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Applying results of the chemical analyses in determining groundwater quality for drinking, agricultural and industrial uses: The case study Rafsanjan plain, Iran

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Abstract

Based on chemical analyses, the quality of ground waters for drinking, agricultural and industrial purposes was determined in Rafsanjan Plain-Iran. Samples for analyses were taken from 22 wells in 2012. Because of high water hardness and total dissolved solids content, water was found to be unsuitable for drinking purposes. Water quality for agriculture was determined with the use of the Wilcox method. Among the analysed water, 10.33% were attributed to C_3-S_1 class (high electrolytic conductivity and low sodium adsorption ratio), 59.5% to class C_4-S_1 (very high *EC* and low *SAR*) and 30.17% to class C_4-S_2 (very high *EC* and medium *SAR*). 89.67% of studied wells were unsuitable for agriculture. Because of corrosive water properties all but two wells on Rafsanjan Plain were undesirable for use in the industry. The results of qualitative analyses were presented in GIS and in databases to support making decision and management of groundwater on Rafsanjan Plain.

Key words: *water quality, water resources management, groundwater, Rafsanjan plain*

INTRODUCTION

Every year 842.000 humans died for unavailability of clean water and contaminated water [CLASEN 2011, KAYSER 2015]. Since 1970, the impact of land use on water quality became a big challenge and concern ZHAOA *et al.* [2015], RIMER *et al.* [1978], WHITE [1976]. Then in 1990 researchers began to analyse the relationship between land use and water quality [JOHNSON *et al.* 1997]. Recently, with the development of landscape ecology and GIS techniques, in water quality studies have founded new forms and effects of land use, hydrological and geological conditions on water quality were a fundamental consideration, [ALLAN 2004; BOOTH *et al.* 2004; HATHAWAY, HUNT 2011; MARINONI *et al.* 2013; RIBOLZI *et al.* 2011; TU 2013]. It is generally accepted that physical and chemical properties, aquatic environment cannot reflect the real state health of an ecosystem [ZHENG *et al.* 2014]. Water quality management in the watershed was essential to obtain the water management strategy [ASHTON *et al.* 1995]. Human sustainable access to safe drinking water is always a vital need. Unfortunately groundwater hydrology due to connections with other water resources was at risk of infection by the destructive process. So access to unsafe and pollution water cause diseases and many problems and damages in social, economic and other fields. The most important factors for water quality determine with using the application, in the various uses [KAYSER *et al.* 2015]. Access to unsafe and pollution water causing diseases, many problems and damages in social, economic and other fields. In this context, awareness of the water quality resources is one of the basic needs in planning the use of water in agriculture, industry, drinking etc. [ABTAHI *et al.* 2015; LOBATO *et al.* 2015]. In addition, today due human activities and various contaminants entering, the water quality is changed and were an impact on human life and users in various sectors of agriculture, industry etc. The human impact factors on water quality of have included time, environment and biological factors, physical and chemical processes involved natural systems etc. One of important factor in this context is the hydrologic cycle that directly affects on the water drainage network affected by contamination sediment, So impact on local flora, fauna and creates many problems too [LOBATO *et al.* 2015; ZHAOA *et al.* 2015]. In this regard, awareness of water quality and its proper use in any field need to research and monitoring water resources is appropriate, having a comprehensive information, accurate and reliable at the right time periods be an important factor in correct decision and policy making. In this regard, many models and methods for water quality have determined such as Wilcox, Schuler, Piper in various uses including agriculture, industry and drinking. Akhondali and Zarei in 2006 showed the qualitative and hydrochemical faces of groundwater and surface water resources Sdabvalbas (Khuzestan) with charts Piper and Wilcox looked in 2005 [ZAREI, AKHONDALI 2007]. DINDARLO *et al.* [2006] evaluated the chemical quality of drinking water in Bandar Abbas concluded the amount of sulphate, chloride, sodium, total hardness and nitrate in groundwater source and desirable total dissolved solids (*TDS*) and calcium were higher than desirable value. In POURMOGHADAS'S [2003] study finds that, groundwaters in Lenjan (Isfahan) city was very hard.

STUDY AREA

Rafsanjan plain with 2,421 km^2 area is between 54°52' and 56°34' latitude and between 29°51' and 31°31' altitude of 1,400 to 3,443 m wide band in Iran. This basin located in northwestern Kerman Province (Fig. 1). Rafsanjan plain's lands has mild slope, so that the maximum slope in this area is not more than two percent. In general sphere of influence Rafsanjan plain consists of a paved area at a distance of 15 km to the North, North-West and North-East region is sandy and loamy. This plain only has a few seasonal rivers because it has a desert climate.

To evaluate the quality of underground water, 25 wells in Rafsanjan plain was sampled and analysed. Also sampling was done during field operations In Figure 2 the position of the wells was shown on the map and Thiessen polygons plotted on the map using GIS software. Thiessen polygons method in which the value was sampled location nearest point. In point this way, the boundaries of the neighbouring polygons were equal and each point of the centre point of the polygon was closer than at other points [CROLEY, HARTMMAN 1985; RHYNSBURGER 1973]. Thiessen polygons (according to the harvest) caused by points that their nearest neighbours were connected by a triangular line. Then the side of the perpendicular to others makes that it was cut node Thiessen polygons. [BRASSEL, REIF 1979]. Finally, the primary lines dividing a region between points removed and Thiessen polygons were completely determined by the placement of sample points. The profile area in each of Thiessen polygons located at the well where were equal, the division was done in GIS software and results in Figure 2 was shown.

As shown in Figure 2, wells dispersed in North-West to the South-East plain the drawn and wells have represented in almost all parts of Rafsanjan plain.

MATERIALS AND METHODS

Table 1 and Figure 3 provided statistical characteristics of the 25 wells in Rafsanjan plain including standard deviation, variation coefficient, variation range etc. One of these parameters was skewed. Skewness of the third torque was normalized. Skewness in the distribution function is a measure of the presence or absence asymmetry. For a perfectly symmetrical distribution of zero skewness and elongation for an asymmetric distribution with positive

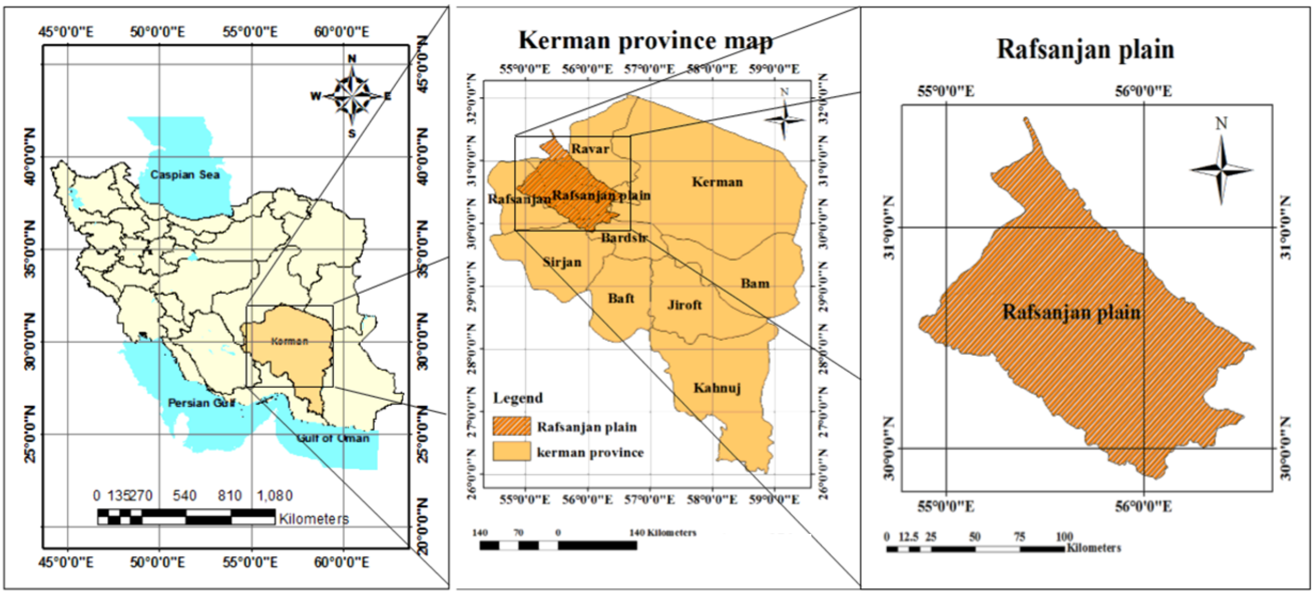

Fig. 1. Location of the Rafsanjan plain; source: own elaboration

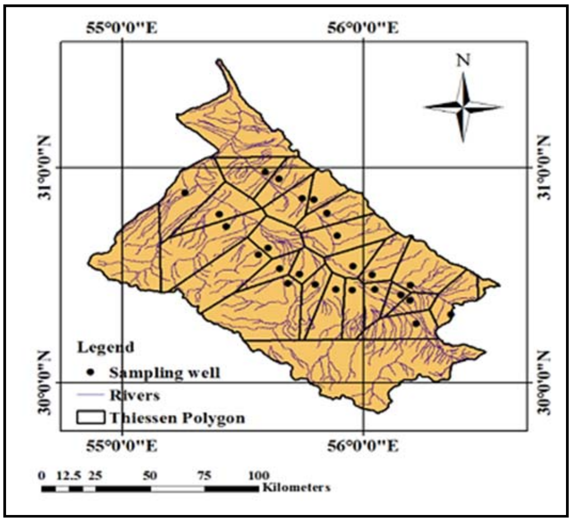

Fig. 2. Position of sampled wells and division on it Thiessen polygon method; source: own elaboration

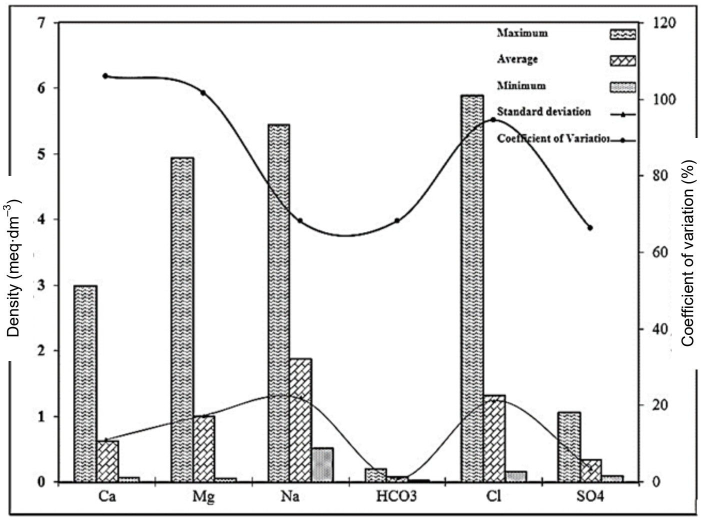

Fig. 3. Rafsanjan plain statistical parameters of various chemical components (2012); source: own elaboration

Table 1. Statistical characteristics in terms of chemical components for 25 sample wells in 2012

Parameter	*EC* (dS·m^{-1})	*TDS* (mg·dm^{-3})	pH	Ca^{2+}	Mg^{2+}	Na^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
				(meq·dm^{-3})					
Arithmetic mean	5703.72	3708.44	7.78	0.62	1	1.87	0.08	1.32	0.33
Standard deviation	3798.58	2468.19	0.33	0.65	1.02	1.27	0.05	1.25	0.22
Variation coefficient (%)	66.6	66.56	4.24	104.84	102	67.91	62.5	94.7	66.67
Maximum	17950	11668	8.4	2.99	4.93	5.44	0.2	5.89	1.05
Minimum	1256	836	7.1	0.06	0.05	0.52	0.02	0.16	0.09
Mode	no mode	no mode	7.8	0.499	0.378	1.648	0.052	no mode	no mode
Median	4660	3029	7.8	0.42	0.7	1.43	0.05	1.01	0.25
Variation range	16694	10832	1.3	2.93	4.88	4.92	0.18	5.73	0.96
Skewness	1.94	1.94	–0.17	2.49	2.66	1.84	1.39	2.54	1.98
Variance	14429206.63	6091939.76	0.11	0.43	1.04	1.62	0	1.55	0.05

Explanations: *EC* = electric conductivity, *TDS* = total dissolved solids.
Source: own study.

skewness towards higher values for elongation to the asymmetric distribution with negative skewness is pretty small [TSE 2016]. In the moments obtained in wells sampled all positive skewness other than pH was skewed. The coefficient of variation the distribution per unit is average states [HARVEY, SIDDIQUE 2000; MARDIA 1970].

According to numbers obtained in the statistical analysis, trend of standard deviation and coefficient of variation for the six core element Ca, Mg, Na, K, HCO_3, Cl and SO_4 was drawn. As Table 1, the highest and the lowest of variation coefficient in Ca and HCO_3 observed respectively.

RESULTS

DRINKING WATER WELLS QUALITY

Drinking water should have a good quality of various aspects including physical, chemicals, toxins, bacteriological and radiological examined characteristics [WASANA *et al*. 2016]. Schuler diagram considered for classification terms of drinking water whose concentration of anions and cations in water samples measured. This diagram has classified to good, acceptable, average, inappropriate, quite unpleasant and non-drinking (Tab. 2) [CHORAMIN *et al*. 2015]. Schuler semi-logarithmic graph used to determine the ability of drinking water. Drinking water shouldn't have colour, smell or taste, and in terms of elements and chemicals in the allowable range was determined by the health system [WHO 2004]. The chemical and physical properties can be measured in human drinking water for anions, cations and total dissolved solids–total hardness (*TDS–TH*) classified using Schuler diagram. *TDS* usually expressed ppm. The amount of *TDS* and *TH* is the most important parameter for water quality that these parameters can be calculated as follows [VINGERHOEDS *et al*. 2016].

Table 2. Schuler percents of each classification classes for drinking water in Rafsanjan plain

Classification	*TDS*	*TH*	PH	Na^{+}	Cl^{-}	SO_4^{-2}
Good	0	94.83	8.75	91.67	95.83	100
Acceptable	4.17	5.17	4.17	8.33	4.17	0
Average	12.5	0	8.33	0	0	0
Inappropriate	58.33	0	0	0	0	0
Quite unpleasant	16.67	0	0	0	0	0
Non-drinking	8.33	0	0	0	0	0

Explanations: *TDS* = total dissolved solids, *TH* = total hardness.
Source: own study.

$$TH = \text{Ca}\,(\text{CaCO}_3/\text{Ca}^{2+}) + \text{Mg}\,(\text{CaCO}_3/\,\text{Mg}^{2+}) \quad (1)$$

$$TH = 2.497\text{Ca}^{2+} + 4.115\,\text{Mg}^{2+} \quad (2)$$

Amount of Mg and Ca in mg·dm^{-3}:

$$(\text{Based on CaCO}_3)\; TH = 50(\text{Ca}^{2+} + \text{Mg}^{2+}) \quad (3)$$

In this regard, Mg and Ca are expressed in terms of meq and total hardness is mg·dm^{-3}.

Groundwater and surface analysis has shown that the soluble salts or total dissolved solids (*TDS*) between dry and there was water electrical conductivity (*EC*):

$$TDS = 0.64EC \quad (4)$$

TDS in ppm and water *EC* in dS·m^{-1}.

Amount of anions and cations present in samples taken from wells Rafsanjan plain Schuler graph classification water plotted in Figure 2. These values were summarized in Table 2. Also, the statistical parameters of various chemical components for this plain are shown in Figure 3.

In Figure 4, 25 series lines are criteria for water quality recognition for drinking. The diagram illustrates the status of each of the wells for drinking data for 25 wells.

Based on the analyses and achieved Schuler graph based on Table 2, two important parameters in determining the water quality Schuler method was hardness values and *TDS*. For this purpose, used kriging method in GIS software, the final maps were shown in Figures 5 and 6.

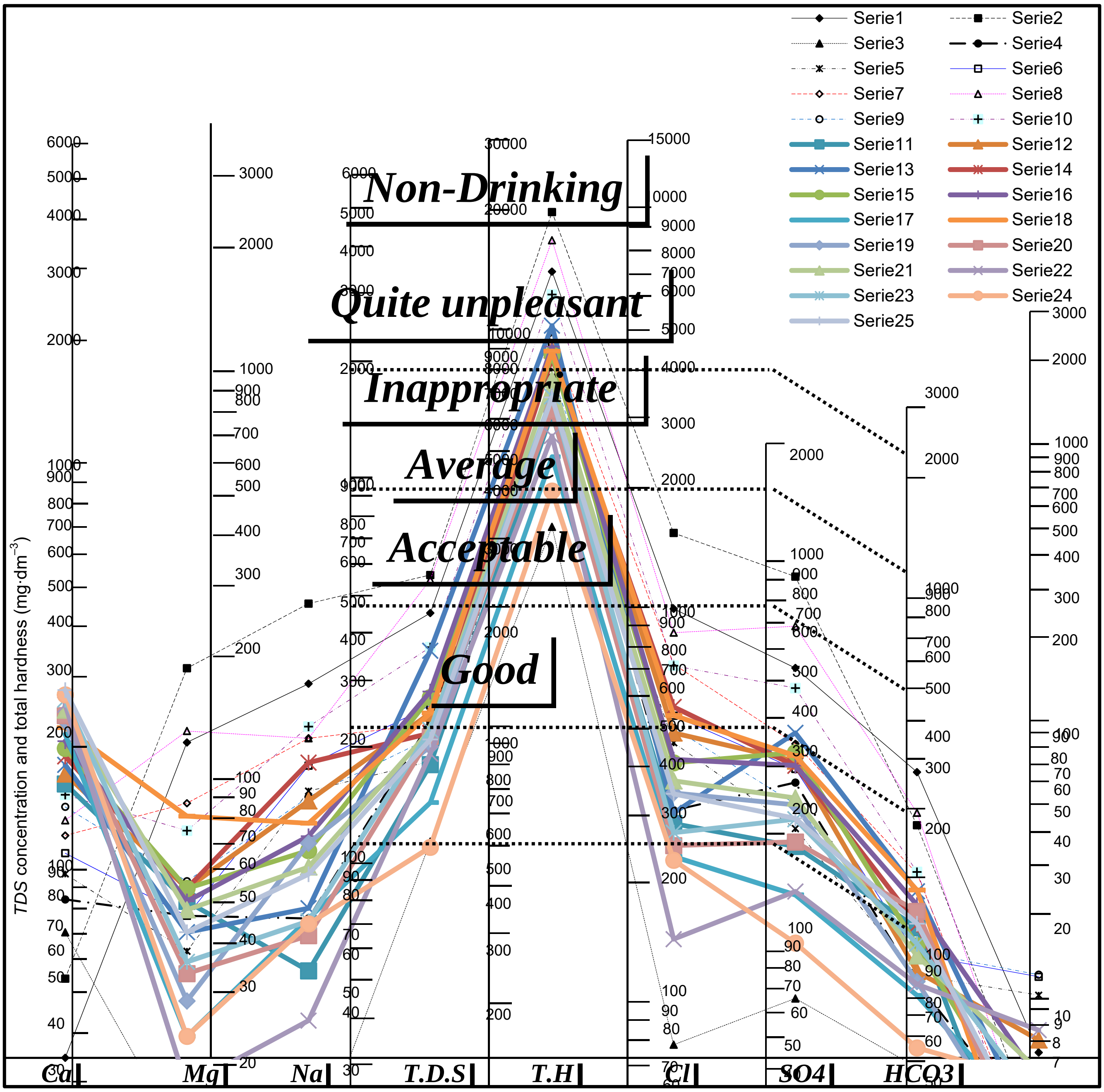

Fig. 4. Schuler diagram drawn for samples taken from wells Rafsanjan plain; source: own study

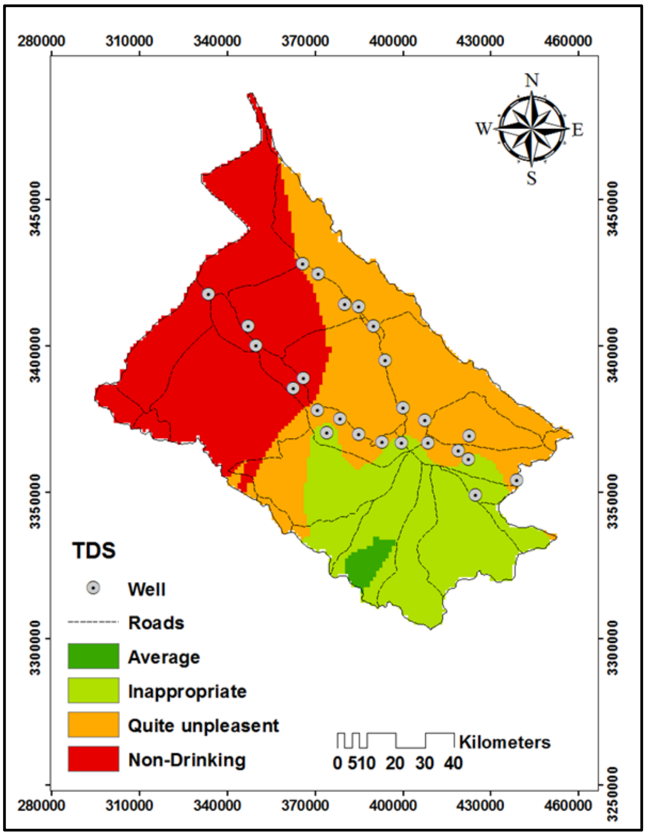

Fig. 5. Total dissolved solids (*TDS*) zoning map with kriging method; source: own study

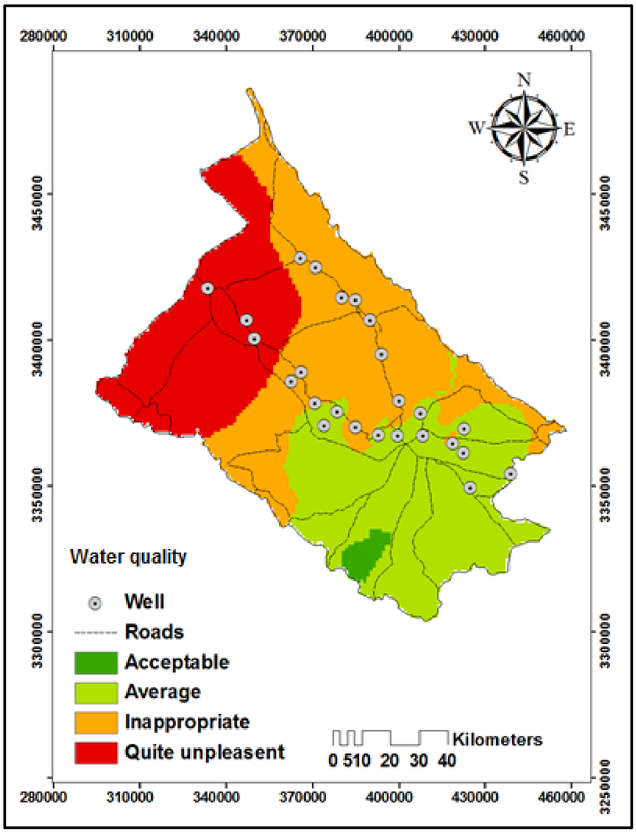

Fig. 7. Zoning groundwater water quality in Rafsanjan plain kriging method; source: own study

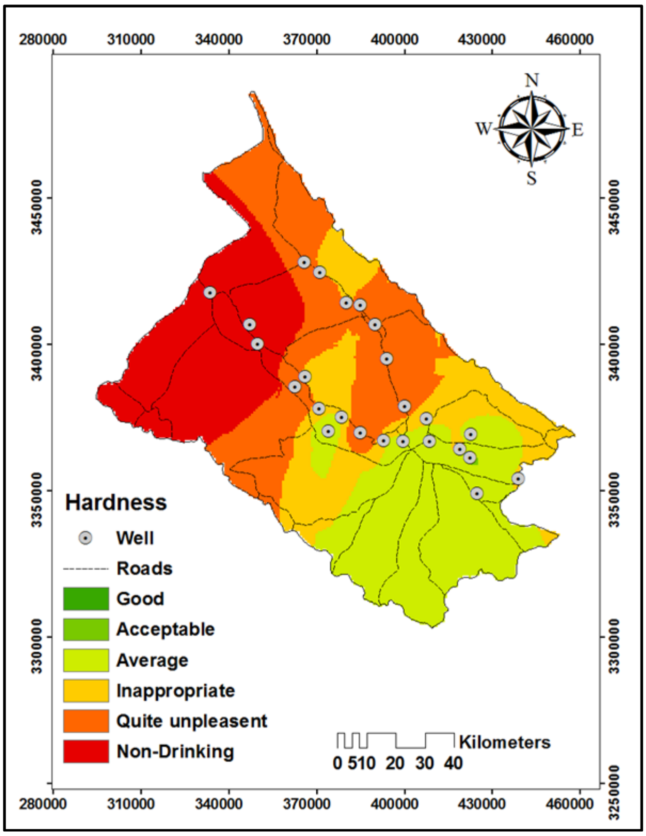

Fig. 6. Hardness zoning map with kriging method; source: own study

To the importance of water for drinking, using GIS software Rafsanjan plain zoning was using kriging method (Fig. 7).

As seen in Figure 7, there is acceptable quality water for drinking in very small portion of south western plains. The rest is allocated to medium and inappropriate quality. Totally, Rafsanjan plain need to further proper planning and sustainable development in order to create a good quality water requires, specialy in inappropriate quality.

AGRICULTURE WATER WELLS QUALITY

We used Wilcox analysis to check the quality of water wells for agriculture in Rafsanjan plain. The most important quality criteria for classification of agricultural water were the amount of sodium and salinity (electrical conductivity) because they effect on plants growing, the proportion of irrigation water and the permeability [DARVISHI *et al.* 2016]. Wilcox diagram salt water in the horizontal axis and the vertical axis is dedicated to sodium adsorption ratio (*SAR*). *SAR* is archived in 4 classes and calculated by flowed equation.

$$SAR = \frac{\mathrm{Na}^{+}}{\sqrt{0.5(\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+})}} \tag{5}$$

Used Wilcox and classification method, it was the most practical methods for the classification of agricultural water in hydrology. In the Table 3 and Figure 8 the coordinates of any water in the area was that the C and S letters

Table 3. The quality classification wells for agriculture

High conductivity C_4				Very high conductivity C_3			
S_4	S_3	S_2	S_1	S_4	S_3	S_2	S_1
percentage share of water samples							
0	0	30.17	59.5	0	0	0	10.33

Explanations: S_1, S_2, S_3, S_4 = sodium adsorption ratio: low, medium, high, very high, respectively.
Source: own study.

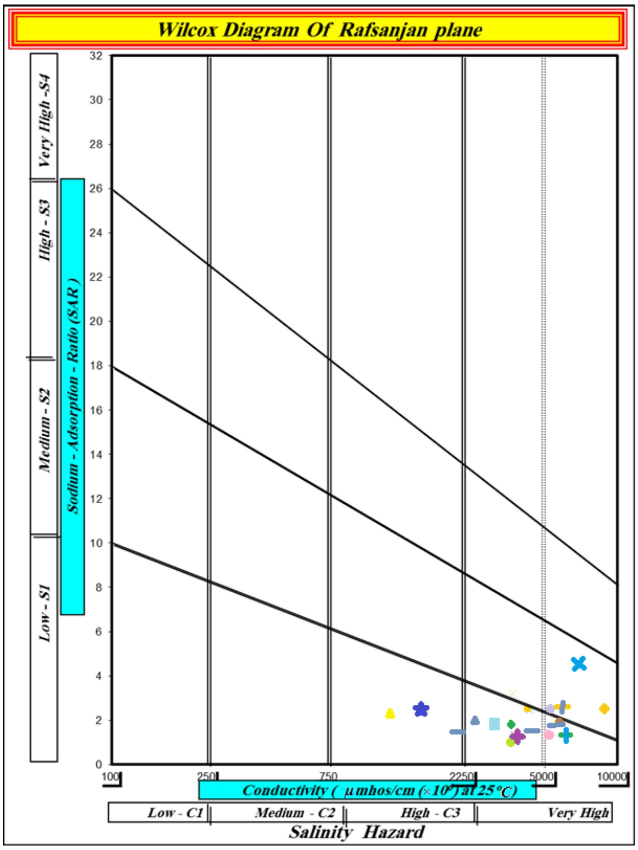

Fig. 8. Wilcox diagram for samples taken from wells in Rafsanjan plain; source: own study

in sodium salt determined. A value of 1, 2, 3 and 4 respectively represent low, medium, high and very high. According to this classification, all water with *EC*'s less than 250 μmho·cm^{-1} was very good. According to the agricultural plot to check the water quality can be seen that all the wells in the C_4-S_2, C_4-S_1 and C_3-S_1 located and have high or very high salinity and low to moderate sodium (Fig. 8). The Table 4 was prepared for the scrutiny of water quality for agriculture where 25 wells were sampled for the *EC* and *SAR* and water classes were given in a column. According to the specified standard there were two water wells for agricultural use as below:

– very salty – unsuitable for agriculture (C_4-S_1, C_4-S_2 classes),
– salty – suitable for agriculture (C_3-S_1 class).

For use water class C3-S1 should plant type and resistance be considered (Tab. 3).

As shown in Table 4, the quality and class of each of the sampled wells for agricultural used by Wilcox method. Based on Wilcox diagram prepared for the wells Rafsanjan plain and analysis was prepared diagram of the table where

Table 4. Determining the quality and class of each of the sampled wells for agricultural used by Wilcox method

No. of well	*SAR*	*EC* (dS·m^{-1})	Water class	Agricultural water quality
1	2.70	10 900	C_4-S_2	very salty – unsuitable for agriculture
2	2.73	17 950	C_4-S_2	very salty – unsuitable for agriculture
3	2.33	1 256	C_3-S_1	salty – suitable for agriculture
4	2.46	4 490	C_4-S_1	very salty – unsuitable for agriculture
5	1.31	3 940	C_4-S_1	very salty – unsuitable for agriculture
6	1.90	5 860	C_4-S_1	very salty – unsuitable for agriculture
7	1.31	6 250	C_4-S_1	very salty – unsuitable for agriculture
8	3.98	14 170	C_4-S_3	very salty – unsuitable for agriculture
9	1.51	4 660	C_4-S_1	very salty – unsuitable for agriculture
10	2.55	9 000	C_4-S_2	very salty – unsuitable for agriculture
11	1.79	3 340	C_4-S_1	very salty – unsuitable for agriculture
12	1.91	5 650	C_4-S_1	very salty – unsuitable for agriculture
13	4.58	6 930	C_4-S_2	very salty – unsuitable for agriculture
14	1.44	5 300	C_4-S_1	very salty – unsuitable for agriculture
15	2.48	5 430	C_4-S_2	very salty – unsuitable for agriculture
16	2.58	5 810	C_4-S_2	very salty – unsuitable for agriculture
17	1.48	2 310	C_4-S_1	very salty – unsuitable for agriculture
18	1.78	5 600	C_4-S_1	very salty – unsuitable for agriculture
19	1.84	3 810	C_4-S_1	very salty – unsuitable for agriculture
20	2.51	4 420	C_4-S_1	very salty – unsuitable for agriculture
21	2.02	2 750	C_4-S_1	very salty – unsuitable for agriculture
22	3.19	3 830	C_4-S_2	very salty – unsuitable for agriculture
23	2.51	1 737	C_3-S_1	salty – suitable for agriculture
24	1.02	3 800	C_4-S_1	very salty – unsuitable for agriculture
25	1.97	3 821	C_4-S_1	very salty – unsuitable for agriculture

Explanations: C = conductivity classes, S = sodium adsorption ratio classes: 1 = low, 2 = medium, 3 = high, 4 = very high.
Source: own study.

the percentage of each of the classes mentioned (Tab. 3). It was known as the 10.33% water in C_3-S_1 class and the C_4-S_1, C_4-S_2 classes were respectively 59.5% and 30.17%.

In order to study the better water quality and more accurately display *EC* and *SAR* in Rafsanjan plain, wells water zoned in the area by used kriging method in GIS software.

INDUSTRIAL WATER WELLS QUALITY

Water of vital industries for paper-making, textile, pharmacy etc. that combined production or preparation of

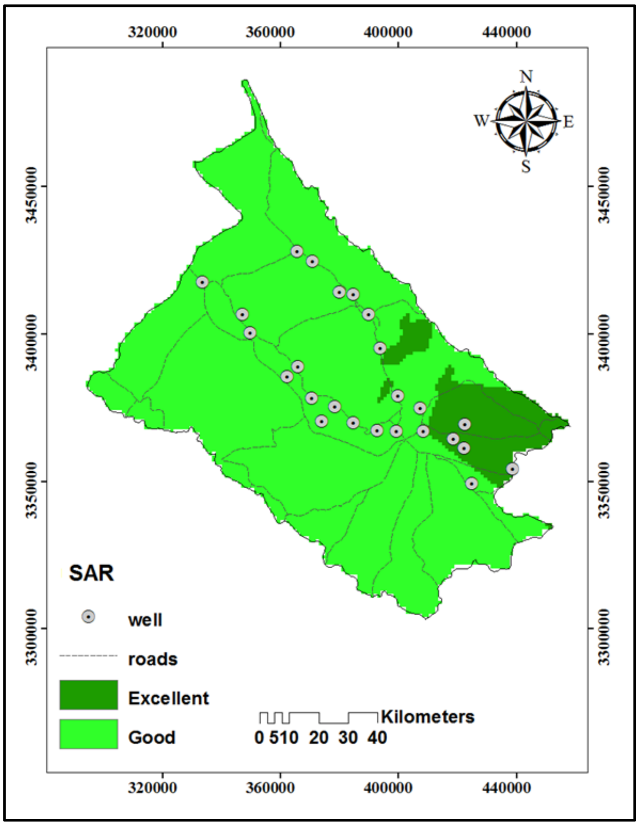

Fig. 9. Sodium adsorption ratio zoning for Rafsanjan plain; source: own study

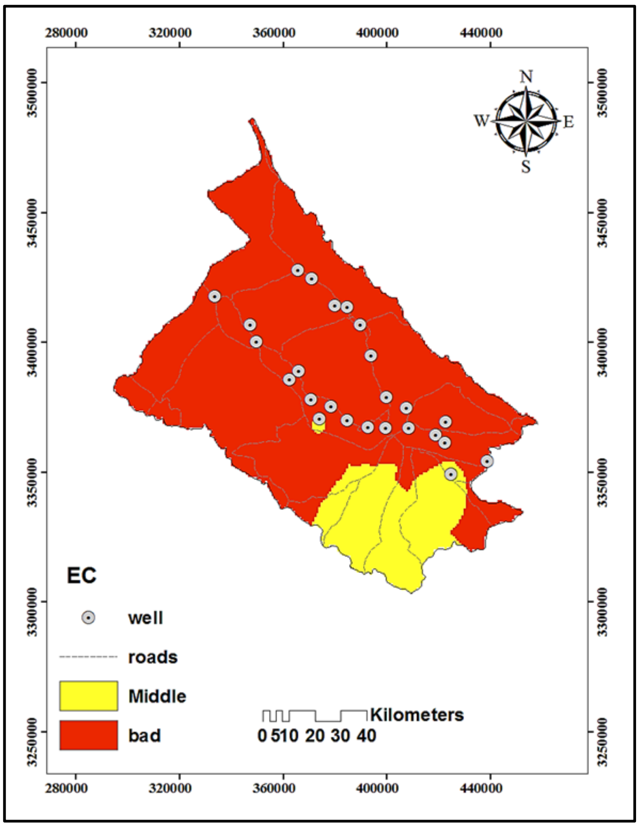

Fig. 10. Electrical conductivity (*EC*) zoning for Rafsanjan plain; source: own study

materials or devices used in cooling. The water used in industry can have a corrosive and adverse effects on devices and industrial facilities as well as production quality. Among the important factors that affecting on water in industrial, used calcium concentration and alkalinity. Here, alkalinity index were expressed in terms of CaO (Fig. 9 and 10). The analysis was carried out for 25 wells sampled in Rafsanjan plain showed low quality wells for used in the industry water, apart from well No. 2, all wells with corrosive water that will cause a lot of problems in the manufacturing and industrial machines (Tab. 5).

Table 5. Industrial quality analysis for sampled wells

No. of wells	Alkalinity according CaO	Ca (mg·dm^{-3})	C factor	PHs	PH	PHs – PH	Industrial water quality
1	90	32.73	11.36	7.9	7.1	0.8	corrosive
2	125	59.88	11.37	7.5	7.7	–0.2	sedimentation
3	12.5	1.19	11.30	10.1	8.4	1.7	corrosive
4	35.3	7.98	11.33	8.9	7.8	1.1	corrosive
5	25.0	5.98	11.33	9.2	7.7	1.5	corrosive
6	40.5	7.98	11.34	8.8	7.3	1.5	corrosive
7	34.5	19.96	11.34	8.5	7.5	1.0	corrosive
8	120	35.92	11.36	7.7	7.6	0.1	corrosive
9	30.6	10.57	11.34	8.8	7.2	1.6	corrosive
10	67.0	15.96	11.35	8.3	7.8	0.5	corrosive
11	24.3	8.98	11.33	9.0	8.0	1.0	corrosive
12	37.9	9.98	11.34	8.8	7.5	1.3	corrosive
13	65.0	6.98	11.34	8.7	8.0	0.7	corrosive
14	31.9	9.98	11.34	8.8	7.8	1.0	corrosive
15	43.4	9.98	11.34	8.7	7.9	0.8	corrosive
16	45.7	8.98	11.34	8.7	7.5	1.2	corrosive
17	17.5	2.99	11.32	9.6	8.1	1.5	corrosive
18	37.9	17.96	11.34	8.5	7.7	0.8	corrosive
19	28.4	3.99	11.33	9.3	7.8	1.5	corrosive
20	31.0	4.99	11.33	9.1	8.2	0.9	corrosive
21	32.7	8.38	11.33	8.9	8.0	0.9	corrosive
22	26.7	1.99	11.32	9.6	8.2	1.4	corrosive
23	32.8	5.48	11.33	9.1	7.9	1.2	corrosive
24	11.9	2.99	11.31	9.8	8.3	1.5	corrosive
25	30.2	6.98	11.33	9.0	7.6	1.4	corrosive

Explanations: PH = a measure of how acidic/basic water is; PHs = difference between PH and Langelier Saturation Index (LSI).
Source: own study.

CONCLUSIONS

Study the quality of water in various sectors including drinking, agriculture and industry is one of the basic parameters of sustainable development and raise the level of safety of products and the community. In this study, the quality of Rafsanjan plain water wells deliberated to advance the goals of sustainable development and proper management of the resources. The results showed groundwater had a high concentration of salts, which are exploitation of these resources has been faced with serious problems in this plain. Rafsanjan plain Groundwater to drinking had several limitations and restrictions related to total dissolved solids and there are 58.33% inappropriate quality wells in the area. The study also showed wells for agricultural use 10.33% of this water in C_3-S_1 class, 59.5% in

C_4-S_1 class and 30.17% is in C_4-S_2 class. In other words, nearly 90% of Rafsanjan plain water not suitable for farming. The survey also found that except for well No. 2, which was depositing water quality of all wells, were corrosive for used in the industrial sector. Conditions in the Rafsanjan plain for construction of water-related industry were also inappropriate quality. Finally, given the importance of water for drinking, agriculture and industry were more prominent attention to water quality that the government and people in the planning and application of ecological sensitive area must be done.

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Zastosowanie wyników analiz chemicznych do określenia jakości wód gruntowych do celów spożywczych, rolniczych i przemysłowych: Przykład wód na Równinie Rafsanjan

STRESZCZENIE

Na podstawie analiz chemicznych w niniejszej pracy określono jakość wód gruntowych wykorzystywanych do celów spożywczych, w rolnictwie i przemyśle. Próbki do analiz pobrano z 22 studni w 2012 r. Z powodu dużej twardości i dużego stężenia substancji rozpuszczonych wody nie nadawały się do użycia jako źródła wody pitnej. Przydatność wód do zastosowań rolniczych określono za pomocą metody Wilcoxa. Spośród analizowanych studni 10,33% przypisano do klasy C_3-S_1 (duże przewodnictwo *EC*, mały współczynnik adsorpcji sodu *SAR*), 59,5% do klasy C_4-S_1 (bardzo duże *EC*, niski *SAR*), a 30,17% do klasy C_4-S_2 (bardzo duże *EC* i średni *SAR*). Z powodu właściwości korodujących wszystkie (poza dwiema) studnie na równinie zawierały wodę nienadającą się do celów przemysłowych. Wyniki analiz jakościowych przedstawiono w systemie GIS i w formie baz danych, które mogą wspierać podejmowanie decyzji i zarządzanie zasobami wody na Równinie Rafsanjan.

Słowa kluczowe: *jakość wody, Równina Rafsanjan, wody gruntowe, zarządzanie zasobami wodnymi*