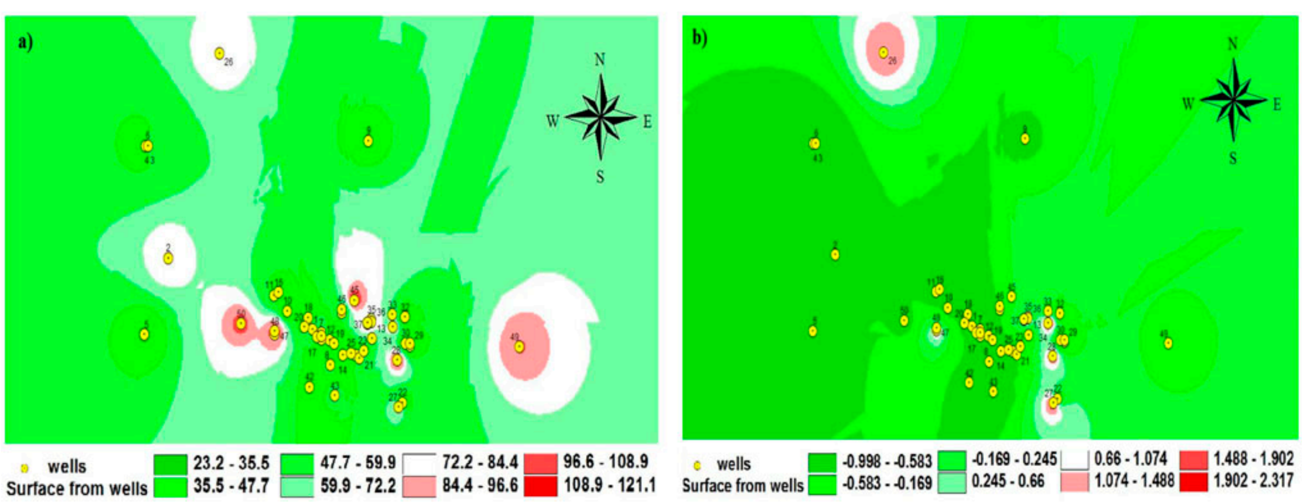

Fig. 2. Contour of GWQI and NPI based on the data of 50 wells: (a) NPI and (b) GWQI.

Table 4
Correlation matrix of various groundwater parameters

	SO_4^{2-}	PO_4^{2-}	pH	Calcium Hardness	NCH	TH	Magnesium Hardness	CO_2	EC	TDS	NO_2^-	NO_3^-	Cl^-	Mg^{2+}	Ca^{2+}	MPN	WQI	NPI
SO_4^{2-}	1	0.12	–	0.12	**0.42**	**0.29**	0.04	**0.33**	−0.07	−0.07	−0.09	0.2	0.9	0.04	0.12	0.17	0.18	0.2
PO_4^{2-}		1	–	−0.12	−0.15	0.03	0.1	−0.03	−0.07	−0.07	0.18	−0.16	−0.05	0.1	−0.12	0.24	−0.17	−0.16
Ca hardness				1	0.11	0.25	**−0.45**	**0.47**	−0.17	−0.17	0.01	0.22	0.07	**−0.45**	**1**	0.01	0.94	0.22
NCH					1	**0.35**	0.09	0.08	−0.03	−0.03	−0.01	0.07	0.03	0.09	0.1	0.09	0.13	0.07
TH						1	**0.6**	−0.03	−0.12	−0.13	0.04	−0.2	−0.14	**0.6**	0.25	0.23	0.19	−0.22
Mg hardness							1	**−0.45**	0.09	0.08	0.04	**−0.3**	−0.24	**1**	**−0.45**	0.17	**−0.44**	**−0.33**
CO_2								1	**−0.35**	**−0.35**	**−0.14**	0.06	**0.3**	**−0.45**	**0.47**	**−0.07**	**0.39**	0.06
EC									1	**0.9**	−0.26	0.1	−0.02	0.08	−0.17	0.07	−0.05	0.1
TDS										1	−0.2	0.1	−0.02	0.08	−0.17	0.06	−0.05	0.1
NO_2^-											1	−0.1	0.2	0.04	0.01	−.04	−0.03	−0.1
NO_3^-												1	−0.08	**−0.3**	0.2	−0.07	**0.5**	**1**
Cl^-													1	−0.2	−007	−0.14	0.02	−0.08
Mg^{2+}														1	**−0.45**	0.17	**−0.44**	**−0.33**
Ca^{2+}															1	0.01	**0.94**	0.2
MPN																1	0.001	−.07
WQI																	1	**0.54**
NPI																		1

Note: Bold values are significant.

Table 5
Cross-validation results of fitted models

Model	AIC		BIC		SSE		RSME	
	GWQI	NPI	GWQI	NPI	GWQI	NPI	GWQI	NPI
Spherical	914.46	211.63	920.48	217.43	1.49e + 007	56	540.67	1.1
Circular	903.49	168.2	909.51	173.42	1.22e + 007	48	489.36	1.12
Gaussian	946.29	210.47	952.31	216.26	2.65e + 007	55	722.13	1.08
Exponential	428.07	166.69	431.73	171.9	2.14e + 007	46	1,011.47	1.1
Linear	924.84	209.56	930.86	215.36	1.8e + 007	54	594.19	1.07

all the studied models. Here, we used the RSME value to choose the best model. Given that the model that has the smallest RMSE value is considered as the best-fit one, consequently the linear model (RSME = 1.07) was chosen as the best-fit model. Linear variogram means that the GWQI and the NPI go up approximately linearly with increasing distance. In other words, with increasing distance from Rumeshgan to the west (northwest or southwest), widespread agricultural uses lead to a decrease in water quality and increasing nitrate pollution. In addition, from southeast toward northwest of Rumeshgan county, the well depth decreases; thus they can be related together.

4. Conclusion

It can be concluded, this study constitutes one of the comprehensive studies of groundwater quality using different method and index. Our results showed contamination of the wells by nitrate is not more considerable and most of the wells were grouped in the unpolluted category. In addition, the WQI is generally in the good water quality category. The piper diagram showed that the studied wells have a water type with permanent hardness. Statistical correlation between parameters and GWQI or NPI showed that we can develop new index by other parameters that are not included in GWQI. Finally, according to the assessment of the spatial distribution of the GWQI and the NPI by semivariogram models, with increasing distance from Rumeshgan, or from southeast toward northwest of Rumeshgan county, the well water quality will decrease linearly.

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Abbreviations

GIS	—	geographic information system
NPI	—	nitrate pollution index
GWQI	—	groundwater quality index
AIC	—	akaike information criterion
BIC	—	Bayesian information criterion
RMSE	—	root-mean-square error
SSE	—	sum of errors
TDS	—	total dissolved solids
TH	—	total hardness
CH	—	carbonate hardness
NCH	—	non carbonated hardness
Mg Ha	—	magnesium hardness
Ca Ha	—	calcium hardness
TC	—	total coliform
MPN	—	most probable number
IMViC	—	indole, methyl red, Voges–Proskauer, and citrate

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