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Assessment and Spatial Distribution of Mineral Groundwater Quality in Ardabil Province, Iran

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Abstract

Background: *The present study was conducted to determine the quality of mineral ground waters and analyze their spatial distribution in Ardabil Province of Iran.*
Methods: *This descriptive analytical study was carried out on natural mineral water wells in Ardabil Province over one year. Samples of water were taken from a total of 44 wells in this province every season, from April 2016 to February 2017. They were then transferred to Khak Azmay-e Moghan Laboratory and their Total Dissolved Solids (TDS), chloride, calcium, magnesium, sulfate, sodium and bicarbonate were measured based on the instructions presented in Standard Methods. The Ground Water Quality Index (GWQI) was then determined based on the measured parameters. The spatial distribution of the ground waters based on the GWQI was then also determined in a Geographic Information System (GIS).*
Results: *The GWQI varied extensively in the natural mineral water wells of Ardabil Province, from 24.88 to 312.58. The best physicochemical quality based on the GWQI was observed in Hammam-e Sangi and the poorest quality in Saghezji-Mardaneh. According to the index, 2.5% of the wells were of very good quality, 30% were of good quality, 32% of moderate quality, 13.5% of poor quality and 22% were of inappropriate quality.*
Conclusions: *According to the results, the most important quality problems included high levels of TDS, chlorine and sulfate and low pH values. Considering that these wells supply people's drinking water in this region, consumers should be warned of their water quality, and purification procedures should also be carried out to allow the hygienic use of these valuable resources.*

Keywords: Mineral waters, Qualitative zoning, GWQI, Ardabil, GIS.
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Introduction

Surface and ground waters are currently at risk of pollution due to the intensive human activities such as solid waste disposal, industrial activities, illegal wastewater discharge, etc.[1,2] The national rainfall in Iran is about one-third of the world's average. The development and implementation of control programs for water resources are therefore a high priority. Mineral water is one of the main sources of drinking and recreational water supply in Iran, especially in some provinces such as Ardabil, West Azerbaijan and Zanjan provinces. Mineral waters come from natural resources such as wells and underground aquifers, and contain special minerals and trace elements.[3]

Mineral waters have surface (geothermal) or underground (juvenile) origins with many therapeutic benefits, and depending on their type and composition, may increase urine and toxin excretion from the body,[4, 5] eliminate constipation, resolve respiratory disorders,[6, 7] regulate the acid-base balance in the body,[8] remedy arteritis and stimulate calcium[9] and thus play an important role in drinking water treatment programs. Determining the qualitative status of these water resources is therefore necessary for adopting appropriate strategies for preventing their quality depletion.[10]

In many countries, monitoring the quality of mineral waters is the main water protection program in place, and monitoring and planning guidelines have been developed as well.

There are different indices for water quality assessment, such as the Water Quality Index (WQI),[12]the National Sanitation Foundation Water Quality Index (NSFWQI),[13]the Water Quality with Minimum Subsidence (WQImin),[14]the Water Quality with Five Subsidence (WQImoc),[15]the Oregon Water Quality Index (OWQI)[16] and the Ground Water Quality Index (GWQI).[17]Some of these indices are used for surface waters and some for ground and mineral waters. These indices help use the results of experiments carried out on the physicochemical characteristics of water by way of mathematical relations and yield a numerical value and a descriptive table, and the quality of mineral waters is thus determined.[11]

In the GWQI, water quality parameters are represented in a single form, as this form facilitates a composite influence over all the parameters in the system and helps compare the overall quality of water with a unique descriptive value.

This index was presented by Babiker et al. and combines eight parameters (pH, total dissolved solids, chlorine, calcium, magnesium, sulfate, bicarbonate and sodium) and analyzes the spatial distribution of water resources in terms of quality.[12]

The present study examined the quality of natural mineral waters in Ardabil Province using the GWQI and the Geographic Information System (GIS) to provide a qualitative map of the province's mineral waters while presenting a portrayal of these resources to enable the formulation and implementation of national and provincial programs for maintaining or enhancing the quality of these resources.

Materials and Methods

Occupying 1.07% of the country's total area, Ardabil Province has a total area of 18050 km^2 and a population of 1,568,956 and is located on the east of East Azerbaijan

Province, the south and southwest of Azerbaijan country, the west and southwest of Gilan Province, and the north of Zanjan Province in Iran (figure 1).[18]

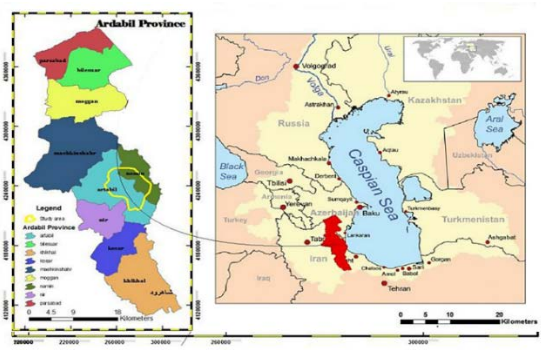

Figure 1. A map of the study area

The province has five permanent rivers, which are called Aras, Balkhli, Ghareh-Sou, Khayyav and Harvabad, two lakes called Shorabil and Nir and more than 80 mineral water wells located in six cities, namely Sarein, Nir, Khalkhal, Namin, Sardabeh and Meshkinshahr. Of the 80 mineral water wells located in the province, 44 are permanent and have a discharge rate of more than 1 L/sec. The discharge of these wells varies from 1 to 120 L/sec.[19]

Since the present study was conducted to determine the quality index of mineral ground waters in Ardabil Province, all the 44 permanent wells in this region were selected as sampling points.

As shown in table 1, this research examined all the 44 permanent mineral water wells in Ardabil Province, located in six cities, including Sarein (12 wells), Nir (six), Khalkhal (two), Namin (one), Sardabeh (ten) and Meshkinshahr (13). Sampling was performed once every season, from April 2016 to February 2017. The containers used for sampling were made of glass and plastic in accordance with standard instructions (Standard Methods, 2008). To prepare the containers, they were first washed with a diluted washing liquid and placed in sulfo-chromic acid, then rinsed with water and again washed with deionized distilled water. The glass containers were first washed with diluted liquid and distilled water and then dried in the oven at 180 °C for 1 hour. For sampling, the tap heads were separated and the tap was cleaned with water using a piece of cloth, and water was then left running for 2 min to remove any sand from the water. These samples were then transferred to a trusted laboratory of the Environmental Protection Administration of Ardabil Province (Khak Azmay-e Moghan Lab.), and the physicochemical parameters required for determining the GWQI, including pH, TDS, chlorine, calcium, magnesium, sulfate, bicarbonate and sodium, were determined using the instructions presented in the Standard Methods (2008). The pH values were measured by a Hach pH meter (250), TDS by weighing using the G2540, the calcium and magnesium concentrations by titration using EDTA, the chlorine content by Argentometry using the 4500-Cl-B, the sodium content by photometry using the PFP7 photometer (GENWAY Co., UK), sulfate by Turbidimetry using the 4500-SO42-E and the bicarbonate content by Titrimetry using the 2320-T.[14]

The GWQI is an effective and useful indicator of the quality of ground and mineral waters. Chander Kumar Singh et al. developed the following equation to calculate the GWQI:

$$GWQI = \text{Anti log}\left[\sum w \log10\, qn\right] \qquad \text{(Equation 1)}$$

where W is the weight of each qualitative parameter obtained from table 2, and qn is the measured concentration of each parameter.[15]

Table 1.The names, geographical latitudes and discharge rates of the studied wells

Name	Latitude	Longitude	Discharge Rate (L/Sec)	City	Name	Latitude	Longitude	Discharge Rate (L/Sec)	City
Artesian	38.9.24	48.4.17	5.6	Sarein	Yelsoui	38.17.1	48.2.12	5.6	Sardabeh
Pahanlosou	38.9.16	48.4.22	11	Sarein	Panlosou	38.16.59	48.2.12	3.4	Sardabeh
Bajilar	38.9.7	48.4.28	8	Sarein	ElishGoulee	38.16.58	48.2.14	2.2	Sardabeh
Gasshooee	38.9.1	48.4.31	6.8	Sarein	Dashbouree	38.16.57	48.2.11	5.8	Sardabeh
Jeneral	38.8.53	48.4.38	15	Sarein	Lihjleesouee	38.16.56	48.2.15	3.1	Sardabeh
Sarisou	38.9.18	48.3.49	12	Sarein	Esmaiilsouee	38.16.55	48.2.19	5.8	Sardabeh
Gharesou	38.9.4	48.4.1	7.5	Sarein	Saadatsouee	38.16.54	48.2.22	3.8	Sardabeh
Ghahvesouee	38.8.47	48.4.17	11	Sarein	Mahtabil	38.16.58	48.2.23	2.1	Sardabeh
Asadbolaghee	38.8.39	48.4.30	6.5	Sarein	Chakhmaghloo	38.17.1	48.2.6	5.2	Sardabeh
Viladarreh	38.8.53	48.3.51	6.2	Sarein	Aghsouee	38.23.36	47.39.49	3.2	Meshkinshahr
Yelsouee	38.8.36	48.4.8	4.6	Sarein	Maleksooee	38.23.32	47.39.48	2.6	Meshkinshahr
GavmishGoilee	38.8.31	48.4.26	10.5	Sarein	Ghinerjeh	38.23.50	47.39.31	6.5	Meshkinshahr
Ilanjigh	38.2.4	48.0.33	6.8	Nir	Ilandoo	38.23.42	47.39.9	11.1	Meshkinshahr
Ghinerjeh	38.2.2	48.0.28	3.2	Nir	GhotorsoueeMoinel	38.23.34	47.39.18	6.8	Meshkinshahr
Borjlou	38.2.01	48.0.18	2.7	Nir	Monilsouee	38.23.17	47.39.52	3.4	Meshkinshahr
Gharehshiran	38.1.51	48.0.10	3.6	Nir	Shabilgarm	38.23.55	47.41.14	5.4	Meshkinshahr
Saghezji-e-mardaneh	38.1.52	47.59.59	3.1	Nir	Shabilsard	38.23.29	47.40.48	6.1	Meshkinshahr
Saghezji-e-Zananeh	38.1.54	48.0.2	3.5	Nir	Ghotorsouee	38.21.6	47.40.7	4.3	Meshkinshahr
Hammam-e-sangi	33.37.33	48.32.18	2.8	Khalkhal	Anzan	38.20.5	47.40.49	7.6	Meshkinshahr
Givi	33.37.19	48.31.27	5.2	Khalkhal	Dodou	38.18.16	47.42.14	3.9	Meshkinshahr
Ghotoursoui	38.25.27	48.28.41	3.5	Namin	Havarsouee	38.22.58	47.33.30	2.5	Meshkinshahr
Sardabeh	38.17.2	48.2.10	2.8	Sardabeh	Dodoinanlou	38.25.58	47.39.38	4.7	Meshkinshahr

Table 2. The weight of the parameters affecting the GWQI

Parameter	Sulfate	pH	Sodium	Chloride	TDS	Calcium	Magnesium	Bicarbonate
Weight	0.1245	0.1036	0.1935	0.1362	0.011	0.089	0.2412	0.101
Permissible Limits	300	6-8	200	250	1000	300	30	500

Table 3 presents a classification of the waters based on the GWQI.

Table 3. The classification of the waters based on the GWQI15

Color	Water Quality	GWQI
Blue	Very good	0-25
Green	Good	25-50
Yellow	Moderate	50-75
Orange	Poor	75-100
Brown	Very poor	100-125
Red	Inappropriate	More than 125

The spatial distribution of the GWQI was analyzed in the study area using the GIS. The GIS is a powerful tool for collecting, storing and transforming spatial information and arriving at real-world and real-time conclusions for particular purposes. It stores information in a geo-referenced or geocoded form. The map of the GWQI was generated in GIS using the interpolation approach. The Kriging method was used in this study by different interpolation methods. The Kriging method examines the spatial correlation between sample points and is mostly used for mapping spatial variability.

The steps of spatial analysis using GIS included: Prepare the base map of Ardabil Province, geo-referencing and rectification, shape file creation-polygon, map digitization, attribute data entry, set layer property, spatial query, data analysis and determining the results based on the conditions. SPSS-16 was used for the statistical analysis of the data.

Results

After sampling the 44 wells and performing the laboratory analysis, the concentration of the parameters was obtained, as shown in tables 4 to 9.

To calculate the GWQI, the weight of the effective parameters had to first be determined using Equation 1. Table 2 presents the weight of these parameters, which were measured in accordance with their individual importance to water quality and the weights obtained in other studies and upon discussions with experts in water quality management (the Ad hoc method).[16, 17, 18]

Table 4. Parameter values in the mineral water wells of Sarein (Mean ± SD)

Well	Parameter*							
	Calcium	Magnesium	Sodium	Chloride	pH	TDS	Bicarbonate	Sulfate
Artesian	92.8±3.8	10.58±2.2	157.5±4.8	233.97±6.7	6.8±0.23	872.9±25.6	352±5.2	93.3±2.7
Pahanlosou	84.8±4.1	12.48±2.7	159.3±2.2	219.75±4.2	5.81±0.31	841.6±19.5	364±6.8	86.4±2.4
Bajilar	80±2.6	17.26±2.7	157.5±2.8	233.9±3.6	6.12±0.19	870.4±23.5	368±4.2	69±3.4
Gasshooee	74±3.8	26.88±1.3	85.33±2.8	106.35±5.2	5.12±0.16	5939.2±28.9	220±5.4	159.7±2.8
Jeneral	96±2.1	9.6±1.8	166.9±2.4	23.97±8.6	5.66±0.23	884.4±24.3	332±4.6	99.3±4.1
Sarisou	116±2.8	33.6±1.4	165.2±2.4	248.15±3.5	5.64±0.35	1076.4±21.7	352±5.9	192±1.6
Gharesou	108±1.7	31.68±1.5	166.9±1.4	241.06±4.6	5.54±0.06	1040.4±26.5	360±4.7	192±1.7
Ghahvesouee	79.8±1.6	27.84±1.7	168.8±1.5	240.6±6.5	5.76±0.42	900.4±23.2	280±4.4	103.9±2.8
Asadbolaghee	41±1.7	22.08±1.9	38.8±1.5	21.27±5.5	5.32±0.38	364.8±20.3	206±6.2	37±1.1
Viladarreh	56±1.3	19.2±1.3	37±1.6	35.45±4.4	5.37±0.24	325±25.6	188±5.7	86.5±2.3
Yelsouee	45.8±1.9	24±1.1	170.6±2.6	226.88±3.2	5.8±0.44	892.8±19.2	296±4.1	96.3±3.5
GavmishGoilee	76.8±2.3	33.6±1.9	168.8±1.5	219.79±5.4	5.77±0.34	901.1±28.1	308±5.1	81.9±2.4

*All the parameters are in mg/L, except for pH, which is without a unit.

Table 5. Parameter values in the mineral water wells of Nir (Mean ± SD)

Well	Parameter*							
	Calcium	Magnesium	Sodium	Chloride	pH	TDS	Bicarbonate	Sulfate
Ilanjigh	78.4±1.3	18.24±1.4	105.8±1.9	120.53±3.8	6.21±0.41	485.7±26.2	164±4.7	141±3.5
Ghinerjeh	200±3.2	52.8±1.7	169±25.4	2836±29.6	6.59±0.26	6412±46.8	800±26.5	211±3.8
Borjlou	48±1.5	33.6±1.2	1855.8±33.5	2556±26	6.85±0.27	6438.4±42	927.2±36.2	744±5.9
Gharehshiran	206.4±1.7	34.56±2.2	1880±32.3	2554±23	6.33±0.21	6329.6±21	1112±21.1	510±3.2
Saghezji-e-mardaneh	200±2.6	48.6±1.4	1875±20.2	2059±31	6.32±0.25	6342.4±25	1512±19.1	681.6±4
Saghezji-e-Zananeh	269±20.5	36.4±1.2	1858.6±21.1	2236.5±20	6.23±0.23	6528±23.1	1781.2±19	595.2±3.2

*All the parameters are in mg/L, except for pH, which is without a unit.

Table 6. Parameter values in the mineral water wells of Khalkhal (Mean ± SD)

Well	Parameter*							
	Calcium	Magnesium	Sodium	Chloride	pH	TDS	Bicarbonate	Sulfate
Hammam-e Sangi	17.6±0.6	2.88±0.1	92.7±1.8	99.4±1.8	9.05±0.24	327.6±24.2	40±0.36	74.3±12.3
Givi	80±2.2	269±20.5	296±17	213±2.6	6.82±0.4	1036.68±35.2	400±5. 6	211.2±16.2

*All the parameters are in mg/L, except for pH, which is without a unit.

Table 7. Parameter values in the mineral water wells of Namin (Mean ± SD)

Well	Parameter*							
	Calcium	Magnesium	Sodium	Chloride	pH	TDS	Bicarbonate	Sulfate
Ghotoursoui	270.4±14	140.16±3.5	788.2±8.2	1775±36	6.32±0.21	3680±41	720±6.5	268.8±5.2

*All the parameters are in mg/L, except for pH, which is without a unit.

Table 8. Parameter values in the mineral water wells of Sardabeh (Mean ± SD)

Well	Parameter*							
	Calcium	Magnesium	Sodium	Chloride	pH	TDS	Bicarbonate	Sulfate
Dodoinanlou	102±2.1	36.48±1.3	44.3±1.2	35.45±1.8	5.96±0.21	595.2±5.6	28±0.52	324±4.2
Yelsoui	84±1.8	52.8±2.4	50.6±1.5	49.63±1.1	4.59±0.31	613.1±14	40±0.8	361±3.6
Panlosou	124±2.2	8.64±0.65	57.5±1.3	28.36±1.4	4.47±0.21	598.4±12.2	28±0.21	410±0.21
ElishGoulee	135±2.1	5.76±0.14	48.3±1.3	35.45±1.1	4.56±1.14	598.4±8.2	32±1.1	391±4.5
Dashbouree	129.7±2.6	5.76±0.1	55.2±2.4	21.27±0.62	3.96±0.11	595.2±7.6	52±1.5	351±5.2
Lihjleesouee	122±2.3	8.64±0.24	50.6±1.2	21.27±0.36	4.73±0.15	584.9±6.9	52±0.8	329±4.1
Esmaiilsouee	125.8±1.1	12.48±0.87	57.5±1.1	28.36±0.65	4.59±0.12	579.8±5.1	28±0.56	441±1.8
Saadatsouee	203.2±4.5	3.87±0.11	59.8±1.9	127.6±2.2	4.54±0.13	77.6±6.4	26±1.1	334±2.5
Mahtabil	175±1.9	17.28±0.21	57.5±1.5	42.54±1.3	3.86±0.14	671.3±5.8	48±1.4	483±2.3
Chakhmaghloo	158.4±2.2	28.8±0.97	59.8±1.1	35.45±0.65	4.32±0.12	602.2±4.6	32±0.47	412.8±21.3

*All the parameters are in mg/L, except for pH, which is without a unit

Table 9. Parameter values in the mineral water wells of Meshkinshahr (Mean ± SD)

Well	Parameter*							
	Calcium	Magnesium	Sodium	Chloride	pH	TDS	Bicarbonate	Sulfate
Aghsouee	60.8±0.2	9.6±0.31	55.2±1.3	85.2±2.5	3.46±0.09	273.2±2.8	36±0.32	124±1.8
Maleksooee	52.8±0.31	10.56±0.2	156.4±3.6	269.42±3.2	6.05±0.36	738.5±8.2	132±2.3	124±1.8
Ghinerjeh	140.8±2.5	13.2±0.21	1138±19.2	1559.8±26	6.08±0.21	3353.6±28.5	176±2.5	253±4.5
Ilandoo	99.2±2.6	31.68±1.2	349.6±4.2	602.65±8.2	5.84±0.32	1268.4±26.3	176±2.5	84±2.6
GhotorsoueeMoinel	56±2.4	43.2±1.6	73.6±0.96	42.6±1.8	3.31±0.08	867.2±9.5	26±1.1	321±1.7
Monilsouee	120±2.1	16.32±0.7	73.6±2.3	85.2±2.1	6.67±0.21	622±4.5	56±0.97	307.2±12.1
Shabilgarm	62.4±1.9	31.4±0.67	262±4.6	276.9±5.4	6.49±0.17	984.3±18.7	340±5.6	241±6.3
Shabilsard	86.4±2.8	31.2±1.3	73.6±1.5	42.54±1.1	4.22±0.13	564.4±6.9	292.8±2.4	163±2.6
Ghotorsouee	128±2.8	57.6±0.35	207±1.3	213±2.4	2.55±0.32	1061.8±65.2	24±0.54	401±5.9
Anzan	440±12.2	180±3.6	2104.5±75	2272±43.2	6.3±0.6	8102.4±85	2952.4±63	792±11.1
Dodou	56±2.3	24±1.1	2104.5±52	184.6±3.5	6.22±0.34	787.2±31	170.8±4.2	211.2±5.8
Havarsouee	88±2.8	24.3±0.56	156.4±2.5	241.4±6.2	5.99±0.23	851±13	170.8±3.5	196.8±5.2
Dodoinanlou	88±2.3	38.4±1.3	407.1±4.6	468.6±8.4	5.99±0.11	1612.8±45.6	195.2±8.7	465.6±14.3

*All the parameters are in mg/L, except for pH, which is without a unit

Table 10. The GWQI of the studied wells

City	Well						
Sarein	Artesian	Pahanlosou	Bajilar	Gasshooee	Jeneral	Sarisou	Gharesou
	58.86	59.2	62.94	57.67	57.92	87.94	58.79
	Ghahvesouee	Asadbolaghee	Viladarreh	Yelsouee	GavmishGoilee		
	73.47	30.56	34.7	66.73	74.32		
Nir	Ilanjigh	Ghinerjeh	Borjlou	Gharehshiran	Saghezji-E-mardaneh	Saghezji-E-Zananeh	
	56.53	265.9	251.2	278.2	312.58	300.8	
Khalkhal	Hammam-e Sangi	Givi					
	24.88	82.39					
Namin	Ghotoursoui						
	282.15						
Sardabeh	Sardabeh	Yelsoui	Panlosou	ElishGoulee	Dashbouree	Lihjleesouee	
	45.16	53.32	33.1	30.44	29.65	32.3	
	Esmaiilsouee	Saadatsouee	Mahtabil	Chakhmaghloo			
	36.65	34.2	45.32	47.5			
Meshkinshahr	Aghsouee	Maleksooee	Ghinerjeh	Ilandoo	GhotorsoueeMoinel	Monilsouee	Shabilgarm
	31.34	51.98	141	97.82	47.52	41.85	97.89
	Shabilsard	Ghotorsouee	Anzan	Dodou	Havarsouee	Dodoinanlou	
	54.38	72.48	520.7	72.46	75.89	126.7	

Table 10 presents the GWQI of the studied wells in different cities of Ardabil Province.

Figure 2 presents the spatial distribution of the natural mineral waters' quality in different cities of Ardabil Province based on the GWQI in GIS. As shown, the GWQI varies from 24.88 to 312.58 in different wells and cities, because the layers of the earth vary in different parts of the province and different geological formations (from calcareous to igneous) can be observed in different parts of the area. Also, there are differences in the depth of the ground waters and their pathways. This wide range shows that the ground water quality in the studied area can be classified into different levels, and the status of ground water quality in Ardabil Province was thus interpolated using the Kriging method and divided into six zone types: inappropriate water quality (more than 125), very poor water quality (100-125), poor water quality (75-100), moderate water quality (50-75), good water quality (25-50) and very good water quality (0-25).

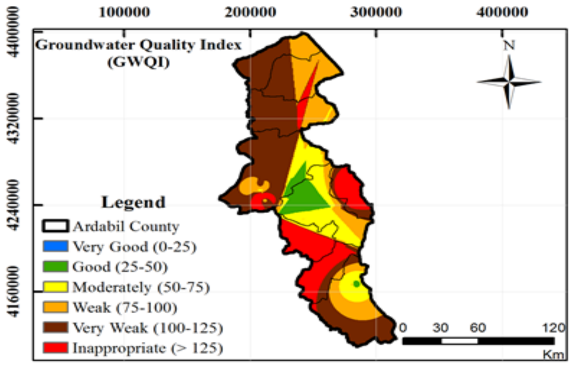

Figure 2. The spatial distribution of the GWQI in Ardabil Province

Discussion

Tables 2 to 9 show the measured parameter values in the 44 natural mineral water wells of Ardabil Province. The comparison of these values with their permissible limits for mineral waters (table 2) shows the following results.

Sarein has 12 natural mineral water wells, in which the levels of calcium, magnesium, sulfate, TDS, chlorine, sodium and bicarbonate are within the permissible limits; however, the pH value in most of these wells, except for Bajjalar and Artesian wells, is lower than the standard range and they are rather acidic due to the geographic proximity of the wells to nitrate streaks. The pH value of these wells should definitely be increased before the consumption of their water.

Nir has 12 natural mineral water wells, in which the level of calcium, magnesium, sulfate, pH, chlorine, sodium and bicarbonate is within the permissible limits; however, the TDS level in most of these wells, except Ilanjian well, is much (2-6 times) higher than the permissible limits, because the region's soil is composed of sedimentary layers with low to moderate adhesion and is highly capable of introducing salts into the water.

A study by Vosoughi et al. on the soils of Ardabil Province showed that they have a high fertility rate, a high rate of reaction with the environment and a high solubility.[19] In a study carried out in Kashan, Iran, the TDS level in ground water resources was more than 1150 mg/L.[20] Also, in a study by Dindarlou et al. in Bandar Abbas, Iran, the TDS level in ground water resources was 1450 mg/L and more than the other parameters.[21]The sedimentary layer is responsible for the high TDS in ground water resources in most cities of Iran.

Khalkhal has two natural mineral water wells, in which the level of calcium, magnesium, sulfate, TDS, chlorine, sodium and bicarbonate is within the permissible limits; however, the pH level in Hammam-E-Sangi well is more than the allowable limit and is rather alkaline due to the presence of calcareous vein in the lower layers of this well as a standing fault. Given the side-effects of high alkalinity on digestion, it is necessary to reduce the pH of water sourcing from these wells before consumption. The study by Vosoughi et al. on the soils of Ardabil Province showed that the soil in this region has stagnant multi limestone streaks.[19]

Namin has one natural mineral water well, in which the level of magnesium, sodium, chlorine, TDS and bicarbonate is more than the permissible limits due to the presence of many mineral contents and mineral streaks in the region and the proximity to these veins. The amounts of chlorine and sodium in this well are 5 and 3 times higher than the permissible limits and drinking its water can potentially lead to an increase in blood pressure and calcium utilization. Its water should therefore be purified prior to consumption.

In the study by Daneshvar et al. in Ardabil, the levels of sodium and chloride were 45 and 48 mg/L,[22] while in the study by Entezari et al. in Mashhad, these levels were 23.5 and 27.5 mg/L.[23]

Sardabeh has ten natural mineral water wells, in which the amount of calcium, magnesium, TDS, chlorine, sodium and bicarbonate is within the permissible limits; however, the pH level in this well is lower and the sulfate level higher than the permissible limits.

The qualitative characteristics of these wells are similar to each other due to being located in a narrow and close geographic area. Moreover, because these wells are located in a zone containing nitrate and sulfate streaks, their pH is small and their sulfate content is double the limit. Considering that sulfate can exacerbate diarrhea in children and also given the effects of acid rain on consumers' health, water treatment is necessary in these wells before the consumption of their water.

Sulfate concentrations in Kashan and Bandar Abbas ground water resources were 125 and 285 mg/L, respectively.[20, 21]

Meshkinshahr has 30 natural mineral water wells, and their physicochemical characteristics differ, as only calcium and magnesium have similar characteristics in all the wells and are within the permissible limits, while the other parameters exceed the range with significant variances. The pH value in all the wells is acidic and lower than the permitted range. The differences in water quality in Meshkinshahr are due to the large geographic distance of the wells from each other and also the different geological structure of Meshkinshahr, as the wells closer to each other have more similar characteristics. Geologically, Meshkinshahr is part of Sabalan Mountains and is rich in mineral deposits. Some types of gemstones within the same range are observed in this region. The other reasons for the difference in water quality in this region include the depth of water movement and the differences in the amount of lime in the layers of the ground through which water passes.

In this study, the GWQI was calculated for all the 44 studied wells, and was found to vary from 24.88 to 312.58. Table 3 shows a comparison of the GWQI.

A: In Sarein, Asadbolaghi and Viladarreh wells are of a good quality (GWQI: 30.56 and 34.70), Sarisou and Gharehsou wells are of a poor quality (87.94 and 73.47) and the other wells are of a moderate quality.

B: In Nir, Ilanjyah well has a moderate quality (GWQI: 56.35) and the other wells are of inappropriate quality because the amount of TDS in them is at least 6 times higher than the permissible limits; however, their other qualitative parameters are within the limits.

C: In Khalkhal, only Hammam-e Sangi well has a very good quality (GWQI: 24.88), and Givi well has a poor quality.

D: Namin has only one natural mineral water well, named Ghotoursoui, which has inappropriate quality.

E: In Sardabeh, Yelsoui well is of a moderate quality (GWQI: 53.32) and the other wells have a good quality.

In a study by Gholami et al., the GWQI was 27.87 and 29.12 for Danesfahan and Ardagh.[24]This index was 12.87 in the city called Avaj, which indicates a very good quality, owing to the low levels of all the measured parameters. In a study by Dakad et al. in Jabawi, India, the GWQI was 65, which means a moderate water quality, due to the high TDS, magnesium, sulfate, sodium and chlorine content.[23]

In the study by Ganesh Kumar et al. in Tamil Nadu, the GWQI was 40, which means a good quality, and the value of all the studied parameters, except for TDS, was within the limits.[25] A study by Nowrouzi et al. in Behbahan, Iran, also showed a GWQI of 48, which means an almost good quality. The upper limit of the 'good' range is 48, and higher values indicate a moderate quality. This finding is due to the high amount of sulfate, sodium and TDS.[26]

The GWQI varies widely in the natural mineral waters of Ardabil Province, from 24.88 to 312.58. The best physicochemical quality was observed in Khalkhal's Hammam-e Sangi well and the worst in Nir'sSaghezji-e Mardaneh well. According to this index, 2.5% of the wells (N=1) are of a very good quality, 30% (N=13) of good quality, 32% (N=14) of moderate quality, 13.5% (N=6) of poor quality and 22% of inappropriate quality (meaning a restriction on drinking). The most important qualitative problems with the wells are their high levels of TDS, chlorine and sulfate, and their low pH (in some wells).

According to the results and considering that these mineral waters supply people's drinking water, consumers should be warned of their quality, and purification procedures should also be carried out to allow the hygienic use of these valuable resources

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Conflict of Interest

The authors declared that they have no conflict of interest.

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