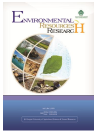

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Evaluation and mapping of groundwater quality for irrigation and drinking purposes in Kuhdasht region, Iran

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Abstract

Preservation of water quality, particularly in areas with inadequate water resources is considered as one of the principles of planning in integrated water management. In Kuhdasht, a region at the west of Iran, groundwater and spring water resources are the major contributors of drinking and irrigation water supply. The aim of this study was to determine the suitability and mapping of springs and groundwater for irrigation and drinking purposes based on the water quality indices. Values of physical (pH, electrical conductivity, total dissolved solids), and hydro chemical characteristics (Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO^{3-}, Cl^- and SO^{4-}) of springs and groundwater were identified. To assess the water quality, chemical parameters like sodium adsorption ratio (SAR), total hardness, Mg-hazard (MH), sodium percentage (Na%), and salinity hazard were calculated based on the analytical results. ANOVA test was used to compare the treatments of different stations' quality parameters and LSD test was used to assess the statistical differences between the regions, for spatial distribution and mapping, geo-statistical interpolation techniques of Kriging method were applied. A Durov diagram plot showed that the groundwater has been evolved from Ca-HCO_3 recharge water followed by mixing and reverse ion exchange processes due to the respective dominance of Ca – Cl water types. Based on Gibbs's diagram plots, chemical weathering of rock forming minerals is the main factor controlling water chemistry in this area. Based on ordinary Kriging, most parts of the region has good water for the drinking and irrigation.

Keywords: Kuhdasht region, Geo-chemical characteristics, Quality analysis, Kriging

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1. Introduction

Groundwater is an important natural resource particularly for drinking and irrigation uses (Sappa *et al.*, 2014). The main factors controlling the chemical characters of groundwater are the climate and vegetation cover, the mineral composition, and physical properties of rock and soil through which the water circulates and the relief of the land surface (Back, 1964). In addition, geochemical processes occurring within the groundwater are responsible for seasonal and spatial variations in groundwater chemistry (Rajmohan and Elango, 2004). The natural water analyses for physico - chemical properties are very important for public health studies (Sappa *et al.*, 2014; Rizwan and Singh, 2009). The issue of water quality is important to agricultural production, human health, and environment (Ma *et al.,* 2014). Complex interactions of different factors such as geology, mineral composition of an aquifer, weathering, topography, tidal effects, climate, and anthropogenic activities are important contributors of groundwater quality (Kura *et al.,* 2013). Physico-chemical characteristics may describe the quality of water, hence, systematic calculation of correlation coefficient between physico-chemical parameters has been carried out, and significant correlation has been verified by using t- test (Bhandari and Nayal, 2008; Garg *et al.*, 1990; Sarkar *et al.*, 2006). According to world health organization (WHO) estimates, about 80% of water pollution in developing countries like India is caused due to domestic wastes (Bhuvaneswaran and Rajeswari, 1999). Poor water quality is responsible for the death of an estimated 5 million children in the developing countries (Holgate, 2000). The problem is further exacerbated since population is increasing rapidly, which leads to poor water-quality management (Huang and Xia, 2001). A research in Malaysia showed that the negative impact of grazing on water quality was noticeable in long-term moderately grazed grasslands (Ajorlo and Abdullah, 2014). Based on the study of Gharbia *et al.* (2015) Gaza Strip faces both groundwater quality and quantity issues as considerable amount of water demand is provided from groundwater. Increasing in population, urban development and agriculture are just some of the factors, which have an impact on the water quality in this area. In addition, climate changes have severed negative impacts on groundwater of the Gaza coastal aquifer. A study conducted by Moasheri *et al.* (2013) showed that ANN method is the best method for predicting "SAR" qualities parameters in Jiroft plain groundwater compared to scope ways and experimental examinations. Jha, D.K., *et al.* (2015) based on the analysis of multiple parameters revealed that water quality in Port Blair and Rangat Bays is poor and its likely cause is anthropogenic activities.

The use of GIS has facilitated the study and analysis of natural resources and environmental concerns, including groundwater. Geo-statistics techniques like Kriging is applied widely in geology and hydrology to interpolate spatial data, and determine water variables in space and time (Stein, 1999; Nas and Berktay, 2010).

In addition, the use of Kriging in the spatial analysis of environmental data has become progressively popular. Nowadays, a number of variants of Kriging have been developed and used such as Simple Kriging, Ordinary Kriging (OK), Universal Kriging, Block Kriging, Cokriging, and Disjunctive Kriging. Among the different variants of the Kriging, OK has been used more as a reliable estimation method (Yamamoto, 2000; Nas and Berktay, 2010). Several methods are available in literature for interpolation, but Kriging methods are recommended as appropriate techniques for normally distributed data (Aidoo *et al.*, 2015).

The geostatistical concepts and applications are described by different researchers around the world. Kriging technique theorizes the spatial correlation between the sample points and is frequently used for mapping spatial variability (Nayak *et al.,* 2015).

The present study is performed to cover all the major aspects governing the groundwater chemistry of the region through hydro chemical plots, spatial profile of the region, and water quality indices. On the other hand, geostatistics techniques and statistical analyses are used together to study groundwater quality in Kuhdasht region, Iran. The main objectives of this study are evaluation of water geochemistry, determination of water quality parameters, assessment, and mapping of water suitability for drinking and irrigation purposes by comparing the identified parameters with the standards and guidelines in the studied area.

2. Materials and methods

2.1. Study Area

Kuhdasht is located in Lorestan province, Iran and is 85 Km far from Khoramabad city, 33° 32′ 06″ N and 47° 36′ 22″ E with 1197 m average height from see level. In the 2006 census, its population was 85,519 in 18,087 families. Kuhdasht is a large plain that is surrounded by mountains (Figure 1). This area is situated in Karkheh river basin with semiarid and arid climate in the west of Iran (Haghiabi and Mastorakis, 2009).

2.2 Stratigraphy and Geological Setting

The area is categorized geologically as part of the Folded Zagros Zone. Structure of the area was created by the upper Alpine rock's movements (Mohajjel and Fergusson, 2000, Mohajjel *et al.,* 2003) that have induced the folds as syncline and anticline structures with NE-SE trends (Farhoudi, 1981; Alavi, 1994; Berberian and King, 1981). The formations of the area according to their ages are as follows: Gourpi, Amiran, Talezang, Kashkan, Asmari, Shahbazan, Gachsaran, and Quaternary alluvial.

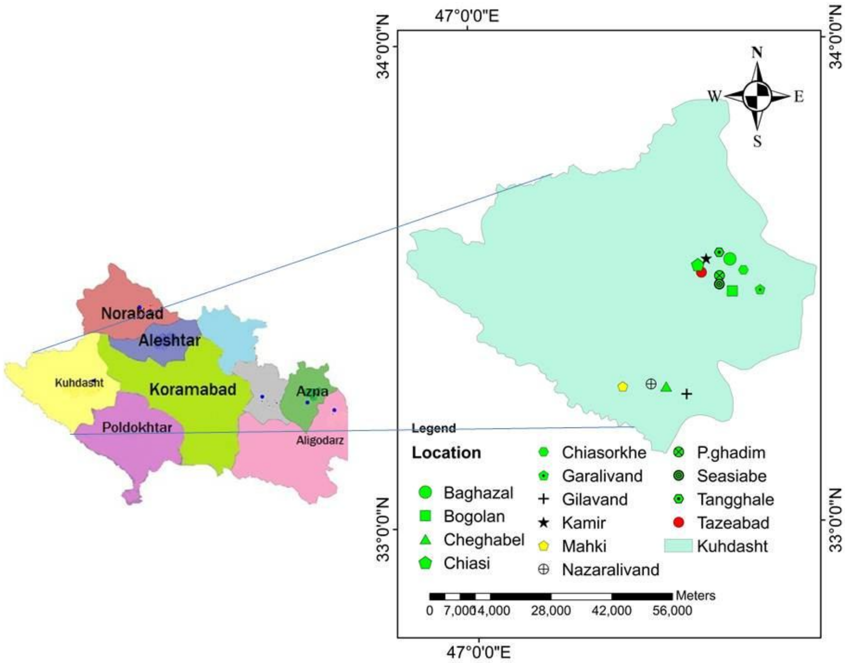


Figure 1. Geographical location of Kuhdasht region in Lorestan Province

In this study 140 samples from 14 springs and groundwater stations which were collected in Lorestan Regional Water Company were analyzed. The characterization of spring and groundwater samples has been evaluated by means of major ions, Ca^{2+}, Mg^{2+}, $HCO3^{-}$, Na^{+}, K^{+}, Cl^{-}, and $SO4^{-}$. For water type's identification, the chemical analysis data of the collected samples have been plotted on the Piper and Durov diagrams using AqQA Geochemistry Software, version 1.1.1 (Rockware AqQA Software, 2011). In addition, for the evaluation of water quality parameters, magnesium and salinity hazard, sodium adsorption ratio (SAR), sodium percentage (Na%), total hardness (as $CaCO_3$), and exchangeable sodium ratio (ESR), values of springs and groundwater samples were also determined using AqQA software and some mathematical calculations.

GIS software package of ArcGIS 10 and Geostatistical Analyst extension were used to interpolate, analyze, and map the water quality data in the study. For choosing the most variant of Kriging interpolation technique, the semivariogram models of Circular, Spherical, and Tetraspherical, were tested for different water quality parameters. The models' prediction performance were evaluated by cross-validation, and root mean square error criterion.

3. Results and discussion

Hydrochemistry of water samples examined for the analysis of water quality are presented in Table 1. The Schoeller, Willcox, Gibbs, Durov's, Piper, and Stiff diagrams have been analyzed. According to the Schoeller diagram (Figure 2), all water samples of the study area are located in the appropriate categories (Schoeller, 1964). Based on the Willcox, all water samples, clustered in the zone of good (Wilcox LV, 1955) (Figure 3). The Gibbs plots are employed to understand the processes which affect the geochemical parameters of springs and groundwater. These diagrams that represent the plot of log (TDS) versus ratios of $Na^+/(Na^++Ca^{2+})$ are widely used to assess the distinction between waters that are controlled by water-rock interactions i.e. leaching and dissolution, evaporation and precipitation (Gibbs, 1970). The water–rock interaction dominates the water chemistry of springs and groundwater. However, in this area, few spring and groundwater samples placed in the region of evaporation zone (Figure 4). Evaporation increases salinity by increasing Na^+ and Cl^- with relation to the increase of TDS. This is also observed by Piper plot, having significant increase of Na^+ in some spring and groundwater samples (Piper, 1944) (Figure 5) which may be attributed to the dissolution of evaporate minerals.

Post-classification change detection analyses showed that 'poor rangeland to barren land', 'poor rangeland to sand plates', 'barren land to poor rangeland', 'poor rangeland to agriculture', and 'barren land to agriculture' are the major land use/cover changes in the region (Figure 5). The changes 'poor rangeland to sand plates', 'poor range land to barren land', 'barren land to poor rangeland', 'poor rangeland to agriculture', and 'barren land to agriculture' indicate a high rate of degradation as well as a high rate of agricultural expansion (Table 2).

On the other hand, the change 'agriculture to poor rangeland' and 'agriculture to barren land' indicate a typical land abandonment pattern particularly in the study area. Thus as land has become less fertile and unproductive, subsistence farmers left it uncultivated, allowing for the regeneration of rangeland or barren land.

Table 1. Analysis of water quality parameters (ions in mEq per liter, TDS in milligrams per liter, and EC in micro-siemens per centimeter)

Sampling Locations	$SO4^-$	Cl^-	HCO^{3-}	K^+	Na^+	Mg^{2+}	Ca^{2+}	Na%	pH	TDS	TH	SAR	EC
Baghazal	3.4	0.6	4.8	0.1	0.7	3.4	4.8	7.9	7.5	603	409	0.4	918
Bogolan	1.1	1.2	6.0	0.0	2.2	3.1	3.0	26.7	7.5	562	306	1.3	862
P.ghadim	2.7	0.5	4.6	0.0	1.3	3.2	3.2	16.7	7.7	586	322	0.7	900
Tazeabad	5.1	1.6	6.1	0.0	1.7	4.8	6.3	16.2	7.5	841	555	0.8	1280
Tangghale	1.4	0.5	4.4	0.1	0.6	2.9	2.7	10.4	7.6	433	280	0.4	665
Cheghabel	0.8	0.7	4.4	0.0	0.4	2.8	2.7	6.6	6.9	379	275	0.2	592
Chiasorkhe	1.9	1.0	5.8	0.0	1.7	3.6	3.5	19.7	7.4	580	351	0.9	893
Chiasi	1.2	0.7	4.2	0.1	1.2	2.5	2.4	20.0	7.8	387	244	0.8	605
Seasiabe	1.8	0.9	4.7	0.1	2.0	2.8	2.7	25.6	7.7	539	276	1.2	826
Garalivand	1.6	1.2	6.6	0.2	2.4	3.5	3.3	25.9	7.7	642	341	1.4	1091
Kamir	0.9	0.9	5.0	0.1	1.1	2.9	2.8	15.8	7.7	479	286	0.7	738
Gilavand	0.3	0.8	4.2	0.0	0.7	1.8	2.8	14.5	7.8	339	225	0.5	531
Mahki	0.5	1.2	5.4	0.1	0.9	3.1	3.1	12.8	7.2	573	308	0.5	594
Nazaralivand	1.1	0.8	4.4	0.0	0.8	1.8	3.8	11.1	7.3	419	278	0.4	649

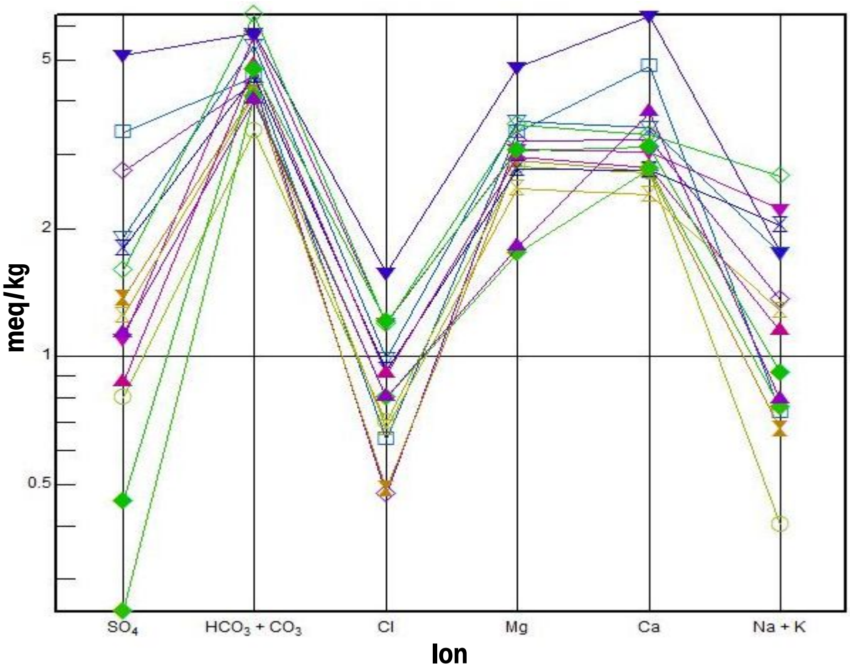


Figure 2. Position of water samples on the Schoeller diagram for drinking

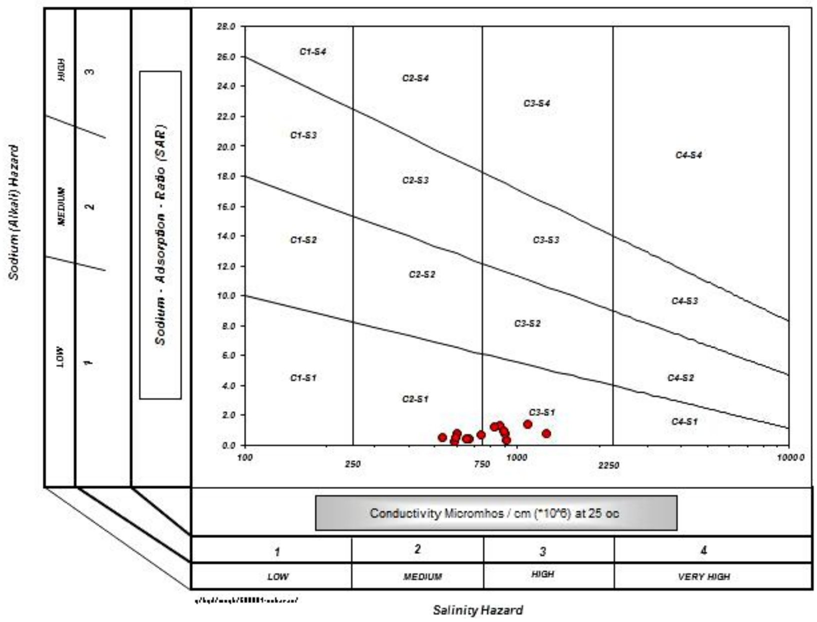


Figure 3. US salinity classification of springs and groundwater for irrigation

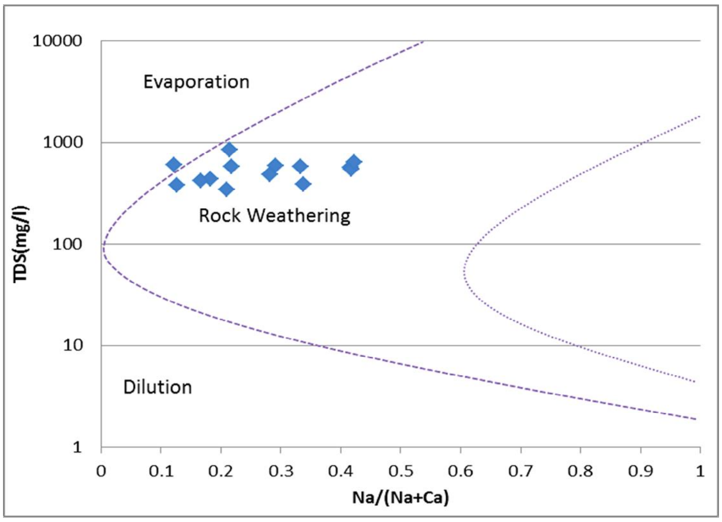


Figure 4. Gibbs diagrams showing the mechanism controlling water chemistry

Durov's diagram helps the interpretation of the evolutionary trends and the hydro-chemical processes occurring in the groundwater system, and can indicate mixtures of different water types (Durov, 1959). In Figure 5, samples fall in zone of low-salinity water (Ca–Mg–HCO_3 recharge water). In the higher salinity environment, the process of reverse ion exchange may create $CaCl_2$ waters due to the removal of Na^+ out of solution for bound Ca^{2+}. Alternatively, $CaCl_2$ type waters could also be a result of the mixing process between fresher water with more saline older water (Adams *et al.*, 2001). Piper plot showed that major water type is Ca-SO4 and HCO_3-CO_3 along with mixed type. The dominance of cation and mixed representation of Ca, SO_4 and HCO_3 is found. Durov diagram showed that the majority of the samples fall below 600 mg/l of TDS and are of alkaline nature.

A Stiff diagram that was developed by H.A. Stiff in 1951, is a graphical representation of chemical analyses. It is widely used by hydrogeologists and geochemists to display the major ion composition of a water sample. A polygonal shape is created from four parallel horizontal axes extending on either side of a vertical zero axis. Cations are plotted in mili equivalent per liter on the left side of the zero axis, one to each horizontal axis, and anions are plotted on the right side. Stiff patterns are useful in making a rapid visual comparison between water from different sources.

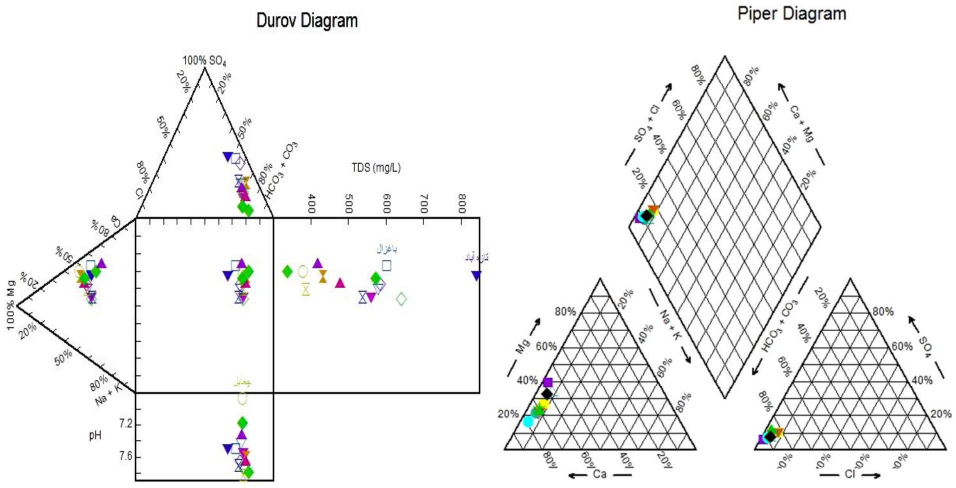


Figure 5. Durov's and Piper diagram of springs and wells for definition of groundwater chemical types

Stiff diagram (Figure 6) shows that the type of most springs and groundwater is Ca and HCO3 in major stations. The obtained results of analysis with AqQA are displayed in Table 2.

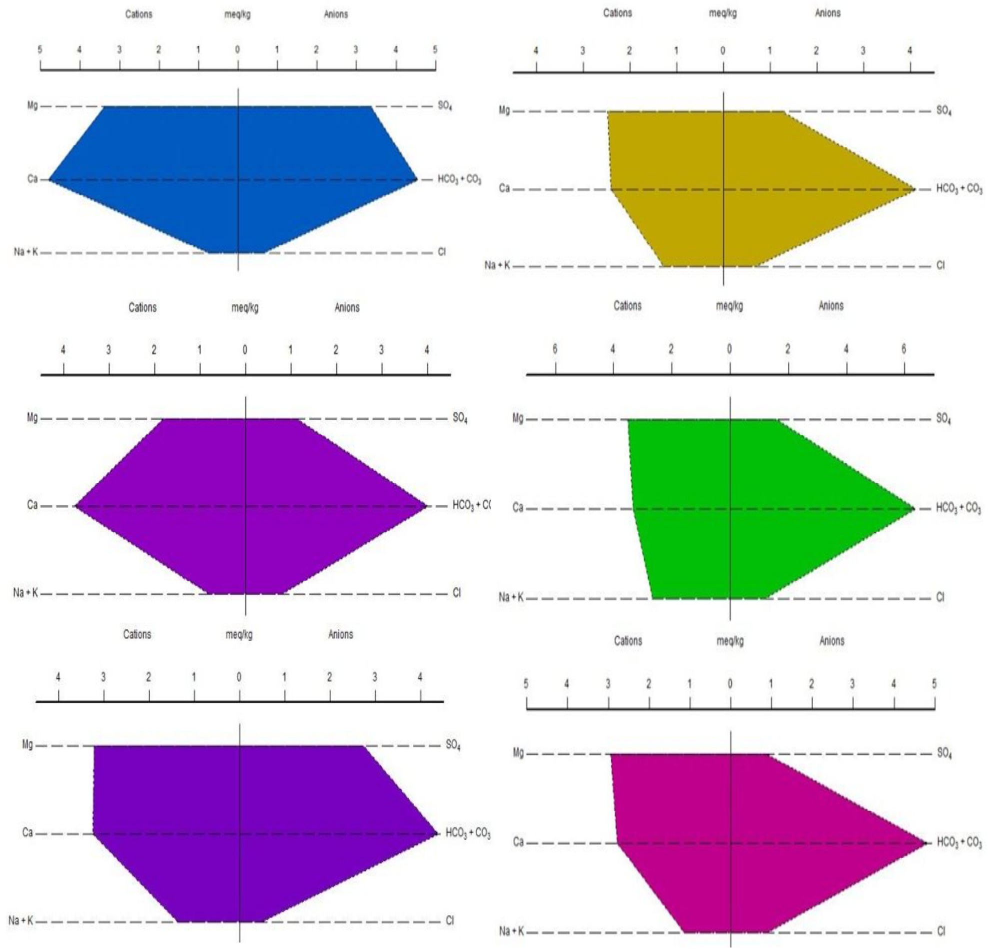
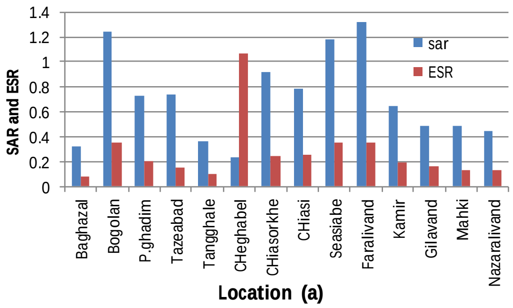


Figure 6. Stiff diagram of springs and wells for definition of groundwater chemical types

Table 2. Water quality parameters for springs and groundwater result of AqQA (ions in mEq per liter, TDS in milligrams per liter, and EC in micro-siemens per centimeter)

Location	Type	TDS	EC	Salinity hazard	SAR	ESR	Mg-hazard	TH
Baghazal	Ca-HCO_3	603.5	918.4	High	0.33	0.082	41.2	408.96
Bogolan	Mg-HCO_3	561.6	861.8	High	1.24	0.355	50.3	305.75
P.ghadim	Ca-HCO_3	585.71	900	High	0.73	0.206	49.8	322.12
Tazeabad	Ca-HCO_3	841.25	1280.3	High	0.734	0.156	43.1	555.1
Tangghale	Mg-HCO_3	433.1	664.6	Medium	0.363	0.109	51.4	280.23
Cheghabel	Mg-HCO_3	379	592	Medium	0.235	1.071	50.9	275.22
Chiasorkhe	Mg-HCO_3	580.4	893	High	0.92	0.246	50.8	350.8
Chiasi	Mg-HCO_3	387	604.7	Medium	0.786	0.252	50.8	243.95
Seasiabe	Mg-HCO_3	539.33	826.1	High	1.18	0.357	50.2	275
Garalivand	Mg-HCO_3	642.1	1090	High	1.32	0.357	51.3	341.5
Kamir	Mg-HCO_3	479.3	737	Medium	0.645	0.191	51.4	286.07
Gilavand	Ca-HCO_3	339	530.5	Medium	0.487	0.162	38.9	225.18
Mahki	Ca-HCO_3	572	594	Medium	0.49	0.14	49.6	307.75
Nazaralivand	Ca-HCO_3	418.5	649	Medium	0.45	0.135	32.4	277.72

The ratio between ESR and SAR has decreased significantly as shown in Figure 7. According to Figure 7, in most of the stations, when SAR increases, ESR increases too. In some stations, hardness is higher than 300 mg/l in Kuhdasht region which is high for water (Table 2). The amount of magnesium does not show a risk for it according to WHO (2008) (<50) (Figure 7).



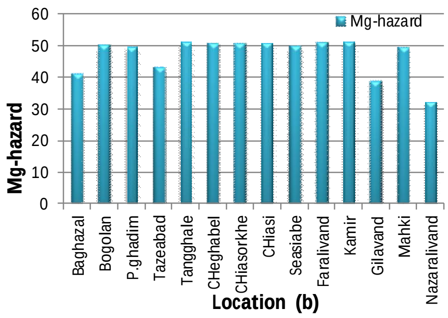


Figure 7. Ratio between SAR and ESR (a) and Mg-Hazard (mg/l) (b)

The results of the analysis of ANOVA test show that only for parameter Mg there is statistically significant difference between stations at 95% confidence level (significant<0.05) (Table 3). To compare the different quality parameters in the base of Baghazal station, LSD test comparison method is used. LSD test is used in ANOVA to create confidence intervals for all pairwise differences between factor level means while controlling the individual error rate to a user-defined significance level. The LSD test results show that the parameters of $So4^-$ in Bogolan, Tazeabad, Tangghale, Chiasi, Seasiabe, Faralivand, Gilavand, and Mahki; Cl^- in Bogolan, Tazeabad, and Faralivand; $HCO3^-$ in Bogolan, Tazeabad, and Faralivand; K^+ in Chaghabal and Faralivand; Na^+ in Tazeabad and Chiasorkhe; Mg^{2+} in Tazeabad; Ca^{2+} in Bogolan, P.ghadim, Tazeabad, Tangghale, Chiasorkhe, Chiasi, Faralivand, and Gilavand; Na% in Chiasorkhe, Chiasi, and Kamir; TDS in Tazeabad, Tangghale, Cheghabl, Chiasi, and Kamir; Th in Bogolan, Tazeabad, Tangghale, Chiasi, Chiasorkhe, Seasiabe, Gilavand, and Kamir; SAR in Bogolan, Tazeabad, Gheghabol, Chiasorkha, Chiasi, and Kamir; EC in Tazeabad, Tangghale, Chiasi and, Kamir have significant difference with Baghazal at 95% confidence level (significant< 0.05) (Table 4).

Table 3. ANOVA test for stations

Ion	F	Sig.
So^{4-}	4.162336	0.000
Cl^-	2.831684	0.001
$HCO3^-$	2.391739	0.007
K^+	2.333372	0.008
Na^+	5.219115	0.000
Mg^{2+}	1.722167	0.064
Ca^{2+}	6.242987	0.000
Na%	6.122793	0.000
TDS	2.941647	0.001
Th	4.082981	0.000
SAR	5.465597	0.000
EC	3.619643	0.000

Using GIS as a tool, different water quality parameters were studied by spatial interpolation over ArcGIS 10 platform. Schoeller diagram of water quality indicated that based on the results, the considered individual chemical parameters are not generalizable to the entire plain. Hence, to understand the spatial distribution of suitable and unsuitable areasusing spatial zoning, each of the five hydro-chemical parameters (Na^+, Cl^-, $So4^-$, TDS and TH) were studied both separately and in combination. In order to provide agricultural water quality, study area zoning techniques was used. Among different variants of the Kriging interpolation technique, OK was chosen as the most suitable method based on the root mean square error of the cross validation in this region. First, EC and SAR values maps were obtained, and then irrigation map was classified into two categories obtained from combining these two maps (Figure 8). The zonation map of the study area (Figure 8, right) shows that the quality of water in most parts of the study area is medium, a small part is suitable, and a very small part of the area is not suitable for the drinking propose (Figure 8, left). Irrigation water zonation map shows that the entire area under studyhas good quality and favorable for the agriculture (Figure 8, left).

Table 4. LSD test results of comparison between water quality parameters of different stations and Baghazal station as control group.

ION	So4$^-$	Cl$^-$	HCO3$^-$	K$^+$	Na$^+$	Mg^{2+}	Ca^{2+}	%Na	TDS	Th	SAR	EC
Location Sig	Baghazal	Baghazal	Baghazal	Baghazal	Baghazal	Baghazal	Baghazal	Baghazal	Baghazal	Baghazal	Baghazal	Baghazal
Bogolan	0	0.002	0.01	0.55	0.16	0.51	0	0.9	0.52	0.01	0.02	0.54
P.ghadim	0.44	0.48	0.66	0.52	0.08	0.78	0	0.023	0.83	0.09	0.08	0.879
Tazeabad	0.02	0	0.02	0.46	0.007	0.01	0.007	0.028	0.003	0.003	0.03	0.001
Tangghale	0.004	0.46	0.37	0.92	0.85	0.34	0	0.45	0.02	0.005	0.82	0.01
Cheghabel	0.08	0.16	0.57	0	0.96	0.46	0.11	0.91	0.1	0.11	0	0.11
Chiasorkhe	0.124	0.19	0.14	0.48	0.01	0.77	0.04	0.008	0.81	0.32	0.023	0.85
Chiasi	0.04	0.89	0.41	0.76	0.23	0.22	0.001	0.01	0.04	0.01	0.11	0.03
Seasiabe	0.007	0.084	0.84	0.79	0.2	0.14	0.46	0.38	0.27	0	0.06	0.27
Faralivand	0.025	0.015	0	0.01	0.09	0.81	0	0.81	0.62	0.17	0.181	0.132
Kamir	0.07	0.079	0.6	0.57	0.08	0.25	0.93	0.001	0.02	0	0.03	0.02
Gilavand	0.02	0.68	0.53	0.62	0.92	0.1	0.03	0.31	0.06	0.04	0.68	0.05
Mahki	0.03	0.16	0.54	0.82	0.76	0.74	0.08	0.45	0.82	0.25	0.67	0.11
Nazaralivand	0.11	0.68	0.67	0.74	0.89	0.11	0.28	0.62	0.19	0.14	0.81	0.18

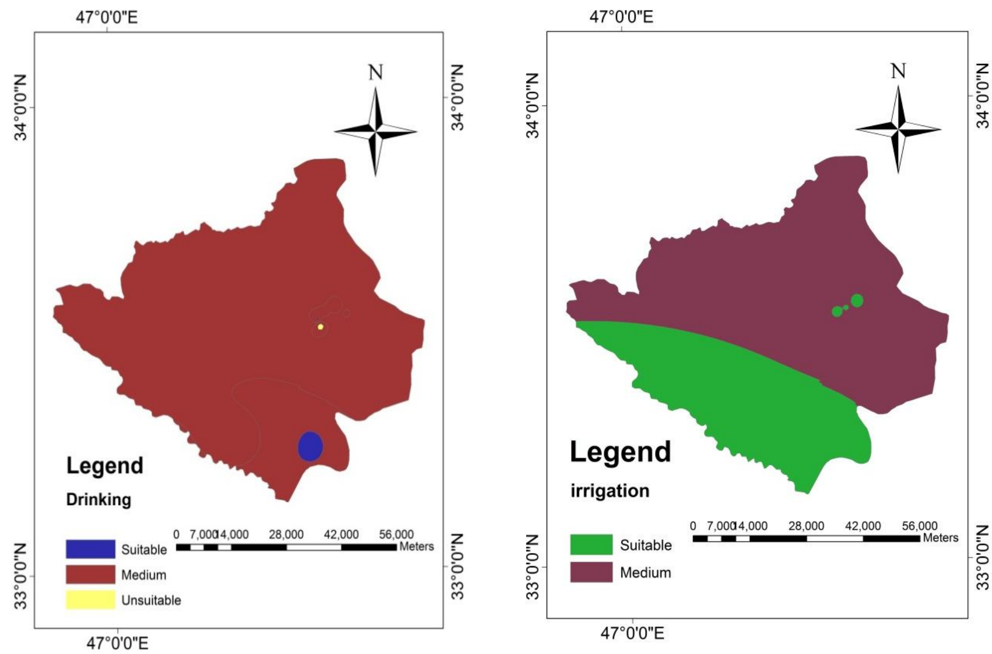


Figure 8. Mapping of water quality for drinking (left) and irrigation (right)

4. Conclusion

Groundwater and spring waters of Kuhdasht region, west of Iran, were examined to evaluate its quality for drinking and irrigation purposes**.** The results of hydro-chemical analyses showed that the springs and wells' water in the study area are considered almost fresh for drinking and irrigation. The types of water that dominates in the study area are CO_3-HCO_3 and mixed facies between Ca–Mg and Ca–SO_4. Gibbs diagrams suggested that the main mechanism that controls water chemistry in this area is water–rock interaction. Based on US salinity diagram, most of the water samples in Kuhdasht region locate in C2–S1 class indicating medium salinity and low sodium content class. Nevertheless, some spring samples fall in the C3–S1 class. Concerning the Na% parameter, most of the waters of the spring and wells in the study area were classified as medium to suitable for irrigation. The results of physico-chemical analyses and the calculated water quality parameters showed that most of the water samples in this area were recognized to be medium and suitable for drinking and irrigation purposes. Moreover, this study evaluated the groundwater parameters variations in Kuhdasht region using spatial geo-statistics in GIS.

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