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Research Article

Evaluation of groundwater quality in Dayyer city Bushehr using groundwater quality index (GQI)

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ABSTRACT

Background and objective: In this study, groundwater resources of Dayyer city in Bushehr province were investigated for a number of different parameters. The use of nitrate fertilizers in the city of Dayyer and the diversion of agricultural effluents containing these compounds to water sources has increased the concentration of nitrate. Calculation of ion ratios showed that weathering was delayed in the aquifers of the city and the infiltration of saltwater led to an increase in the concentration of chloride and sodium. The increase in the concentration of other ions, such as calcium and magnesium, has a geological origin.

Materials and methods: For this purpose, in three stages (October, November and December 2019), 7 wells located in this city were sampled and a number of various parameters including electrical conductivity, pH, hardness, total alkalinity, total soluble solids, nitrate concentration, sulfate, Nitrite, chloride, calcium, magnesium, sodium, potassium, fluoride, iron and bicarbonate were determined using standard methods.

Results and conclusion: The results were analyzed using one-way analysis of variance and ArcGIS software was used to prepare zoning maps by the kriging method. Nitrate and sulfate concentration parameters, electrical conductivity, total soluble solids, total hardness, chloride, calcium, magnesium, sodium, potassium, fluoride and bicarbonate concentrations are 17.9-56.4 and 1100-3800 mg/l, respectively, 3740-7460 micro siemens per centimeter, 2240-4480, 2828-1393.8, 635.26-2034.83, 315.12-630.24, 145.44-349.056, 274.19-1068.1, 13-20, 3.12-3.8, and 68.32-131.76 mg/l were obtained. The results showed that except for the parameters of iron concentration (0.03-0.05 mg /l) and nitrite (0.0099-0.03.63 mg /l) and pH (7.13-7.34), The value of the other parameters is too much. Sulfate concentration has increased due to the oxidation of pyrite-containing soils and the presence of evaporative minerals such as gypsum. According to the results obtained from the measurement of groundwater quality index, the value of this index is between 51 to 61, which means the average quality of water resources in this city.

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1. Introduction

Increasing population growth has turned groundwater into an important source of drinking water in Iran and many other parts of the world. Natural factors and human activities lead to the pollution of these resources. The use of various chemicals and pesticides in agriculture and animal husbandry intensifies groundwater pollution. Other factors of terrestrial origin, such as weathering of rocks or infiltration of saline water into water sources, have also increased the severity of this pollution (Jamali et al., 2020). The limitation of these underground resources and their excessive use in Iran, especially in desert areas, has created problems for human health. Therefore, it is necessary to determine the quality characteristics of groundwater (chemical, physical and biological properties) that will indicate its suitability for the intended use. In recent years, many studies have been conducted on groundwater quality. For example, Wu et al. (2020) calculated the water quality index by measuring 17 physicochemical parameters. In this study, most of the collected samples were in good condition in terms of quality. Water quality index has been mentioned as a useful tool for planners, managers and officials to estimate the potential for pollution from various sources of pollution (Duraisamy et al. 2019). In calculating the water quality index, a coefficient is used for each measured parameter, which is related to the health risk of each parameter. The higher the health risk of a parameter, the higher its coefficient in calculating the water quality index. Determining the value of the coefficient of each parameter for practical applications and decision-making should be done with great care because the uncertainty in determining these coefficients has a great impact on the classification of water resources in terms of quality (Seifi et al, 2020). Seifi et al. (2020) proposed a framework based on the Monte-Carlo method for estimating these uncertainties. In their study, Adimalla and Taloor (2020) collected 194 water samples from Madak area in the Indian state of Telangana and calculated the groundwater quality index in terms of 10 parameters for these samples. According to the results of water quality index in this study, about 90% of the collected samples were in the range of good and excellent in terms of quality, but in 10% of the samples due to human activities and ground characteristics regional science, water quality was not in good condition. Popugaeva et al. (2020) by using the water quality index showed that groundwater quality in northwestern Russia is declining due to mining activities. The value of water quality index in this study, which was calculated using 12 parameters, was reported between 60 and 70. Muzenda et al. (2019) obtained values between 27.65 and 97.65 for groundwater quality index. In this study conducted in Zimbabwe, 8 physicochemical parameters of water were considered to calculate the index. In Iran, the groundwater quality index has been used to assess the quality of water resources. Rostami et al. (2019) calculated the water quality index using 11 physicochemical parameters for 63 samples collected from Marand plain. According to the results obtained from the calculation of the index, most of the collected samples were placed in medium and weak categories.

The purpose of this study was to investigate the quality of groundwater resources in Dayyer city in Bushehr province. This was done by measuring the amount of different physicochemical parameters and calculating the groundwater quality index. Also, by drawing zoning maps for different parameters, the factors involved in increasing some parameters were studied.

2. Materials and methods

Sampling was done in three stages in Dayyer city (Fig 1), in October, November and December 2017 from 7 wells (with geographical coordinates of Table 1).

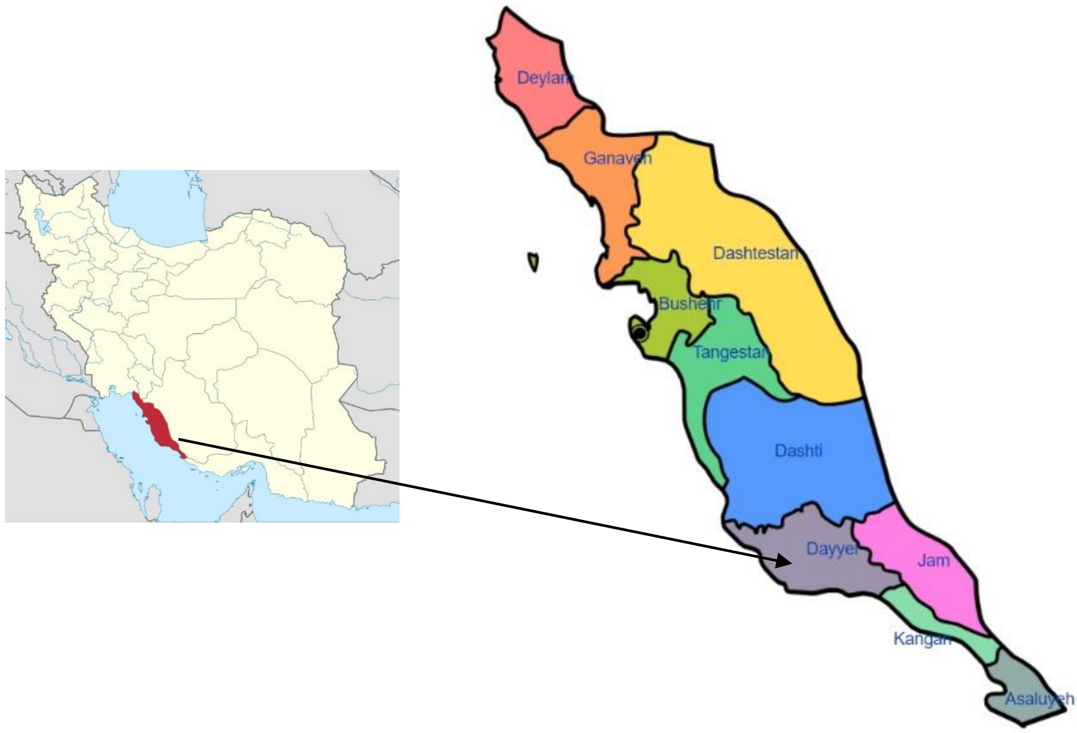


Fig. 1 - Iran, Busher Province and Dayyer city

At the time of sampling, 1 liter of sample was taken from each well and poured into a polyethylene container. Also, pH and electrical conductivity of the samples (using TES-1381) were measured in the same place. Nitrate concentration parameters (Standard No. 2352 of the Iranian Institute of Standards and Industrial Research) and sulfate (Standard No. 2353 of the Iranian Institute of Standards and Industrial Research), chloride concentration (potentiometry), calcium (using EDTA), magnesium (using EDTA Sodium (flame emission photometer), Potassium (flame emission photometer), Fluoride (SPADNS colorimetry), Iron (Standard 8651 of the Organization for Standardization and Industrial Research of Iran), Nitrite (spectrophotometry) and Alkalinity (titration) The basis of standard methods was measured.

Table 1. Geographical coordinates of sampling points (Zone: 39)

Well no.	UTMx	UTMy
1	575212	3106875
2	595974	3095568
3	595757	3095741
4	547609	3106136
5	575393	3107045
6	575212	3106876
7	575393	3107046

Zoning, land use, geology and slope maps were used using ArcMap software and kriging interpolation method. It should be noted that zoning maps were drawn based on the quarterly average of the measured parameters. Groundwater quality index (GQI) was also used to assess groundwater quality. Equation 1 was used to calculate this index:

$$GQI = 100 - [\left(\frac{r_1 w_1 + r_2 w_2 + \cdots + r_n w_n}{n}\right) \quad (1)$$

where n represents the rank of each sampling point, w represents the relative weight of each parameter, and n represents the number of parameters. The relative weight of each parameter is related to their average ranking value (r). The mean r + 2 equation is used for parameters that have potential health effects (such as nitrate). Index less than 25 indicates low quality, between 26 to 50 indicates poor quality, between 51 to 70 indicates average quality, between 71 to 90 indicates acceptable quality and between 91 to 100 indicates good quality Is.

2.1. Data analysis

One-way analysis of variance was used to examine the mean changes of the studied parameters in the three months of October, November and December and to determine the significance or meaning of these changes. In this test it was $\alpha = 0.05$. In order to investigate the difference between the mean of each parameter and the standard value defined by the Standards and Industrial Research Organization of Iran, a single sample t-test was used. For this test, the value of α was considered equal to 0.05.

3. Results

3.1. Measuring parameters

The results of measuring the parameters and concentrations of pollutants in seven water wells of Dayyer city for October, November and December are given in Tables 2, 3 and 4, respectively. What is clear in these tables is that most of the measured values are more than the standard value defined by the National Organization for Standardization and Industrial Research of Iran (Table 5). The amount of different parameters changed during these three months, which is examined in the next section.

Table 2. The amount of parameters measured in the water resources of study area in October

Well no. / Parameters *	1	2	3	4	5	6	7
EC (µs/cm)	7405	7440	7425	3705	7430	7400	7395
TDS	3850	3847	3775	1890	3759	3761	3721
pH	7.8	7.66	7.8	7.98	7.9	8	8
Total Hardness	1929.81	2040.45	1959.12	876.63	1810.36	1864.45	1808.01
Hardness of calcium	1053.73	976.83	1095.43	523.65	988.80	1101.68	1075.60
Magnesium hardness	876.08	1063.62	863.69	352.98	821.56	762.77	732.41
Cl^-	170075	1700.60	1465.20	428.31	1627.92	1368.43	1018.64
Total Alkalinity	71	70	30	73	71	70	68
Ca^{2+}	421.49	390.73	438.17	209.46	395.52	440.67	430.24
Mg^{2+}	210.259	255.268	207.285	84.716	197.174	183.065	175.778
Na^+	724.66	488.45	700.72	271.84	719.34	710.51	703.69
K^+	18	18	17	11	20	18	19
F^-	2.37	2.69	2.51	2.34	2.56	2.78	2.61
Fe^{2+}	0.10	0.07	0.10	0.06	0.08	0.09	0.09
NO_3^-	38.5	38.5	38.1	4.7	38	38.2	38.1
NO_2^-	0.0125	0.016	0.0089	0.0197	0.009	0.036	0.0129
SO_4^{2-}	2670	1710	1950	520	2530	2520	2715
HCO_3^-	74.48	75.50	47.38	83.17	74.40	74.64	69.24

* **Wherever the unit of measurement of parameters is not mentioned, its unit is milligrams per liter.**

Table 3. The amount of parameters measured in the water resources of study area in November

Well no. / Parameters *	1	2	3	4	5	6	7
EC (µs/cm)	7425	7465	7445	3730	7440	7450	7435
TDS	4513	4621	4750	2107	4630	4347	4322
pH	7.08	7.09	7.1	7.14	7.15	7	6.9
Total Hardness	2737.76	2693.50	2687.78	1316.99	2682.86	2642.67	2602.60
Hardness of calcium	1522.98	1357.40	1433.95	736.80	1300.90	1341.98	1349.20
Magnesium hardness	1214.78	1336.10	1253.83	580.19	1381.96	1300.69	1253.40
Cl^-	2004.76	2003.90	1836.80	641.27	1985.37	1729.48	1379.41
Total Alkalinity	95	97	48	99	96	97	91
Ca^{2+}	609.19	542.96	573.58	294.72	520.36	536.79	539.68
Mg^{2+}	291.548	320.664	300.918	139.245	331.670	312.166	300.816
Na^+	982.15	612.38	905.15	379.29	974.61	957.28	955.17
K^+	19	19	20	13	20	21	20
F^-	3.18	3.51	3.27	3.16	3.45	3.60	3.52
Fe^{2+}	0.04	0.01	0.03	0.02	0.03	0.03	0.04
NO_3^-	54.8	53.5	52.6	15.9	53.4	54.5	54.6
NO_2^-	0.0131	0.0164	0.0099	0.0197	0.0098	0.0362	0.0132
SO_4^{2-}	3625	2142	2860	1009	3460	3405	3490
HCO_3^-	117.52	118.12	65.91	120.76	117.60	117.95	103.81

* **Wherever the unit of measurement of parameters is not mentioned, its unit is milligrams per liter.**

Table 4. The amount of parameters measured in the water resources of study area in December

Well no. / Parameters *	1	2	3	4	5	6	7
EC (µs/cm)	7460	7475	7480	3785	7480	7470	7460
TDS	5017	4972	4886	2724	5022	5272	6337
pH	6.7	6.63	6.65	6.9	6.68	6.45	6.64
Total Hardness	3755.81	3712.56	3412.85	1987.78	3748.40	3613.29	3709.79
Hardness of calcium	2150.07	1749.07	1833.85	1102.95	1831.12	1858.95	1999.00
Magnesium hardness	1605.74	1963.49	1579	884.83	1917.28	1754.34	1710.79
Cl^-	2398.98	2400.01	2355.83	836.20	2491.20	2496.90	1919.76
Total Alkalinity	146	146	90	152	145	145	129
Ca^{2+}	860.03	699.63	733.54	441.18	732.45	743.58	799.60
Mg^{2+}	385.378	471.237	378.961	212.360	460.148	421.042	410.589
Na^+	1497.60	746.13	1104.93	471.45	1417.92	1228.20	1206.20
K^+	23	23	23	15	20	21	21
F^-	3.87	5.02	4	3.85	4.01	5.1	4.01
Fe^{2+}	0.01	0.01	0.02	0.01	0.01	0.01	0.02
NO_3^-	77.1	76	75.5	33	74.2	76.5	76.4
NO_2^-	0.0139	0.017	0.011	0.0199	0.010	0.0366	0.0135
SO_4^{2-}	5105	3048	3890	1771	3910	3675	4295
HCO_3^-	188.64	187.02	91.66	191.35	188.65	188.05	178.30

*** Wherever the unit of measurement of parameters is not mentioned, its unit is milligrams per liter.**

3.2. The results of Statistical analysis

Some statistical parameters including minimum, maximum, mean and standard deviation of the collected data as well as the standard value for each parameter are given in Table 5.

Table 5. The Results of statistical study of measured parameters in water resources comparison with standard values

Parameters *	minimum	maximum	mean	standard deviation	standard value
EC (µs/cm)	3740	7460	6914.3	1399.8	1800
TDS	2240	4480	414.6	841.63	1500
pH	7.13	7.34	7.2	0.070	6.5-8.5
Total Hardness	1393.8	2828	2553.9	514.32	500
Cl^-	635.26	2034.83	1707.3	517.49	400
Ca^{2+}	315.12	630.24	541.4	103.47	300
Mg^{2+}	145.44	349.056	288.1	66.169	30
Na^+	374.19	1068.1	845.6	255.29	200
K^+	13	20	19	2.6458	12
F^-	3.12	3.8	3.4	0.2724	1.5
Fe^{2+}	0.03	0.05	0.04	0.009	0.3
NO_3^-	17.9	56.4	50.586	14.424	50
NO_2^-	0.0099	0.0363	0.02	0.0092	3
SO_4^{2-}	1100	3800	2871.4	914.17	400
HCO_3^-	68.32	131.76	117.82	22.261	-

***Wherever the unit of measurement of parameters is not mentioned, its unit is milligrams per liter.ment of parameters is not mentioned, its unit is milligrams per liter.**

The results of one-way analysis of variance in October, November and December 2019 showed that the average parameters of EC, pH, total soluble solids, total hardness, total alkalinity, concentration of chloride ions, calcium, magnesium, sodium, fluoride Iron, nitrate, sulfate and bicarbonate are significantly different in three consecutive months ($p < 0.05$). However, during these three months, no significant difference was observed in the mean concentration of potassium and nitrite ions ($p > 0.05$). According to the results of t-test, except for calcium concentration in October and nitrate concentration in October, other parameters were significantly different from the defined standard value. It can be said that in autumn, with the onset of rainfall, rainwater acquires acidic properties by absorbing carbon dioxide from the air and transferring it to the soil and then dissolving carbonate-containing compounds such as calcium carbonate present in the soil. Then, with the transfer of rainwater to groundwater sources, the pH of these sources also decreases. This decrease can be seen by comparing the pH values in Tables 2 to 4. On the other hand, with the entry of carbonate into water, its alkalinity increases. A decrease in pH has also been observed in the research of Sharma and Chhipa (2016) and Ibrahim et al. (2015).

Lowering its pH generally leads to an increase in dissolution and thus an increase in the concentration of other ions. For example, the solubility of gypsum increases with decreasing pH. The higher the solubility of this type of rock, the more calcium and sulfate ions enter the groundwater sources as a result of its dissolution in water. This increasing trend can be observed by comparing the average concentrations of ions of calcium, magnesium, sodium, fluoride, nitrate, sulfate and bicarbonate in different months. Another reason for the increase in the concentration of some ions during these three months could be the increase in agricultural activities. For example, various studies have shown that with increasing agricultural activities as well as increasing rainfall, the concentration of nitrate ions in water sources increases (10). Also, the increase in rainfall causes the combination of runoff with local wastewater and the transfer of residual nitrate fertilizers, plant and animal waste, as well as sanitary wastewater to groundwater, which increases the concentration of various ions, especially chloride and nitrate in the references (Sharma and Chhipa, 2016; Ibrahim et al. 2015). An increase in nitrate in water resources has also been reported by Sharma and Chhipa (2016), Ibrahim et al. (2015) and Trivedi et al. (2010)

Increasing the amount of water-soluble ions increases the total soluble solids as well as the electrical conductivity of water. Various researchers such as Ibrahim et al. (2015), Makwe and Chap (2013) have pointed to the increase of two parameters of electrical conductivity and total soluble solids with increasing rainfall. Trivedi et al. (2010), Sangeeta and Neha (2015) and Sharma and Singh (2016) to increase the concentration of calcium and magnesium to increase the concentration of sodium in water sources The underground is marked by the onset of rain. Sharma and Chhipa (2016), Trivedi et al. (2010) and Sangeeta and Neha (2015) achieved an increasing trend for fluoride concentrations in water sources. In the research of Ibrahim et al. (2015) and Trivedi et al. (2010) with increasing rainfall, iron concentration decreased. The trend of increasing sulfate concentration with the onset of rainfall was observed in the research of Sangeeta and Neha (2015). Regarding the lack of change in potassium concentration, it can be said that the reason for this may be that most minerals containing potassium are resistant to decomposition by weathering and as a result, increasing or decreasing the water level cannot have a significant effect on the concentration of this ion in water (Ganiyu et al, 2018).

4. Discussion

4.1. Ionic ratios

One way to study the nature of groundwater and determine its probable origin is to use the ratio of ions in it. The values of these ratios for different wells are given in Table 6 and these ratios are examined below.

Table 6. Different ion ratios for water samples

Well / Ratio	1	2	3	4	5	6	7
$\frac{Cl^-}{\text{Total anions}}$	0.34	0.46	0.39	0.34	0.37	0.36	0.28
$\frac{Cl^-}{Na^+}$	1.91	3.31	2.09	1.7	1.96	1.95	1.51
$\frac{SO_4^{2-}}{Ca^{2+}}$	6.03	4.19	4.98	3.49	6	5.58	5.93
$\frac{Ca^{2+}}{Ca^{2+} + SO_4^{2-}}$	0.14	0.19	0.17	0.22	0.14	0.15	0.14
$\frac{Mg^{2+}}{Mg^{2+} + Ca^{2+}}$	0.32	0.39	0.34	0.31	0.38	0.35	0.33
$\frac{Cl^-}{HCO_3}$	16.04	16.04	27.6	4.82	16.04	14.86	12.29

The ratio of $\frac{Cl^-}{\text{Total anions}}$ is used to determine whether water has retained its original origin or whether the weathering of various rocks has changed the chemistry and concentration of elements in the water. Due to the fact that this ratio is less than 0.8 in all samples (Table 6), rock weathering has been done.

The ratio of $\frac{Cl^-}{Na^+}$ chloride to sodium is often used to determine the source of salinity in water. The major source of chlorine in water is sodium chloride. Sodium is also derived from the dissolution of halite (NaCl), sodium plagioclase, and ion exchange. If this ratio is less than one, it is determined that it has a non-halite origin, such as weathering of silicates (Zakaria et al 2012). Considering that this ratio is more than 1 in all collected samples (Table 6), it can be concluded that the infiltration of saline water into the water resources of the city has been done late.

The ratio of $\frac{SO_4^{2-}}{Ca^{2+}}$ A common source of calcium in water is the dissolution of calcite, gypsum and anhydrite. Sulfate ions in water usually result from the direct dissolution of gypsum (or anhydrite) or the neutralization of acidic waters by calcite or dolomite. According to Hanslow, if the concentration of sulfate ions in water is higher than the concentration of calcium, it indicates that calcium is most likely removed from the solution by precipitation or ion exchange, and if the concentration of calcium is higher than sulfate, then calcium In water, it is probably derived from a source other than gypsum (such as calcite, dolomite, or silicates), and the fact that the concentration of calcium and sulfate is equal indicates that the gypsum has dissolved. According to the values calculated in Table 6, the sulfate concentration in all samples is higher than the calcium concentration in them, so as mentioned, calcium has been removed from these samples due to precipitation or ion exchange.

The ratio of $\frac{Ca^{2+}}{Ca^{2+}+SO_4^{2-}}$ the dissolution of sulfated minerals can also be investigated through this ratio. If this ratio is equal to 0.5, it indicates the dissolution of gypsum, and if it is more than 0.5, it indicates that calcium is derived from a source other than gypsum (such as carbonate and silicate). Given that this ratio is less than 0.5 in all samples, it is likely that calcium was removed by precipitation or ion exchange.

The ratio of $\frac{Mg^{2+}}{Mg^{2+}+Ca^{2+}}$ using this ratio, based on the weathering of the silicates, be able to determine the type of weathering to some extent. When this ratio is less than 0.5 (as in the samples collected in this study), light weathering (acidic igneous rock weathering) is predominant.

The ratio of $\frac{Cl^{-}}{HCO_3}$ Chloride ion is more considered in most studies due to its high variability, high solubility and unreactivity. Chloride is normally found in small concentrations in natural waters. This is generally less than 100 mg / L unless the water is saline. Chloride is used by humans in a variety of jobs and enters surface and groundwater sources through industrial effluents, sewage, animals, and road salt spraying. According to a study by Raghunath (1987) if this ratio is higher than 2.8, it indicates severe pollution due to the infiltration of salt water and high evaporation. Also, reducing the ratio of chloride to bicarbonate ion to less than 1, indicates the nutrition of the aquifer from calcareous sources and vice versa indicates an increase in salinity and infiltration of saline water fronts from sources such as saline lakes, salt domes, chemical fertilizers, land formations. Cognition and so on. As shown in Table 6, the value of this ratio for all samples is more than 2.8, which can be concluded that the studied water resources have been affected by the infiltration of saline water and high evaporation.

4.2. Investigation of the geological status of the study area

Since the type of land has a significant effect on the quality of water resources (He et al., 2020; He et al. 2021; Jamali et al., 2022), first the geological situation of the city of Dayyer is examined. The geological map of Dayyer city is shown in Figure 2. This figure shows the geological formations of this city. The most important constituents of these formations are listed in Table 7. According to Figure 2, one well is located among the quartz deposits, four wells are located in Aghajari Formation and two wells are in Kozhdami Formation.

Table 7. The most important building blocks of the geological organization

Formation	Aghajari	Quartz deposits	Bakhtiari	kajdamy	Gach-saran
The main constituent compounds	$CaSO_4.2H_2O$, $CaCO_3$	SiO_2	$CaCO_3$	$CaCO_3$	$CaSO_4$, $CaCO_3$
Formation	Bangestan Group (Kozhdami / Sarvak / Surgah / Ilam)	Asmari-Jahrom	Mishan	Raw group (Surmeh, Heath, Fahlian, Gadvan and Darian)	
The main constituent compounds	CaO, FeS_2, $CaCO_3$	$CaMg(CO_3)_2$, CaO	$CaCO_3$, CaO	$CaCO_3$, $CaMg(CO_3)_2$, $CaSO_4$	

Comparing Tables 2 to 4 with Table 7 leads us to the conclusion that the main reason for the high amount of most pollutants such as calcium, magnesium, sulfate and total hardness is the type of soil at the aquifer (Qanbari and Jamali, 2015). Another factor that has a great impact on water quality is the human activities in the region. These activities can be shown in the form of land use map. The land use map of Dayyer city is shown in Figure 2. According to this figure, the main industrial activity of this city is related to agriculture, which is done in the northwest, east and part of the central areas of this city. Also, the major residential areas that produce sanitary sewage are located in the east and west of the city. Another important factor is the slope of the land in the study area. The slope of the land is important because it plays an important role in the movement of pollutants by rain and rivers. A contaminant upstream of water sources can be easily transported downstream by flood or river flow and contaminate water sources (Parsasyrat and Jamali 2015). According to the map of the elevation classes of Dayyer city (Figure 3), the northern, eastern and central areas of this city are higher than other areas.

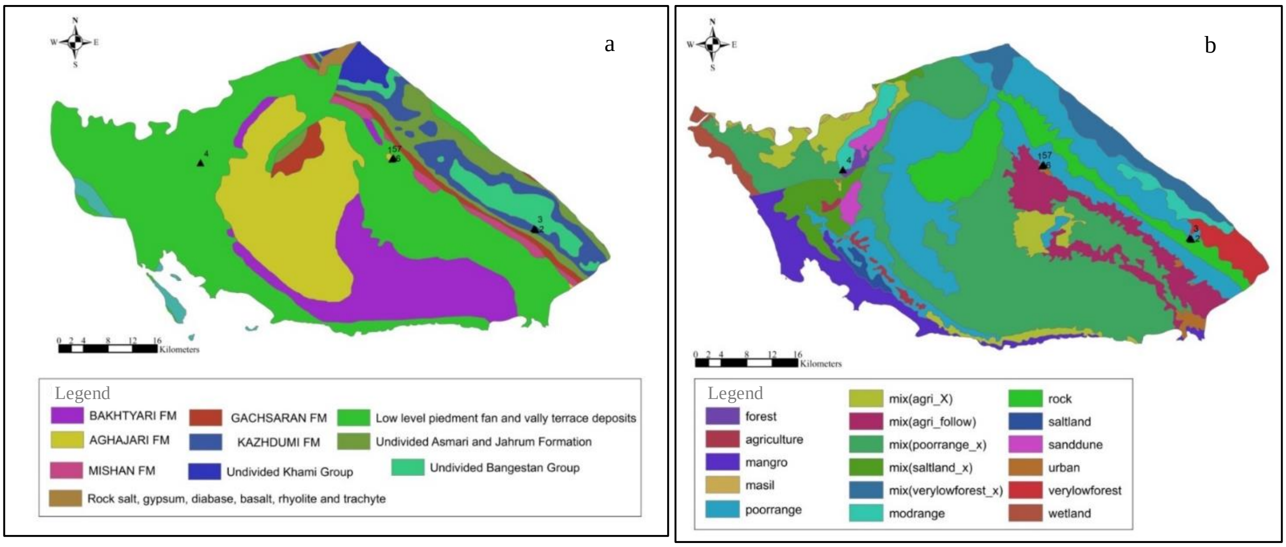


Figure 2. Geology (a) and Land use map (b)

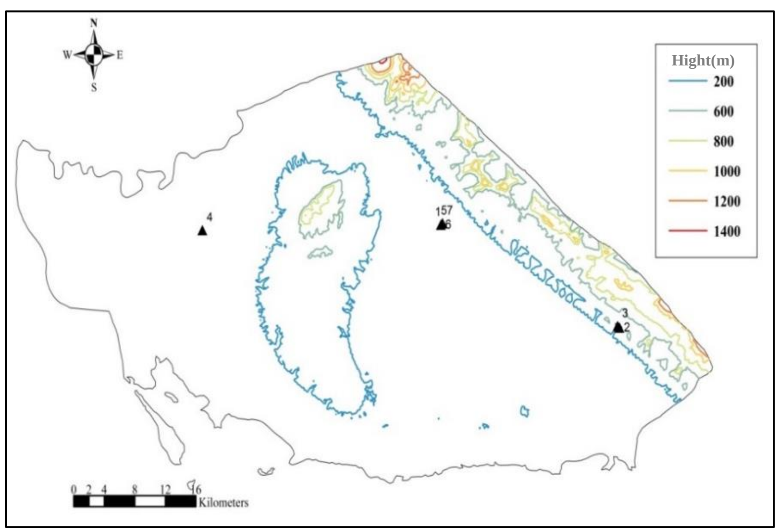


Figure 3. Map of the elevation classes

4.3. Zoning maps

The zoning map of nitrate and sulfate ions is shown in Figure 4. According to studies by Garrels and Mackenzie (1967), in general, abnormal increases in sulfate concentrations in groundwater can be due to: 1- Oxidation of pyrite minerals (FeS_2) and marcasite, 2- Evaporative minerals such as gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$), 3- Sulfates released from sulfated organic matter including organic matter in sediments, oil and coal, 4- Hydrothermal waters, 5- Melting Becoming sulfide sources. As can be seen in the sulfate zoning map (Figure 4-a), the concentration of this contaminant in all water sources is higher than the allowable amount. In the case of well No. 4, it can be said that due to being located downstream of Aghajari Formation (in terms of slope), which contains sulfate, sulfate is probably transferred to well No. 4 along with rainwater from this formation.

Then, this sulfate penetrated into the ground and contaminated the water source. According to the results, this well has the lowest amount of sulfate, which can be due to the relatively low permeability of quartz, which has prevented the concentration of sulfate contaminants to reach a level around the concentration of this contaminant in other wells. Wells 1, 5, 6 and 7 are located in the middle of Aghajari Formation, which, as mentioned, contains sulfate and, as expected, has contaminated groundwater resources. These four wells have the highest sulfate contamination. Two wells No. 2 and 3 are also downstream of Bangestan Group. Soils in this group contain pyrite (FeS2) which in the presence of water and oxygen can be converted to sulfate. Due to the gypsum and calcareous nature of the formations of this group and as a result of permeability as well as high erosion of this group, it can be expected that the weathering of the soil of these formations has caused some sulfate, which is finally due to the flow of rainwater to these two. The well is gone.

Nitrate as an indicator of groundwater pollution has always been considered by researchers. Most cases of nitrate pollution in groundwater are related to agricultural wastewater and the use of nitrogen fertilizers (Akber et al, 2020; Fathmawati et al, 2018). As can be seen in Figure 4-b, in the western part of Dayyer city, the nitrate concentration in water sources is within the standard, but moving to the east of this city, the nitrate concentration increases. The reason for this can be attributed to agricultural activities that are more concentrated in the east of the city. The use of nitrate fertilizers in these agricultural activities has caused this contaminant to enter their contaminated water sources.

The most important factors for increasing the concentration of magnesium ion in groundwater are clay cations, dolomite, anions and pyroxenes. The concentration of magnesium ions in water is usually less than 50 mg / l, but in saline waters it will reach more than 5700 mg / l. According to the magnesium concentration zoning map shown in Figure 5-a, throughout the city of Deir, the concentration of magnesium is higher than the standard amount required for drinking water. The reason for the high concentration of magnesium in water sources is the presence of CaMg (CO3) 2 in Asmari and Jahrom formations. Due to the fact that these formations are located upstream of water sources, water flow transports this compound downstream and after decomposing this compound in water sources, the concentration of magnesium in water increases.

The most important sources of calcium are amphiboles, feldspars, gypsums, pyroxenes, calcite, dolomite, and clay cations. The concentration of calcium ions in water is usually less than 100 mg / l, but in saline waters it may be more than 7500 mg / l. As shown in Table 7, calcium is present in almost all formations, whether in the form of gypsum, lime, or other compounds. This abundance makes it easy to find and contaminate water sources. According to Figure 5-b, there is a problem of calcium contamination throughout the city of Dayyer ez-Zor, and this problem is more severe in the eastern and northeastern parts of the city.

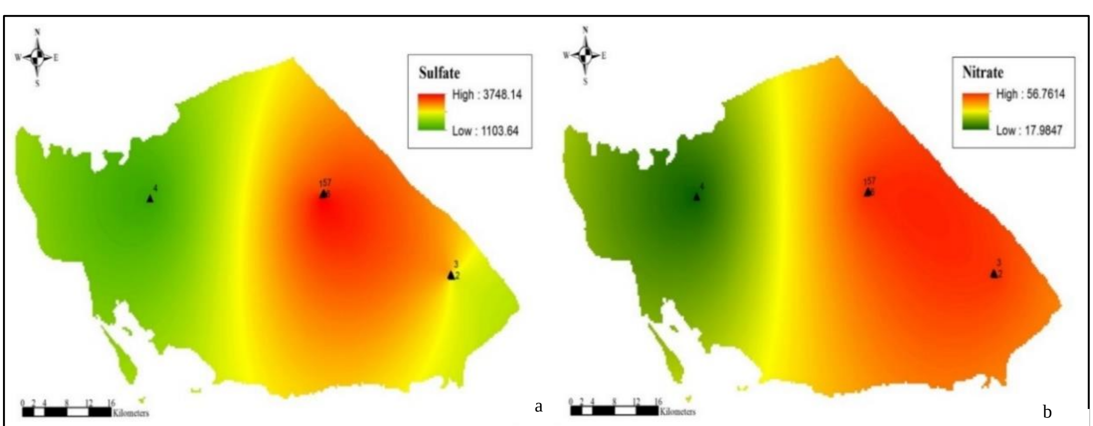


Figure 4. Zoning map of sulfate (a) and nitrate (b) concentrations in water resources

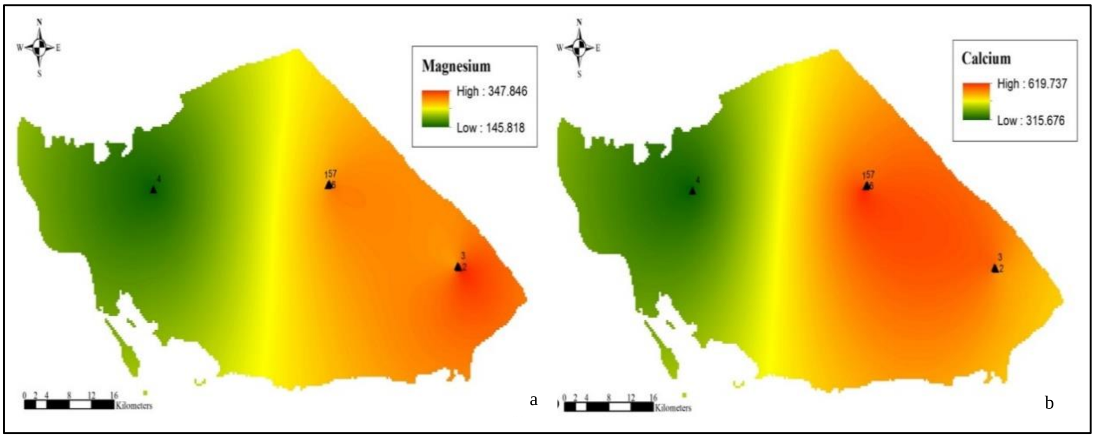


Figure 5. Zoning map of magnesium (a) and calcium (b) concentrations in water resources

The distribution map of sodium concentration in the water resources of Dayyer city is given in Figure 6-a. As can be seen, the concentration of sodium in all water sources of the city is very high. The first reason for this is the presence of salt in the Gachsaran Formation, which is located above water resources. The second reason is the proximity of Dayyer city to the sea, which causes the amount of sodium in these areas to increase with the infiltration of sea water into the adjacent soil layers.

Chlorine ions in groundwater are derived from natural resources, domestic wastewater, industrial wastewater, and saline inflows (Dugan et al; 2020; Jat and Serre 2016). The chloride concentration zoning map in Dayyer city is shown in Figure 6-b. According to this figure, the concentration of chloride in the water resources of this city is much higher than allowed. This problem is more severe in the east of the city. According to the ionic ratios explained (chlorine to sodium ratio), it can be said that the most important reason for the high concentration of chloride in the water resources of this city is the inflow of sea water into the soils adjacent to water wells.

The molar ratio of chloride and sodium in groundwater is usually largely the same, indicating a common origin for the two ions. If the molar ratio of chloride and sodium is not equal, different sources can be considered for these two ions. Given that ionic chloride is stable and is not affected by other reactions in the saturation zone except dissolution / deposition reactions, it can be inferred that the inequality of the ratio of sodium and chloride in water sources Dayyer ez-Zor probably occurred due to ion exchange processes in the aquifer.

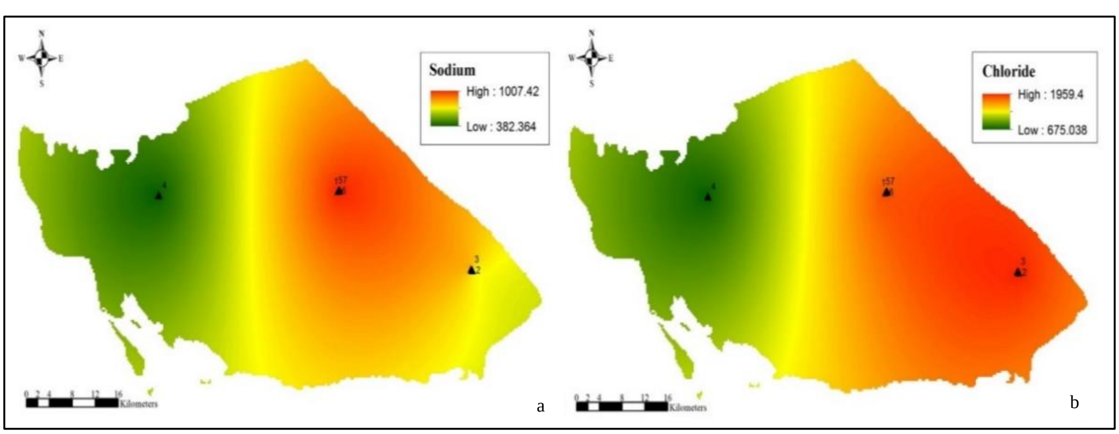
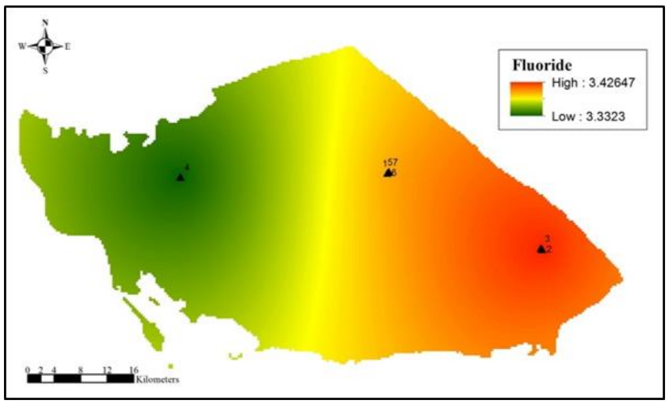


Figure 6. Zoning map of sodium (a) and chloride (b) concentrations in water resources of Dayyer city

Fluoride is an essential element for human health that plays an effective role in preventing tooth decay, but the entry of large amounts into the human body leads to problems such as dental and bone fluorosis. Since most of the body's need for fluoride is met through drinking water, it is important to determine its amount in drinking water (Ali et al, 2016; Lacson et al, 2020). According to the fluoride concentration zoning map (Figure 7), the concentration of this element in all water sources is excessive. Presence of gypsum and salt formations in the region, especially Gachsaran and Mishan and observation of correlation of fluoride with calcium, sulfate and sodium ions, it can be concluded that weathering and dissolution of evaporative minerals and sulfate is probably the cause of release of fluoride ions into groundwater.

Figure 7. Fluoride concentration zoning map in water resources



4.4. Groundwater quality index

The distribution of groundwater quality index in the water resources of Dayyer city is shown in Figure 8. Given that the GQI value for all wells is in the range of 51-51, the quality of these water resources is moderate. According to this figure, the quality of all groundwater resources in the city of Dayyer is lower than the desired value (in the average range, based on the GQI index). As expected, the value of this index in the western part of the city is less than its value in the eastern parts of the city, because as shown in Figures 5 to 8, the concentration of parameters measured in the eastern part is higher than the western part of the city, which leads the amount of GQI decreases, which indicates a decrease in the quality of water resources.

Comparison of Figure 8 with the land use map and geological map of Dayyer city shows that the presence of urban areas and agricultural lands near wells 1, 4, 5, 6 and 7 is probably due to the entry of sanitary sewage. And agriculture to water resources has reduced the water quality index. Another factor that has been effective in reducing water quality is the same type of aquifers that contain the city's water resources, which are often made of gypsum and lime and are easily washed by water and increase the concentration of pollutants in water resources. This issue affects the water quality of all sources, but in well number 4, due to the fact that the aquifer is mainly quartz and the permeability of quartz is relatively low, the rate of water quality reduction is less than other wells.

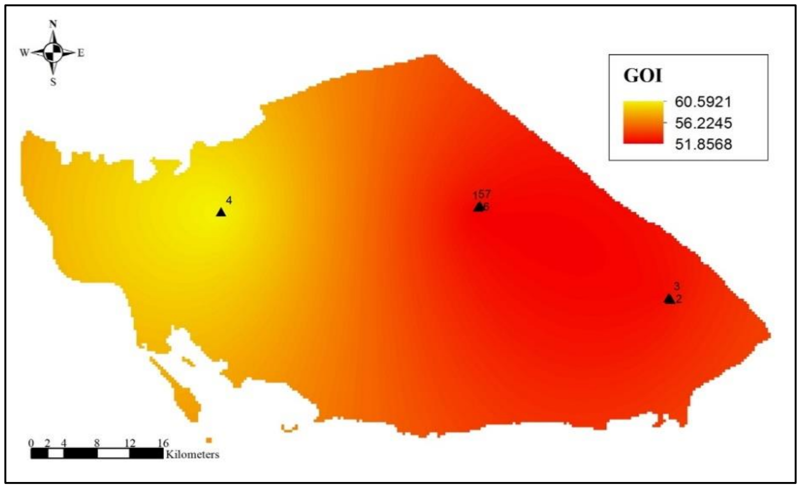


Figure 8. Groundwater quality index distribution map in water resources

5. Conclusion

In this study, the quality of groundwater resources in Dayyer city was measured by measuring various parameters such as pH, electrical conductivity, total soluble solids and concentrations of ions such as sulfate, nitrate, nitrite and fluoride and calculating the groundwater quality index. Changes in the value of various parameters during the sampling period were investigated by one-way analysis of variance and these values were compared with standard values announced by the National Organization for Standardization and Industrial Research of Iran using one-sample t-test. The results showed that the mean of the measured parameters except for the two parameters of potassium and nitrite concentrations have changed significantly. These changes can be attributed to the increase in rainfall as well as the increase in agricultural activities. The results of t-test showed a significant difference between the measured values and the declared standard value. Calculating different ion ratios and comparing the distribution of concentrations of different pollutants with geological, land use and slope maps of Dayyer city showed that the pollutants in the studied water sources are mainly of geological origin. Also, the main human activity that leads to increased pollution of water resources was agriculture.

Declarations

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Conflict of Interest /Competing interests (None)

Availability of Data and Material (Data are available when requested)

Code availability (Not applicable)

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