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Hydro geochemical properties and groundwater quality using FGQI method from the stand point of Iranian standards and World Health Organization (A case study in Naqadeh plain, Iran)

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ABSTRACT

Excessive exploitation of groundwater resources has negatively affected their equilibrium and the groundwater level in several aquifers. Naghade plain (one of Urmia lake aquifers) requires a proper and qualitative management which has suffered a decline in recent years. One of the most important indicators for assessing and zoning the quality of groundwater is to measure the concentration of water ions and determine the groundwater quality index (GQI) by combining the concentration of ions and their relationship with safe standards. The purpose of this study is to apply GQI and FGQI methods for assessing groundwater quality in Naghade plain, based on the World Health Organization (WHO) and the National Standard of Iran (INSO). For this purpose, the chemical parameters were used for sampling and analysis of hydro geochemical parameters and compared with the WHO and INSO standards. Due to the uncertainty that exists, the ability of the fuzzy set in the decision making process with the Fuzzy GQI method and the water quality of the area were studied based on the FGQI method. The results of FGQI were based on two WHO and INSO standards of between 0 and 100 variables and groundwater quality in terms of the totally undesirable levels. Finally, the FGQI method in threshold values is considered better than the GQI method and gradual changes in groundwater quality are considered and is a useful method for assessing groundwater quality in the area.

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1. Introduction

The groundwater system does not respond quickly to pollution, and the time it takes for contaminants to reach the groundwater and release it into the aquifer is usually long. It often takes time and money to clean up contaminated groundwater and reuse it and finding an alternative water source is not always possible. Therefore, the best and most effective solution is to prevent pollutants from entering this valuable source. Determining the level of groundwater pollution is one of the most important hydrogeological studies in which the identification of areas prone to pollution and the study of aquifer vulnerability is extremely important.

Healthy drinking water should have good quality characteristics (such as physical and chemical properties). One of these indicators is the concentration of main ions in the water. Organizations such as World Health Organization and Institute of Standards & Industrial Research of Iran have provided standards for soluble salts and various contaminants in drinking water (WHO, 2008), (Institute of standard, 2009). These standards have limitations due to factors such as changes and fluctuations in rainfall as well as the amount of harvest in different seasons of the year. On the other hand, the standards set by the relevant organizations do not have the necessary certainty.

Since all major ions contribute to the quality of drinking water, it is important to obtain a criterion in which the effect of all of these ions is considered in combination. For this purpose, (Babiker et al., 2007) introduced the Groundwater Quality Index (GQI) and used it in one of the aquifers in Japan in 2007. In the GQI index based on GIS software, several parameters affecting groundwater quality are combined. The World Health Organization (WHO) standard has been used as a reliable guideline for all countries in the world in all studies conducted so far based on the Groundwater Quality Index (GQI). Many researchers have proposed measuring the quality of surface and groundwater. Sayad et al, (Sayyad et al., 2012) evaluated groundwater quality in Dargaz plain aquifer in north of Mashhad by estimating GQI index. Azizi and Mohammadzadeh (Azizi and Mohammadzadeh, 2013) have studied the water quality of Jafar Gachsaran Imamzadeh plain using WGQI index. The purpose of this study is to use GQI method in evaluating groundwater quality of Mashhad aquifer and comparing it with other methods such as Schuler diagram. NikPeyman and Mohammadzadeh (Nickpeyman and Mohammadzadeh, 2013) have studied the quality of groundwater in Mashhad plain aquifer by estimating the GQI index. (Soleimani et al., 2013) conducted a study entitled "Investigation of qualitative changes in water resources of East koohsorkh" using the GQI quality index in the GIS environment. Similar studies have been conducted in other countries. In 2012, Al-hadithi used WQI to assess the water quality of Ratmao-Pathri Rao basin in India (Al-hadithi, 2012). Due to the importance of groundwater in Naqadeh area, which is also used for drinking, the identification of suitable or unsuitable areas for use has been investigated too. In this study, the results of the standards of World Health Organization and the Industrial Research Organization of Iran have been compared and also attempts have been made to consider the inherent uncertainties resulting from sampling, measurement, analysis and interpretation that are not considered in other qualitative indicators using the new FGQI method and the results are evaluated by graphical and GQI methods.

2. Material and Methods

2.1. Study area

With an area of approximately 377 square kilometers, Naghadeh plain is located in the south of West Azerbaijan province and southwest of Lake Urmia and is part of the Alborz-Azerbaijan structural zone. The average height of Naghadeh plain is 1307 meters and the height difference from top of the plain to end of the plain is 42 meters. Naghadeh plain is located in the drainage basin of Lake Urmia in terms of natural divisions and this basin has a cold and semi-arid climate based on the experimental method of Amberge (Emberger, 1952) and using the statistics of Naghadeh station. Figure 1 shows the geographical location of the study area and sampling points. The annual rainfall of the region according to 30 annual statistics (1987-2017) of Naghadeh station in the plain and mountainous part is 287 and 345 mm, respectively, and the average rainfall is 283 mm per year.

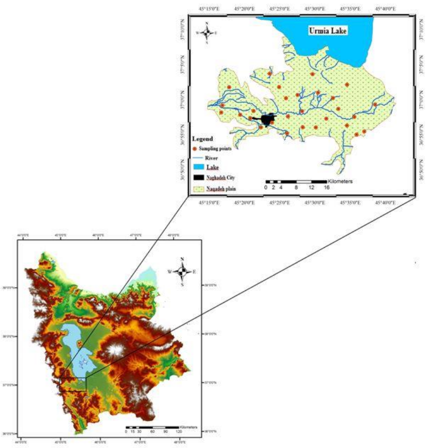

Fig.1. Geographical location of Naghadeh plain and sampling points of the study area.

The rate of evaporation and transpiration potential and evaporation from the pan is 720 and 1590 mm per year, respectively. Godar Chai is one of the most important surface drains of Naghadeh plain thatsurface water resources of these rivers flow into Lake Urmia after passing Naghadeh plain. The Godar Chai River originates in the highlands of GrivehDagh border and consists of three main tributaries of Gadar River, Chamghaltan and Oshnoyeh. The length of this river is about 90 km and the area of its drainage basin in DarbandNaghadeh is about 875 km. Its average annual running water is about 200 million cubic meters in Bahram Lou Bridge (West Azarbaijan, 2013).

2.1.1. Geology and hydrogeology of the study area

Groundwater collides with a variety of geological formations as it moves along its underground routes. This changes the quality of the water and increases its salinity, which depends on the type and lithology of the rocks and geological formations and water shelf life. On the other hand, the effect of tectonics on the formation or cutting of aquifers and groundwater aquifers is clear. According to hydrogeological studies, quaternary sediments cover most of the hydrous formations in the region and have good discharge. These deposits include fluvial sediments (Qal) that spread slowly on both sides of permanent and seasonal rivers, Qt2 and Ql sediments, which are more commonly seen on the slopes, and Qt1 sediments, which form high terraces. Medium-yielding rocks, mostly found in Shemshak, Lalon, and cretaceous sandstone-shale units formations, make up most of the water resources in Naqadeh region. Formations with medium to high discharge are also found in orbitolina calcareous units, inseparable Jurassic and Cretaceous formations and Lar and Delichai calcareous units. There is also a group of destructive-pyroclastic rocks with poor discharge capacity, which includes volcanic ash unit with pyroclastic rocks, conglomerate and miocene sandstone, gray marl unit with some Cretaceous limestone and Precambrian dolomitic shale and limestone. Other formations, which are not very large, have poor drainage. These formations are widely located on the shores of Lake Urmia, have quaternary age (Qs) and include clay sediments that, in addition to having very low permeability, have an adverse effect on water quality due to the presence of gypsum and salt layers. Figure 2 shows the geological map of Naqadeh study area.

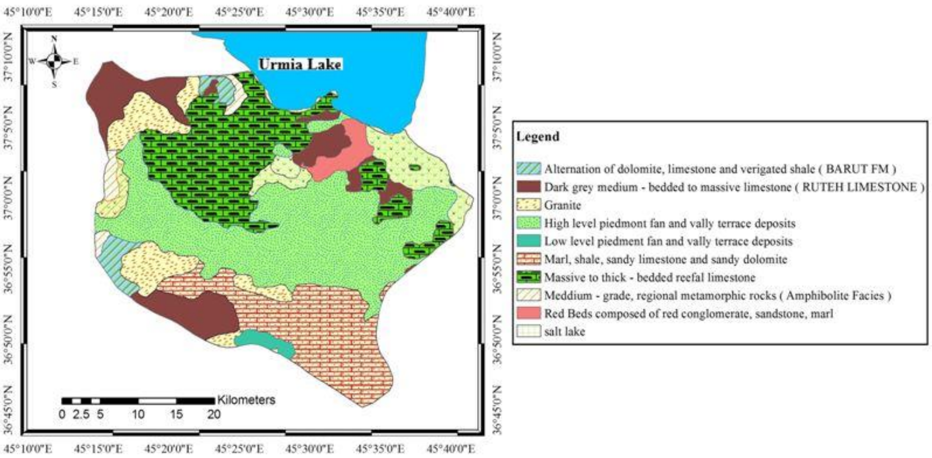

Fig. 2. Geological map of the study area.

The free type of aquifer belongs to the Naqadeh plain, which is mostly composed of old alluvial deposits, new alluvial deposits, conifers and river sediments, and the main constituents of the aquifer are sand, silt and clay sediments. According to the maps of alluvial sediments, drilling logs and geophysical data, in the upper parts of the plain, the particles form the coarse-grained aquifer and the closer we get to the center of the plain, outlet areas and to Lake Urmia, the less granular the sediments are. Groundwater balance calculations for the 96-95 water year indicate that in the range of the balance, changes in the volume of aquifer water are negative; So that in the mentioned year, its discharge is 2.23 million cubic meters more than the amount of feed. According to the hydrograph of Naqadeh plain unit, the groundwater level has decreased by 0.24 meters during the year. The direction of groundwater flow is from the western part to the central and eastern part of the plain. Based on groundwater level curves, the highest groundwater level is seen in the western parts of the aquifer and the lowest groundwater level is seen in the eastern part and around Lake Urmia. Figure 3 shows the groundwater level map in June 2018.

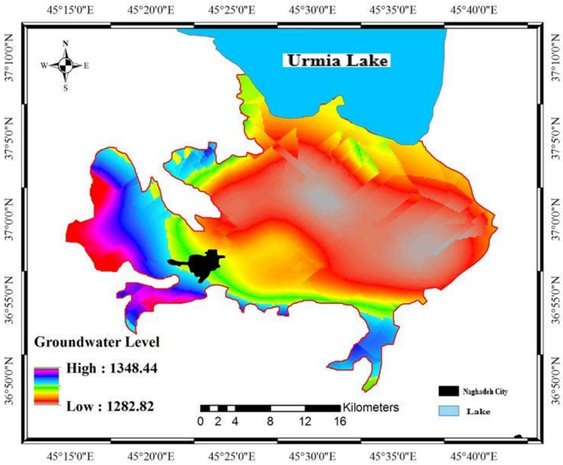

Fig. 3. Map of groundwater level of Naghadeh plain in June 2018.

2.2. Qualitative indicators

The main uses of water in the study area are for agriculture and drinking, which is mainly supplied from groundwater sources and a small part through rivers. Due to the importance of drinking water quality and its relationship with human health, the concentrations of elements and parameters evaluated in water resources have been compared with global drinking water standards. Organizations such as World Health Organization, Ministry of Energy, and National Standards Organization of Iran have provided standards for soluble salts and various contaminants in drinking water. Short-term deviations from guideline values do not necessarily mean that water is unsuitable for human consumption. In order to define the mandatory limits, it is necessary to examine the guideline values according to local or national conditions from an environmental, social, economic and cultural perspective (WHO, 2008). The World Health Organization, as the highest international insitution for water quality control, has provided guidelines for various contaminants in drinking water. The guideline value suggests a concentration for a component that does not pose a serious risk to the health of the consumer during a period of use (WHO, 2008). The National Drinking Water Standard of Iran (Standard, 1053) was developed by the Institute of Standards and Industrial Research of Iran (IRISI) in 2009 based on WHO guidelines. Given that not all pollutants, especially chemical pollutants are present in all water resources or in all countries, it is necessary for WHO to consider factors such as the type of material, geographical and geological conditions of the region and the type of human activity in developing national standards. In order to evaluate the groundwater quality of Naghadeh plain in terms of drinking standards with the expressed methods, the results of chemical analysis of water from 26 wells related to September 2017 were used. For this purpose, the values of chemical parameters that have a high frequency in groundwater and are also important in terms of impact on human health have been compared with the values of INSO and WHO standards. The statistical indices of these parameters and their maximum limits based on the standards of World Health Organization (WHO, 2008) and Institute of Standards and Industrial Research of Iran (Institute of Standard and Industrial Research of Iran 1053, 2009) for beverage consumption are given in Table 1. One of the simplest and far from mathematical and statistical complexities ways that can describe the water qualityis the use of water quality indicators so that it can be used as a powerful management tool for relevant decisionsin water quality management. Therefore, FGQI (Fuzzy Groundwater Quality

Index) and GQI were used for Naqadeh plain groundwater quality zoning. The FGQI method provides a solution for summarizing several parameters affecting groundwater quality in an index and studying spatial variations across the aquifer.

Table 1. Statistical indicators of groundwater quality parameters in Naqadeh plain and their maximum level according to INSO and WHO standards (all units in mEqper liter)

Parameter	min	max	average	World Health Organization (WHO)	Iran National Standard Organization (INSO)
Calcium	2.48	8.45	4.34	300	300
magnesium	2.89	24.1	12.113	300	200
Sodium	1.2	25.8	1097	200	200
chlorine	2.5	44	20.14	200	400
sulfate	0.18	21.93	6.76	250	400
nitrate	0.52	31.1	14.1	50	50
Bicarbonate	5.01	17.89	11.11	150	150
potassium	2.92	15.13	7.4	12	12
Solids left	867	3554	1456	600	1500

2.2.1. Calculation of Groundwater Quality Index (GQI)

To calculate the GQI index, a concentration raster map was prepared for each of the ten chemical parameters in ArcGIS by introducing point data Kriging. In order for the different data to have a common scale and criteria in the next step; the concentrations of each pixel (K) of the raster maps created in the previous step using the following formula correspond to the standard INSO and WHO values of that parameter (KWHO) (Eq. 1).

$$C = \frac{K - K_{WHO}}{K + K_{WHO}} \qquad (1)$$

Unifying the scales produces six new maps that their pixel values change between (-1) and (1). Now the concentrations in these maps are graded between (1) and (10) to get the ranked map of each parameter. In these maps, rank (1) indicates good groundwater quality and rank (10) indicates degradation of groundwater quality. In fact, in this unit conversion, the value of (-1) in the map produced in the previous step should be changed to (1), (0) to (5) and (1) to (10) in the ranked map. For this purpose, the following equation, which is a polynomial function, is used to convert the unit of each pixel of the previous map (C) to a new value (r) (Eq. 2).

$$r = 0.5 \times C^2 + 4.5 \times C + 5 \qquad (2)$$

To create a map that represents all ten chemical parameters and shows the general status of plain water chemical qualityin comparison with INSO and WHO standardsin the final stage, the layers related to the parameters are combined using Groundwater Quality Index (GQI).

$$GQI = 100 - [\frac{r_1 w_1 + r_2 w_2 + \cdots + r_n w_n}{n}] \qquad (3)$$

In this formula, “r” is the rank of each pixel in ranking maps and “w” is the relative weight of each parameter, which is equal to the average value of total pixels of the corresponding ranked map. To calculate the GQI, in fact, the weighted average is taken from various parameters, and the parameters with a larger value (greater difference than the standard value) have a relative weight and are therefore more effective. Because the amount of toxicity of different elements to humans is different, it is important to note that it is correct to use the mean for all parameters if the amount of toxicity and dangerousness to humans is almost the same, and if one or more elements are more toxic than the other ones, the proposed formula must be re-calibrated and modified (Hiyama and Hu, 2003).

2.2.2. Calculation of Fuzzy Groundwater Quality Index (FGQI)

The groundwater system generally faces many uncertainties. Decision-making about water quality based on information obtained at all stages, from sampling to review and analysis of results, faces all kinds of uncertainties. Given the importance of water-soluble salts effect on the human body and the uncertainty associated with measurement in the sampling and analysis stages, the use of classical methods in assessing the quality of drinking water and even agriculture does not seem suitable. Different methods and criteria have been presented in different sources for decision making and evaluation of drinking water and agricultural quality by fuzzy method. Ambiguity and lack of inherent certainty in water resources in evaluating goals, criteria and decision-making units on one hand, and inconsistencies and inaccuracies in opinions and judgments of decision-makers on the other hand, has led to a trend toward fuzzy set theories, followed by fuzzy logic as an efficient and useful tool for planning and decision-making in water resources. (LiY et al, 2009), (Bardossy and Duckstein, 1995). By designing a suitable fuzzy model, uncertainty can be eliminated in the stages of sampling, measurement, and interpretation of water quality (Liu et al., 2003).

3. Results and discussion

3.1. Hydro geochemical study of Naghadeh City plain aquifer

Groundwater quality is the result of all the processes and reactions that operate on water from the time it is in the atmosphere until it is drained from a well or wellhead. Also, the chemical composition of water reflects the origin and history of the groundwater with which water has been in contact. (Alley, 1993) Due to the importance of groundwater, it is very important to determine its quality characteristics for agricultural and industrial uses, as well as to evaluate the parameters affecting quality change. The study of groundwater chemistry provides information about the geology and sediments of the region as well as its origin according to the water cycle. However, the quality of groundwater in the flow system is widely related to the quality of power supplies (Goldschmit, 1972). With this description, non-observance of technical points of operation and improper management of operation and quality protection, causes a quantitative and qualitative decline of water resources. Therefore, hydro geochemical studies of aquifers can provide useful information about the impact of aquifer and region constituents, water flow path, floor rock impact, feeding and discharge areas, groundwater evaporation areas and the effect of surface water on groundwater and groundwater quality, agriculture and industry. The purpose is to study the quantity and quality of groundwater resources in the region, the factors affecting it and to investigate the quality of water in the study area for different uses. Due to the fact that it is not possible to determine the source of groundwater without chemical analysis, 26 samples of water sources in Naghadeh area were sampled and subjected to hydro chemical analyzes with suitable dispersion. Hydro chemical parameters studied include electrical conductivity, acidity, anions and cations of carbonate, bicarbonate, sulfate, nitrate and silica calcium, magnesium, sodium and potassium. The results of hydro chemical analyzes are given in Table 2. The salinity of groundwater in Naghadeh plain has increased dramatically in recent years. Figure 4 shows the spatial variations of electrical conductivity and other main elements of groundwater in Naghadeh plain, which are obtained based on the kriging method in GIS environment. In general, the amount of electrical conductivity increases from the west to the east of the plain, which corresponds to the direction of groundwater flow. Due to the fact that the groundwater in eastern part of the plain is at a shallower depth, a sharp increase in salinity due to the presence of fine-grained formations with much less permeability that causes water to rise due to capillary force and be located at shallow depth, and finally shallow water Groundwater causes severe evaporation and increase the salinity of groundwater, and with the withdrawal of water, groundwater flow is established upstream of the aquifer, and as a result, the establishment of this salinity flow to the upstream parts of the aquifer (Norouzi and Asghari Moghddam, 2015). Due to coarse-grained sediments in western parts of the plain, the region has a high slope compared to the eastern parts and groundwater is at a greater depth and due to less evaporation and absence of salt mineral formations, the amount of electrical conductivity has not changed much compared to ten years ago. Due to high agriculture in summer and spring in other parts of the plain,the salinity rate increases due to the return of agricultural water flow during the high irrigation season in central areas of the plain, but in low irrigation seasons the electrical conductivity does not change much and depends on the water-rock interaction of geological formations that have gypsum and salt minerals. It can also be said that the amount of electrical conductivity in western parts of the region is low due to proximity to feeding areas and origin of conglomerate sediments, and are of good quality.

Table 2. Results of hydro chemical analyzes of groundwater in Naghadeh plain.

NO	UTM X	UTM Y	So_4	Cl	Hco_3	pH	Tds	Th	Sar	Ec	K	Na	Mg	Na	Class
1	536900	4098280	22	13.5	5.5	7.3	2743	1075	6.1	4220	0.22	20	12.5	9	c4-s2
2	553900	4086893	3.1	3	18.5	6.7	1703	945	1.952	2620	0.11	6	12.9	6	c4-s1
3	546863	4090031	3.3	1.5	8	7.5	864.5	550	0.768	1330	0.21	1.8	6	5	c3-s1
4	533150	4087679	2	1.5	7.5	7.1	754	525	0.436	1160	0.12	1	4	6.5	c3-s1
5	541791	4091997	1	0.5	8.5	7	689	450	0.613	1060	0.23	1.3	5	4	c3-s1
6	549392	4092617	1	1.4	6.8	7.2	617.5	370	0.884	950	0.09	1.7	4.4	3	c3-s1
7	544686	4087714	8	7	14	6.5	1969	800	4.596	3030	0.3	13	9	7	c4-s2
8	541926	4087761	10	3.5	7.5	6.7	1560	800	1.768	2400	0.2	5	10	6	c4-s1
9	535464	4088933	0.4	0.5	5	7.6	351	265	0.369	540	0.13	0.6	3.3	2	c2-s1
10	551231	4088256	1	2.2	10	7.2	897	575	0.834	1380	0.7	2	5	6.5	c3-s1
11	538642	4086113	0.6	1	6.6	7.4	546	360	0.527	840	0.4	1	4.2	3	c3-s1
12	524768	4091571	0.5	0.6	5.5	7.6	442	295	0.408	680	0.12	0.7	3.4	2.5	c2-s1
13	530882	4090086	0.8	0.7	4	7.6	370	250	0.38	570	0.9	0.6	3.3	1.7	c2-s1
14	557109	4093811	4.9	34.8	9	7.4	4217	1450	4.99	5210	0.2	19	21	8	c4-s2
15	531565	4091962	1	1	6	7.7	546	365	0.419	840	0.8	0.8	4.8	2.5	c3-s1
16	528761	4090978	0.5	0.4	5.5	7.6	422	300	0.346	650	0.83	0.6	4	2	c2-s1
17	538367	4095377	3	1.6	5.8	7.8	669	410	0.988	1030	0.1	2	5.6	2.6	c3-s1
18	526409	4098216	0.8	1	5.6	7.7	468	340	0.217	720	0.54	0.4	4.4	2.4	c2-s1
19	553266	4085880	1	1.1	14.7	6.8	1066	750	0.73	1640	0.1	2	6	9	c3-s1
20	524998	4093446	0.7	0.5	5	7.1	403	285	0.296	620	0.89	0.5	2.8	2.9	c2-s1
21	534926	4101835	4	2.5	6.2	7.6	812	360	2.741	1250	0.1	5.2	4.2	3	c3-s1
22	554904	4086722	1.2	1.8	18.7	6.7	1365	985	0.733	2100	0.2	2.3	8.7	11	c3-s1
23	545095	4096869	1.2	1.3	6	7.4	552	385	0.357	850	0.83	0.7	3.2	4.5	c3-s1
24	548251	4095457	2	0.5	10.5	7.5	780	615	0.403	1200	0.23	1	9	3.3	c3-s1
25	538825	4090580	1.1	1.3	9	7.4	715	515	0.529	1100	0.08	1.2	6.3	4	c3-s1
26	540827	4096239	2.2	4.3	10.5	7.6	1040	735	0.922	1600	0.15	2.5	7.2	7.5	c3-s1

Nitrate has always been considered by researchers as an indicator of groundwater pollution. Most cases of nitrate contamination in groundwater are related to agricultural wastewater and the use of nitrogen fertilizers. The most important sources of nitrate pollution in groundwater are agricultural and industrial activities, industrial and urban pollutants, livestock pollutants, fertilizers, and solids in urban areas of the region. In areas where shallow wells are excavated from groundwater aquifers, nitrite and nitrate are more likely to be present in excess than permitted levels in groundwater. Most cases of nitrate infiltration into groundwater as a pollutant are caused by agriculture and nitrate concentration can be related to the use of nitrate fertilizers. An increase in nitrate ions above 45mg/L can cause Methaemoglobinaemiain children as well as carcinogenesis in adults. The problem of high nitrate concentrations in water sources is mainly in groundwater, including wells. Shallow wells and wells close to sources of chemical and animal fertilizers such as soil, are more vulnerable to nitrate contamination than deep wells. Agricultural crops are at the highest risk of contamination. However, nitrate is not a problem in surface waters such as rivers and dams because in surface water nitrate is absorbed by plants and algae. Figure 5 shows the spatial variations of nitrate in the groundwater of Naghadeh plain. The amount of nitrate in Naghadeh plain is higher in southern parts of the region, which is mostly related to active agriculture in this area.

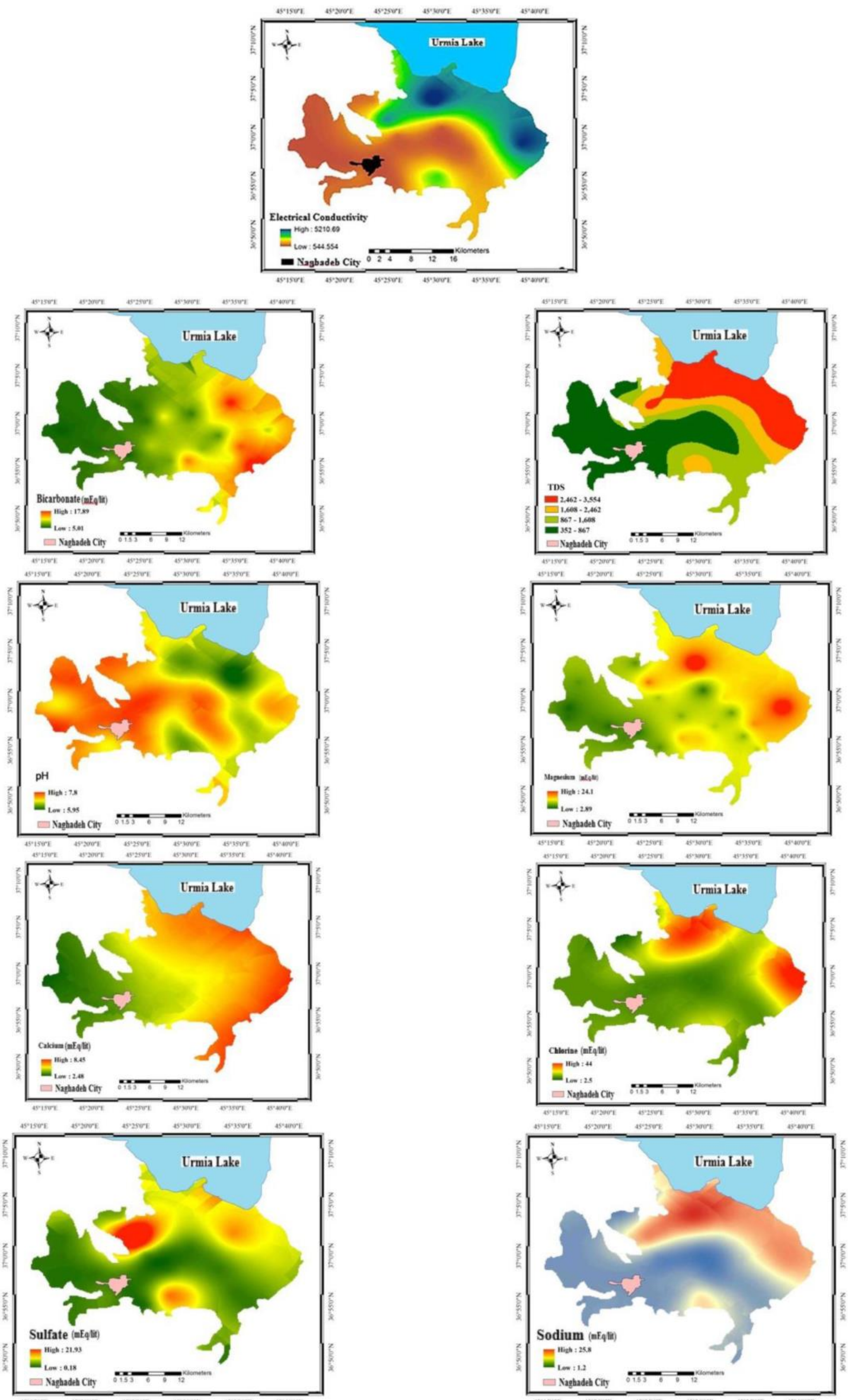

Fig. 4. Spatial changes of the main elements of Naghadeh plain.

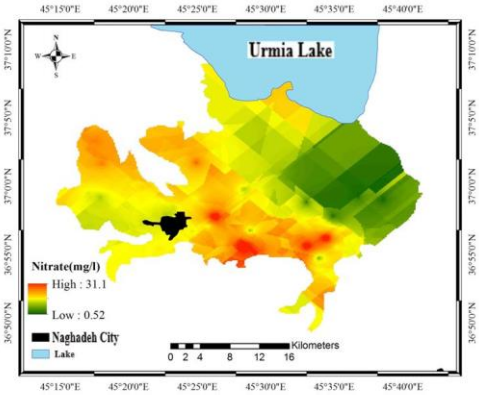

Fig. 5. Spatial variations of nitrate in groundwater of Naghadeh plain.

To show the groundwater quality changes and to determine the type of groundwater in different parts of the aquifer and to evaluate the quality of groundwater for different uses, hydro chemical diagrams of quality sources of Naghadeh plain aquifer were drawn using hydro chemical results of 26 samples of groundwater resources. In order to determine the type of groundwater in different parts of aquifer, the chemical composition of the existing samples of water resources inmEq/lit is plotted on a piper diagram. Figure 6 shows the resulting piper diagram for 26 samples of groundwater resources from Naqadeh plain. The results of the following figure show that changes in the plain ions in the flow path from bicarbonate to sulfate and in the outputs are of chloride type. At the mouth of Godar Chai River, the composition of groundwater is bicarbonate and in the central parts is sulfate. Also, in the outlet parts of the plain and towards Lake Urmia, the composition of groundwater is of chloride type and finally at the outlet of the plain, it becomes strongly chloride type. According to Schuler diagram in Figure 5, in most places, especially in western parts, the groundwater quality changes from acceptable to moderate, and as we approach the plain outlets, the water quality decreases and is in an unsuitable range.

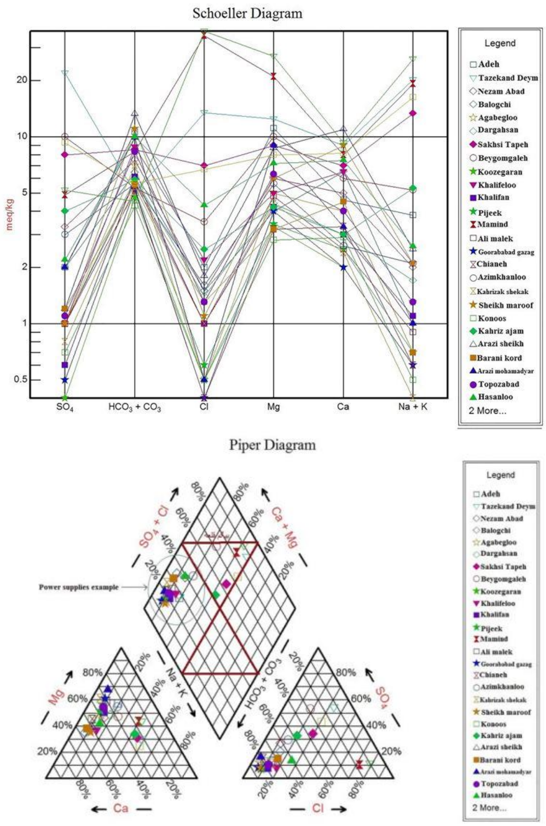

Fig. 6. Piper and Schuler diagram of Naqadeh plain groundwater resources.

3.2. Investigation of groundwater quality indicators in Naghadeh plain

Naghadeh plain aquifer has rich groundwater reserves due to its abundant nutritional sources. High groundwater level on the one hand increases the potential for evaporation and consequently the salinity of groundwater on the other hand increases the vulnerability of groundwater to the infiltration of surface pollution. Significant groundwater pollution results from the concentration of agricultural activities, the entry of fertilizers and irrigation water into the land, and the transfer of industrial and municipal effluents to groundwater. Increasing the concentration of various ions in groundwater beyond the values of global standards creates problems for drinking, agriculture and industry. In this study, it was tried to study the hydro geochemical characteristics of the plain and evaluate it in terms of international standards as well as Institute of Standards and Industrial Research of Iran. The final GQI calculation map based on WHO standard is shown in Figure 7. High values of groundwater quality index indicate good quality and low values indicate poor groundwater quality.

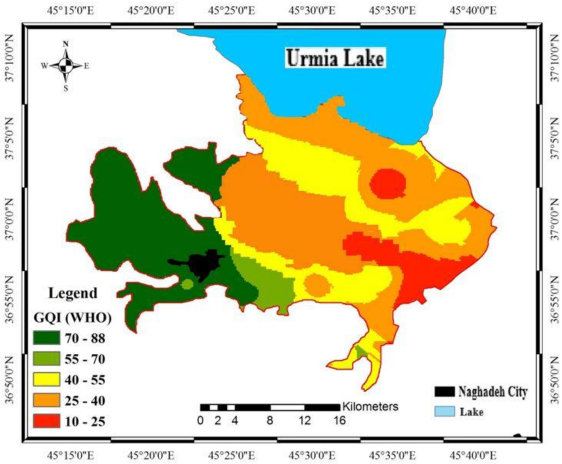

Fig. 7. Groundwater Quality Index (GQI) map according to WHO standard.

In the present study, considering the existing uncertainty in assessing the quality of drinking water and also the ability of the fuzzy set in decision-making process, an attempt has been made to investigate the quality of drinking water in the region based on FGQI by fuzzy GQI method. Therefore, in order to calculate the FGQI index by introducing point data kriging for each of the ten chemical parameters in GIS environment, a concentration raster map was prepared. The raster maps were then converted to fuzzy raster maps using the linear membership function. Then, using Equation 1 mentioned in GQI method, the concentrations of each pixel (K) of the fuzzy raster maps created in the previous step correlate with the standard INSO and WHO values of that parameter.The output will be ten maps, which will also be fuzzy with the linear membership function. Then, by placing the fuzzy maps in Equation 2, ranking map of each parameter is obtained. The output of these maps is also fuzzy by the linear membership function method. Finally, Equation 3 is used to create the final map and the final map is obtained according to WHO or INSO standards. Figure 8 shows the fuzzy map of groundwater quality index (FGQI) in Naghadeh plain according to WHO standard. Given that the values of INSO standard are the same as World Health Organization; the maps derived from the FGQI groundwater quality index classification are almost identical. As it is known, the groundwater quality is good in inlet parts of the plain and the groundwater quality decreases in the middle parts and near the end of the plain. The results show that FGQI value according to both WHO and INSO standards varies between 0 and 100 in terms of quality, groundwater is between completely unsuitable to suitable categories.According to the water quality classification based on GQI and FGQI, water quality of the area is divided as shown in Table 3. According to the calculations, value of quality index in the study area based on GQI and WHO and INSO standards has varied between 10% _ 88% and a significant percentage of the study area in terms of drinking water standards are in poor quality, but according to FGQI, the value of water quality index in both WHO and INSO standards varied from 0 to 100% and according to Table 3 are in completely unsuitable to suitable categories. In this research, GQI method proposed by Babiker et al. has been used to achieve a better understanding of the management of groundwater quality spatial variability. Therefore, an attempt has been made to make a complete comparison of the groundwater quality of the study area by applying the guidelines of World Health Organization and INSO.

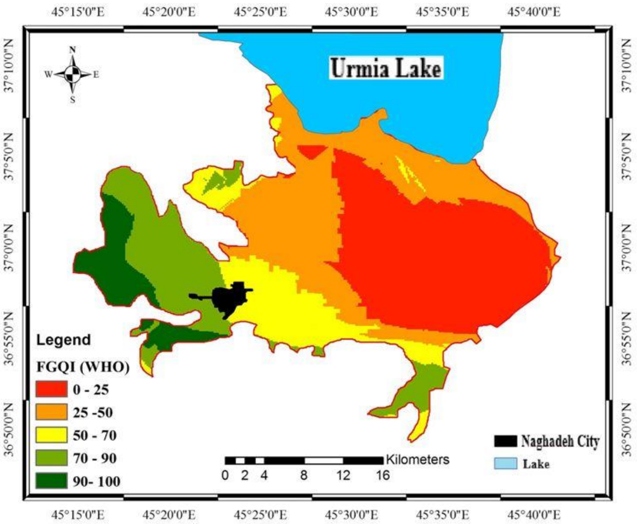

Fig. 8. Specific Groundwater Quality Map (FGQI) according to WHO

The FGQI method is a gradual process and has a higher capability than GQI method. The advantage of the fuzzy method over the definitive method is in the boundaries of changes in water quality classification categories. So that in FGQI method, the changes are fuzzy using the linear membership function and overlaid using the linear fuzzy function so that the boundary of groundwater quality changes can be considered gradually. A comparison of WHO and INSO standards shows that there is no significant difference in the results of FGQI method, while due to the quality focus in category in GQI method, the results of WHO and INSO two standards are very different. The final GQI map can be used to investigate how and why spatial groundwater quality changes. To do this, the information in this map can be related to geological information, land use, water level depth, etc. to determine the factors that control groundwater quality changes. According to these maps, the decline in water quality in eastern parts of the plain can have several reasons. First, the direction of groundwater flow in this area is from west to east, and by moving away from the feeding area and approaching the discharge area, groundwater quality decreases. Second, more water persistence and also more evaporation in the region pointed out that in eastern parts of the region the rate of evaporation is higher due to lower groundwater altitude.

Table 3. Percentage of areas related to GQI and FGQI in the study area

Water quality classification based on (GQI)		GQI %		FGQI %	
Water classification parameter	GQI amount	INSO	WHO	INSO	WHO
suitable	90-100	19	16	11	8
reasonable	70-90	34	32	19	17
Medium	50-70	8	6	15	13
Unsuitable	25-50	31	39	31	34
completely unsuitable	0-25	8	7	24	28

4. Conclusion

Increasing the concentration of different ions in Naghadeh plain groundwater to exceed the values of international standards has created problems in terms of drinking, agriculture and industry. In this study, the hydro geochemical characteristics of the plain were studied and evaluated in terms of international standards as well as the Iran National Standards Organization. The use of water quality indicators is one of the simplest methods away from mathematical and statistical complexities that can describe the quality of water and can be used as a strong management tool for relevant decisionsin water quality management. Therefore, FGQI and GQI were used for Naqadeh plain groundwater quality zoning. The FGQI method provides a solution for summarizing several parameters affecting groundwater quality in an index and studying spatial variations across the aquifer. According to GQI, WHO and INSO standards, quality index value in the study area varies between 10% to 88% and a significant percentage of the study area in terms of drinking water standards are in the category of poor quality. But according to FGQI, the water quality index value in both WHO and INSO standards varies from 0% to 100% and are in completely unsuitable to suitable categories. The results of FGQI method show that according to WHO standard, about 64% of the area is of unsuitable quality for drinking. For further studies, the information of this map can be related to geological information, land use, water level depth, etc. to identify the factors that control groundwater quality changes and to be used for better area management.

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