



## The Impact of Geological Units on the Ground waters Quality of Hastijan, Southeastern of Delijan, Iran

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### Abstract

This study was conducted to evaluate the quality of the ground waters and the impact of geological units on these waters in Hastijan area. For this purpose, 11 samples of water resources were collected with appropriate dispersal. Physico-chemical parameters of Mn, Ni, Cd, Cu, Zn, As, Fe, Cr, and ions  $K^+$ ,  $Na^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Cl^-$ ,  $So_4^{2-}$ ,  $Hco_3^-$  as well as indicators TH, TDS, EC, and pH were determined. In order to assess water quality, the Piper diagram, Gibbs diagram, sodium absorption ratio (SAR), chloro alkaline index (CAI), the saturation index (SI), heavy metal pollution index (HPI), and the metal index (MI) were used. Investigating surrounding rocks of the area showed the existence of limestone, dolomite, sandstone, marl, and shale with layers of gypsum have declined the quality of water and have specially increased the salinity and concentration of  $Na^+$  and  $Cl^-$  in groundwater resources of the study area. The calculation of saturation index indicated that these waters are super-saturated toward the dolomite and calcite minerals, but under-saturated toward sulfate minerals. The iron concentration was higher than the standard limits of 0.2 ppm in about half of the samples that was caused by iron-bearing sandstones of Zaigun and Lalun formations located just upstream of springs.

**Keywords:** Groundwater quality, Physico-chemical parameters, Geological units, Drinking water, Hastijan area, Delijan

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## 1. Introduction

Personal and public hygiene, as well as quality of drinking water are among the major issues of public health. Initially water is pure, clear, and generally without contaminants; however, most of the added infections usually are caused by human interference. Advancements and industrialization of societies have been generating various toxins entering our environment, particularly into water resources, reducing their quality.

The quality of water for our health is so important that the World Health Organization (WHO, 2008) noticed the gravest public failure of the 20th century is the lack of access to safe and adequate drinking water (Safari and Vaezi, 2003). The study of hydro-chemical system of the flow of groundwater usually takes place based on the comprehensive information of groundwater chemistry which is influenced by different factors such as the geology of the surrounding environment, rock type, the amount of rocks weathering, the quality of nutritional water into aquifer, and the hydro-geochemical reactions (Guler 2004; Subramanie *et al.*, (Date) Coetsiers and Walraevens, 2006).

Identification of hydro-chemical processes helps advise on usage of the groundwater resources. So, the qualitative and quantitative management of the groundwater resources has been paid much attention to lately (Foster and *et al.*, 2000; Olajire and Imeokparia, 2001; Nagaraju *et al.*, 2016).

Many elements in acidic pH are normally soluble and fluid, so that raising their concentration can contribute to extensive pollution as well as poisoning of plants. Various studies show that the high spread of limestone results in the enhancement of calcium and bicarbonate concentrations rather than other cations and anions (Hounslow, 1995). In areas including quartzite sands-bearing alluvial deposits, many anions and cations are dissolved in water compared with other regions (Vissers 2006). In areas that spread of easily weathered rocks are dominant, the anions and cations' concentration such as calcium, magnesium, sodium, potassium, sulfate, and chloride increases, and as a result, the quality of the water declines significantly (Vanderperk, 2006).

Mineralogical composition of geological formations has a great effect on the groundwater's quality, as it may result in the generation of harmful chemicals in groundwater leading to deterioration of concrete lining of tunnels. Ghobadi and *et al.*, (2016) studied the future problems of the corrosiveness of concrete due to groundwater chemistry along Tabriz metro line 2 (TML2) in Iran.

Hastijan village located in the center of Iran is prone to underground water pollution. In the study area, some diseases have been reported (Department of Water Affairs, Markazi Province, 2002). One of the probable causes of these diseases may be related to the pollution of underground resources. In this area no quantitative and qualitative study had been done before in relation to water

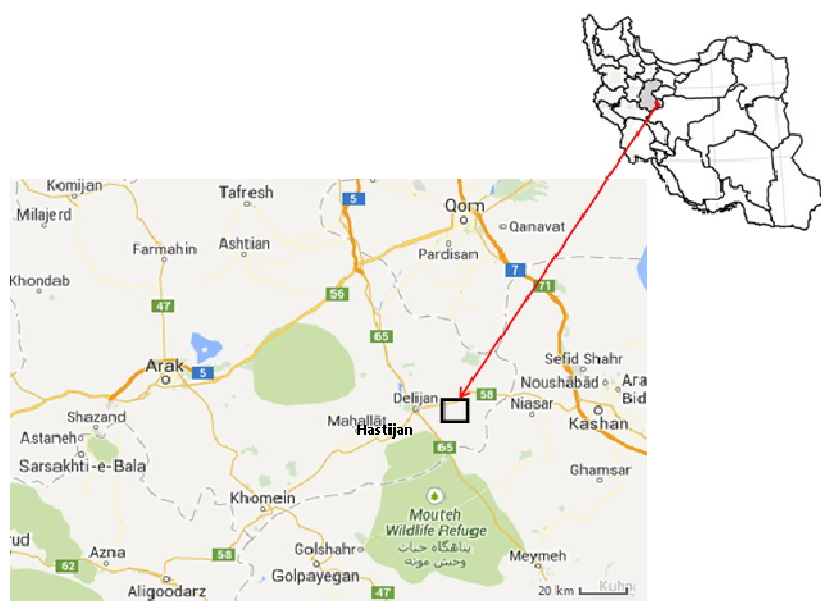
resources and their quality. Therefore, the present study is the first scientific research regarding the issue in this area.

## 2. Materials and methods

### 2.1. Study Area

Hastijan area is located on 15 km south-southeastern of Delijan, a city that ranges between longitudes  $50^{\circ} 43' 55''$  to  $50^{\circ} 47' 29''$ E and latitudes  $33^{\circ} 49' 02''$  to  $33^{\circ} 52' 02''$ N. Its highest point is about 2520 meters above the sea level. Topographic gradient changes from moderate to mild. Mean annual precipitation is about 187.5 mm, and the highest and lowest recorded annual average temperature is 20.1 and 5.9 ( $^{\circ}$ C) respectively. A common source of drinking water, agriculture, and animal husbandry in Hastijan is underground waters which are provided by wells, aqueducts, and springs.

Hastijan is one of the areas where the risk of underground water contamination has been reported (Department of Water Affairs, Markazi Province 2002). From the point of accessibility, the area is accessible through two roads; one is through the road of Delijan to Mahallat and Khomein passing northern part of the zone, and the other is Delijan to Isfahan highway that is located in the eastern part of the region, as shown in Figure 1.



**Figure 1.** The location of the study area.

## 2.2. Geology and Hydrogeology

From the geomorphological standpoint, the study area can be divided into vast plains and mountains. At the height, the steep walls are mainly made of limestone and dolomite; however, in the vast plain at the foothills repeatedly Eocenes formations and stones, and tuffites are exposed. Kahar formation is the oldest non-metamorphic series existing in north of Muteh. In the northern part of the region, Soltanieh dolomite is covered by a series of red and green shales. Permian formations are located directly on Paleozoic formations (Mila, Lalun, Soltanieh and Kahar), and then the Precambrian metamorphic is situated. Orbitolina limes in the study area are often exposed in solid masses or crushed (Aghanabati, 2004). In some areas, Qom formations are located on Soltanieh dolomite and Permian formations. Permian limestones and Soltanieh dolomite limestones have been fractured and are able to conduct rainfalls (Figure 2).

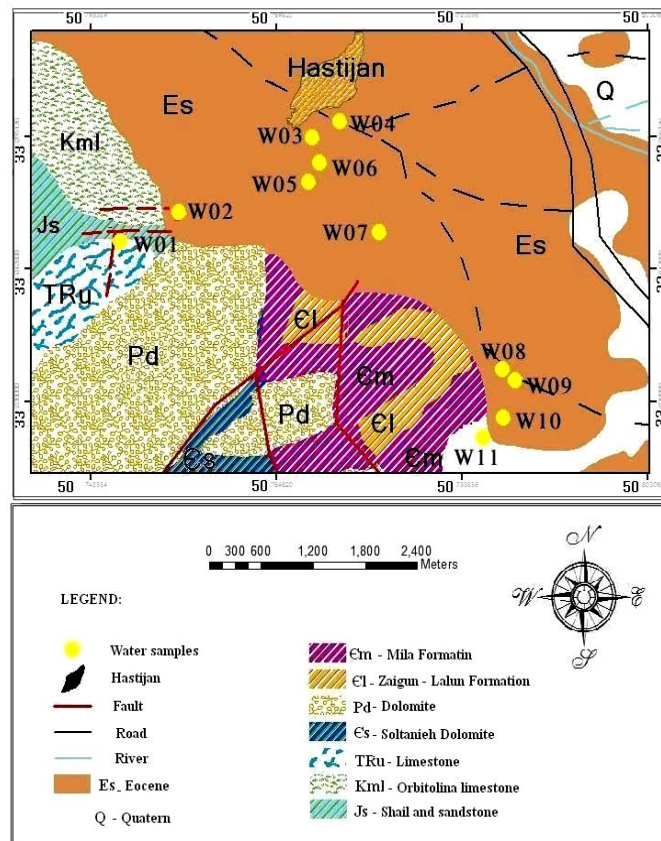


Figure 2. Geological map associated with the location of the sample points

The main river called the Shoor River lies in the northeastern parts of the region which originates from high altitude of Muteh and eventually reaches Panzdah-e-Khordad dam (Figure 3).

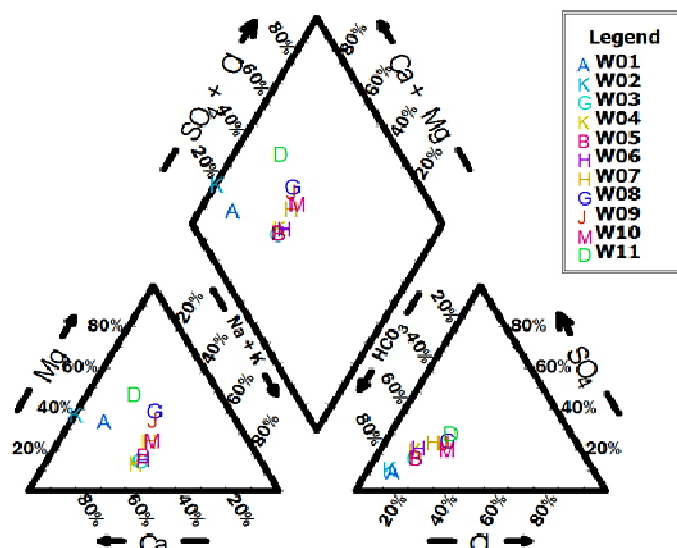


Figure 3. The study area, (the arrows show ground water direction)

First of all, geological and hydro-geological conditions of the aquifer were examined in order to analyze the quality of groundwater of Hastijan area. Then, various regional water formations were investigated from the standpoint of their impact on the quality of water. Finally, the sampling was done from water resources; since there is no surface water in the study area, the activity was limited to the ground waters.

To this aim, 11 water samples were collected from which 2 samples were from the wells, 4 samples from the aqueducts, and 5 samples from the springs. As there is no significant change in the water resources discharging in the study area during the whole year, sampling has only been done once in December 2013.

Parameters such as water temperature, pH, and EC were measured in situ. However, to specify the presence of the major ions and the chemical analysis of ground waters, all other collected samples were analyzed in the laboratory in accordance with WHO (2008) and National Iranian standards-1053(1992), (Table 1 and 2).

This study also examines the quality of the existing water resources of the region for various purposes through the interpretation of the diagrams, ratios, existing indicators, and by comparison with the global standards.

**Table 1.** The concentration of major cations and anions of water samples in the study area

Sample No.	pH	E.C μs/cm	T.H mg/l	T.D. S	HCO <sub>3</sub> <sup>-</sup> (ppm)	Cl (ppm)	SO <sub>4</sub> <sup>2-</sup> (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)
W01	7.15	560	1145	240	320	26	34	70.6	29.5	22	0.5
W02	6.17	2100	1160	1365	1100	74	132	284	67.7	100	1.3
W03	7.44	957	302	498	391.7	53.52	80.21	90.78	18.23	80.45	2.737
W04	7.32	962	318	510	401	53.13	102.24	98.65	18.21	84.42	3.312
W05	7.64	861	267	447	349	52.46	72.04	74.75	19.45	73.56	2.737
W06	7.34	973	299	505	372.18	52.11	102.3	87.57	19.45	85.05	3.128
W07	7.94	585	187	304	195.85	40.765	69.165	44.89	18.23	48.275	2.346
W08	7.1	612	240	338	195.5	56.5	77.8	42.07	26.74	51.04	2.54
W09	7.68	618	198	322	195.85	57.6	76.42	41.32	29.41	50.78	2.62
W10	7.56	614	194	319	195.85	58.49	63.36	45.7	19.45	51.72	2.737
W11	7.5	609	247	336	172.66	53.17	85.01	40.08	35.74	25.286	2.346
ISIRI1053	6.5-9	—	500	1500	—	400	400	—	—	200	—
WHO2008	6.5-8.5	—	500	1000	—	250	250	—	—	200	—

**Table 2.** The concentration of water resources heavy metals in the study area (ppm)

Sample No.	Fe	F	Cr	Mn	Ni	As	Hg	Pb	Cd	Zn	Cu
W01	0.035	0.39	ND <sup>a</sup>	0.006	ND	ND	ND	ND	ND	0.126	ND
W02	0.044	0.65	0.007	0.007	ND	ND	ND	ND	ND	0.021	0.008
W03	0.03	0.39	0.003	0.005	0.005	ND	ND	0.005	0.003	0.006	0.007
W04	ND	0.4	0.006	0.005	0.005	ND	ND	ND	ND	0.005	0.005
W05	0.01	0.61	0.003	0.01	0.006	ND	ND	0.001	0.001	0.005	0.005
W06	0.01	0.49	0.003	0.005	0.005	ND	ND	0.001	0.003	0.008	0.005
W07	0.24	0.54	0.003	0.009	0.004	ND	ND	ND	ND	0.005	0.007
W08	1.2	0.5	0.003	0.008	0.005	ND	ND	0.001	0.001	0.005	0.006
W09	1.3	0.55	0.003	0.007	0.004	ND	ND	0.001	0.001	0.005	0.005
W10	3.8	0.65	0.004	0.067	0.004	ND	ND	0.005	0.002	0.007	0.008
W11	3.2	0.6	0.002	0.02	0.001	ND	ND	0.001	0.001	0.005	0.006
ISIRI 1053	—	1.5	0.05	0.4	0.07	0.01	0.006	0.01	0.003	—	2
WHO 2008	0.2	1.5	0.05	0.4	0.07	0.01	0.006	0.01	0.003	3	2

<sup>a</sup>ND stands for NO Data

### 3. Results and Discussion

#### 3.1. Evaluation of the Hydro-chemical Characteristics

Table 1 shows statistical values of Physico-chemical parameters of groundwater samples of the area under study. The results show that the electric conductivity (EC) of water resources in the region changes between 560-2100 micromhos per centimeter. Examining the anions and cations concentration in the groundwater, the study suggests existing anionic and cationic conditions as followed:  $Mg^{2+} > Ca^{2+} > Na^+ > K^+$  and  $HCO_3^- > SO_4^{2-} > Cl^-$ . The expansion of carbonate minerals in the area of Hastijan and dissolution of carbonate minerals are the main sources of  $Mg^{2+}$  and  $Ca^{2+}$  in the groundwater. Also the high concentration of  $HCO_3^-$ , as the main anion, is mainly due to erosion and weathering of carbonate minerals. Conditions such as geology, climate, velocity, groundwater flow paths, and the rocks' type through which water passes effect on the concentration of Ca, K, Na,  $HCO_3^-$ ,  $CO_3^{2-}$ ,  $SO_4^{2-}$  and Cl. The amount of EC and total dissolved solids (TDS) in the water

samples are lower than those of the international standards. However, only sample W2 shows a bit higher EC level and a higher concentration of calcium, magnesium, bicarbonate, and carbonate; this might be caused by faults and dolomite formation in the vicinity of the well.

Regarding water hardness values (Todd, 1985), Table 3 demonstrates that samples W05, W06, W07, W08, W09, W10 and W11 are in the category of hard while W01, W02, W03, and W04 are classified as very hard.

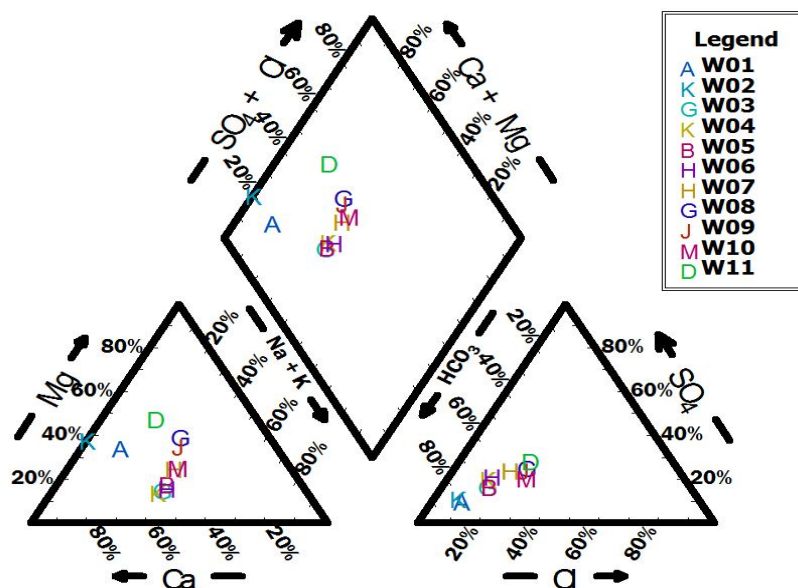


Figure 4. Piper diagram of water resources in the study area

Table 3. Classification of water hardness values (Todd, 1985)

TH mg/l (CaCO <sub>3</sub> )	Water
75>	Soft
75-150	Relatively hard
150-300	Hard
300<	Very hard

### 3.1. The Type and Facies of the Water Resources

Piper diagram (Piper1944) was used to determine the types and facies of the ground waters. As shown in Fig 4, the water resources of the area fall into three different types. From north to south of the area, water resources include bicarbonate calcic in samples W01, W02, W03, W04, W05, W06, and W07, bicarbonate sodic in samples W08 and W10, and bicarbonate magnetite in samples W09 and W11. Since the types and facies of most waters are bicarbonate calcic and

magnetite, waters contain temporary hardness and hold higher levels of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  concentration than those of  $\text{Na}^+$  and  $\text{K}^+$ ; also  $\text{HCO}_3^-$  concentration is higher than that of  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$ .

### 3.1. Classification of the Ground waters for Various Uses

#### 3.1.1. Determining the Drinking Water Quality

Using Schoeller's diagram (Schoeller, 1967) which projects the standards of drinking water for human beings on a map of water resources of the area, drinkability is affected by different parts of the aquifer.

Schoeller's diagram (Schoeller, 1967) is only based on solute and ions required for the body which has been set up according to the international scientific research centers (Moghimi, 2005). It is worth noting that in this division, bacteria and toxic elements such as arsenic are ignored. Figure 5 shows Schoeller's diagram (Schoeller, 1967) for the water resources in the study area. In Table 4 the percent of each class of the Schoeller's classification (Schoeller, 1967) has been compared for drinking usages in the whole study area. Evaluation of the ions' concentration in water indicates that their level is desirable and acceptable in most samples and is considered good, medium, and acceptable for drinking.

**Table 4.** Schoeller's classification for each classes of the entire area (Schoeller, 1967)

class of water	TDS	TH	PH	Na	Cl	$\text{SO}_4^a$
Good	72.73	45.45	45.45	100	100	100
Acceptable	18.18	45.45	27.27	0	0	0
Average	9.09	9.09	18.18	0	0	0
Inappropriate	0	0	0	0	0	0
Quiteunpleasant	0	0	0	0	0	0
non-potable	0	0	9.1	0	0	0

<sup>a</sup>Concentrationsin meq/l

#### 3.1.2. Determining Water Quality for Agriculture

To classify the agricultural use of water in the study area, Wilcox diagram (Wilcox, 1995) is used that demonstrates EC and sodium adsorption ratio (SAR); (see Figure 6). High concentration of salt will cause soil salinity and high amount of sodium leads to the production of alkali soils and deficiency of calcium which ultimately turns the soils to be impermeable and the area becomes uncultivable. The risk of high level of sodium and salinity in water are two important criteria for the classification of water for agricultural purposes (Sedaghat, 2003). Therefore, for agricultural use, low amount of salt (or SAR) is recommended in water.



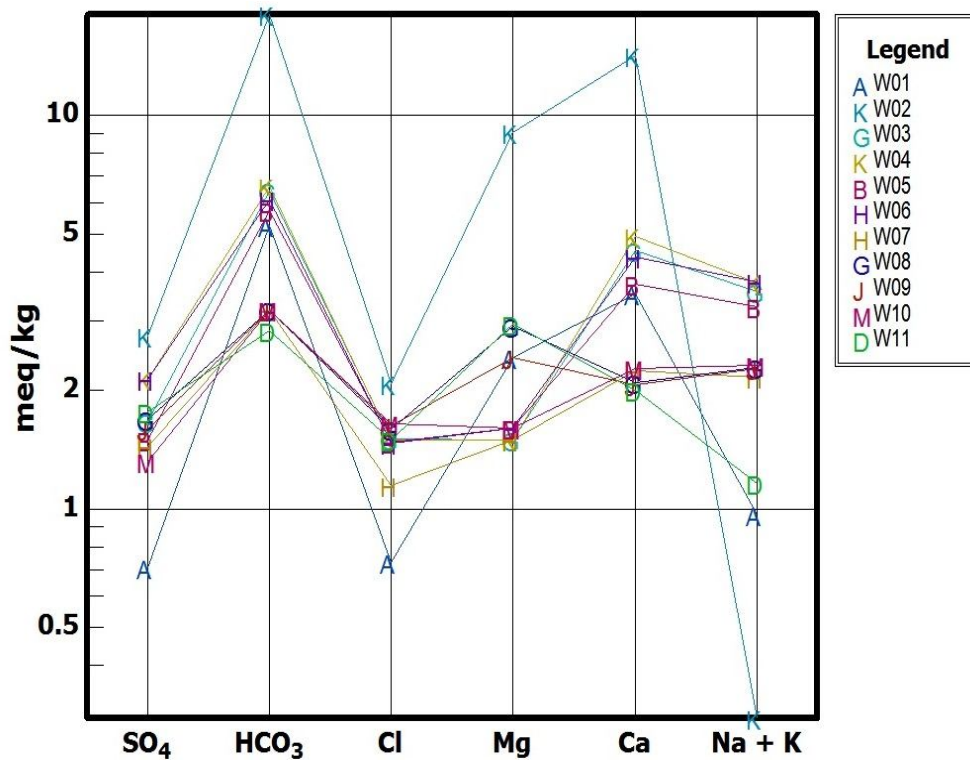
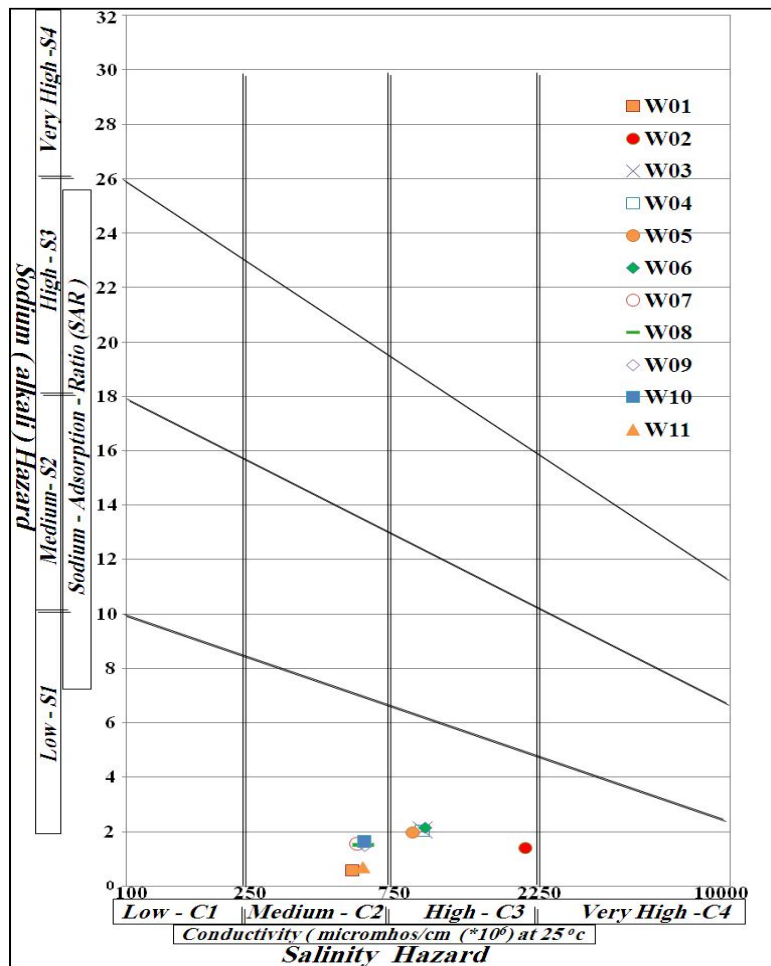


Figure 5. Schoeller’s diagram of water resources in the study area (Schoeller, 1967)

The other risky parameter is bicarbonate in agricultural waters expressed by residual sodium carbonate (RSC). The high concentration of bicarbonate can disrupt the vegetation growth, increase soil permeability, and reduce soil erosion. In view of that, water with RSC r more than 2.5 milli eqivalan per liter (meq/l) is inadequate for irrigation. Based on Wilcox’s (1995) chart, samples W07, W08, W09, W01, W11, and W10 fall in class C2-S1 and are in the scale of 55.54%, which represents smaller amount of salt in water. On the other hand, samples W02, W03, W04, W05, and W06 are classified as C3-S1 and are in the scale of 45.45% meaning the water is salty and unusable for agricultural consumption. Wilcox’s classification, (RSC) and water classes for the study area are shown in Table 5.

**Table 5.** Classification of water quality for agricultural purposes in the study area

Sample No.	RSC (meq/l)	EC (µs/cm)	SAR	RSC (meq/l)	Quality based on RSC (meq/l)	Class	Water quality for agriculture purposes
W01	-0.7	560	0.56	-0.7	suitable	C2-S1	Slightly salty-good
W02	-1.52	2100	1.39	-1.52	suitable	C3-S1	Salty-usable
W03	0.39	957	2.02	0.39	suitable	C3-S1	Salty-usable
W04	0.15	962	2.05	0.15	suitable	C3-S1	Salty-usable
W05	0.39	861	1.96	0.39	suitable	C3-S1	Salty-usable
W06	0.13	973	2.14	0.13	suitable	C3-S1	Salty-usable
W07	-0.53	585	1.54	-0.53	suitable	C2-S1	Slightly salty-good
W08	-1.1	612	1.51	-1.1	suitable	C2-S1	Slightly salty-good
W09	-1.27	618	1.48	-1.27	suitable	C2-S1	Slightly salty-good
W10	-0.67	614	1.62	-0.67	suitable	C2-S1	Slightly salty-good
W11	-2.11	609	0.7	-2.11	suitable	C2-S1	Slightly salty-good



**Figure 6.** Wilcox diagram of water resources in the study area (Wilcox, 1995)

### 3.1.3. Determining Water Quality for Industrial Use

To use water for industrial purposes, depending on the type of industry, water must have certain standards. One of these is the calculation of Langelier Saturation Index ( $I_s$ ) represented below (Aghazadeh *et al.*, 2008):

$$IS = pH - pH_s \quad (1)$$

Where  $pH$  is the real measured value of the water acidity evaluated in situ, and  $pH_s$  is in a state of saturation in which pH levels as an indicator of saturation state can be calculated by the following relationship:

$$pH_s = C + P_{ca} + p_{alk} \quad (2)$$

Where  $C$  is a constant parameter depending on temperature,  $P_{ca}$  and  $p_{alk}$  are the negative logarithm of the concentration of  $Ca^+$  and the water alkalinity, respectively.

If Langelier index is negative, water is corrosive meaning it is under-saturated and tends to dissolve solid calcium carbonate; however, if the index indicates zero, water is balanced, and the positive index shows that water is super-saturated and tends to precipitate a layer of calcium carbonate (Moghimi, 2005). According to the results shown in the Table 6, samples W01, W02, W04, W06, W8, W09, W10, and W11 are rated as corrosive which may reduce life expectancy of pipes and even cause their fracture. Samples W07, W03, and W05 cause sedimentation in and damage to water pipes as well as water supply facilities.

**Table 6.** Classification of water for industrial purposes in the study area

Sample No.	pH	pHs	pHs-PH	Factor C	Ca(mg/l)	Alkalinity by CaO	Water quality for industrial purposes
W01	7.15	8.1	0.95	11.28	70.46	22.479	Corrosive
W02	6.17	6.9	0.73	11.32	279.44	100.947	Corrosive
W03	7.44	7.4	-0.04	11.29	90.6	83.23	Sedimentation
W04	7.32	7.4	0.08	11.29	98.4	84.8	Corrosive
W05	7.64	7.5	-0.14	11.29	74.6	76.33	Sedimentation
W06	7.34	7.4	0.06	11.29	87.4	88.22	Corrosive
W07	7.94	7.9	-0.04	11.28	44.8	50.64	Sedimentation
W08	7.1	7.9	0.8	11.28	42	53.556	Corrosive
W09	7.68	7.9	0.22	11.28	41.22	53.443	Corrosive
W10	7.56	7.9	0.34	11.28	45.6	54.48	Corrosive
W11	7.5	8.2	0.7	11.28	40	27.64	Corrosive

## 3.2. The reciprocal relationship between water and surrounding rocks

### 3.2.1. Gibbs's Diagram

Gibbs's diagram (Gibbs, 1970) is used (Subbarao2001) to determine the composition of major ions in the groundwater, to evaluate the lithological effect of rocks on water resources, and to establish the mechanism governing the flow of water. Based on Figure 7, water samples of Hastijan area mainly appear in the area of the diagram with dominant rock-phenomenon. This reflects an interaction

between the chemistry of surrounding rocks and ground waters originating from meteoric waters. The study shows only sample W02 is in the area of the diagram that evaporation and crystallization process are dominant and that an increase of TDS in the samples could be the result of perturbations in the aquifer.

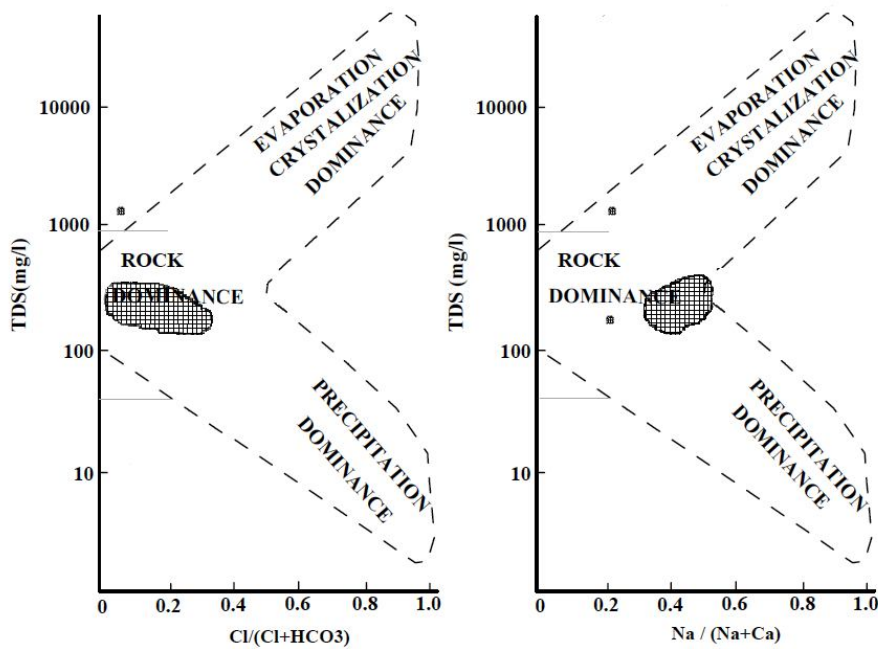


Figure 7. The position of the studied water samples on the Gibbs diagram

### 3.3. Ratio of Reagents

For determining the type of reservoir rock in the groundwater, the ratio of some reagents can also be used in addition to the results of geological and geophysical surveys and drilling and well logging studies. According to Table 7, to show the degree and purity of limestone and dolomite, reagents ratio of  $mCa^{+2}/mMg^{+2}$  is used ( $m$  is molarity of the respective fitted ions).

A molar ratio of calcium to magnesium less than 1 represents dolomite reservoir rocks, and ratios 5 to 8 represent limestone reservoir rocks; ratios higher than 8 indicate pure limestone reservoir or even gypsum impurities. For the ratios less than 1, the water is saturated with calcium carbonate which causes the precipitation of calcium carbonate and travertine in the dolomite reservoir rocks (Moghimi, 2005).

**Table 7.** The relationship between ratio of reagents and reservoir rock in the study area

Sample No.	Reagent ratios			Reservoir rock
	Na/Ca	Ca/Mg	Non-equilibrium of chlorine and alkaline	
W01	0.27	1.46	-0.32	Dolomite limestone
W02	0.1	2.51	-0.94	limestone Dolomite
W03	0.25	3.02	-1.36	limestone Dolomite
W04	0.25	3.28	-1.45	limestone Dolomite
W05	0.25	2.33	-1.21	Dolomite limestone
W06	0.28	2.73	-1.57	limestone Dolomite
W07	0.22	1.49	-0.88	Dolomite limestone
W08	0.14	0.95	-0.43	limestone Dolomite
W09	0.14	0.85	-0.41	Dolomite
W10	0.15	1.43	-0.41	Dolomite limestone
W11	0.23	0.68	0.03	Dolomite

### 3.3.1. Chlorine Alkalinity Index

Evaluation of how the quality of water changes and how a source of groundwater exchanges ions with the surrounding environment in its course of flow is conducted in hydro-geochemical studies (Aastri, 1994). For these purposes, the chlorine alkalinity index (CAI) was proposed by Schoeller (1967). This is the indicator of ion exchange between ground waters and the surrounding environment.

When there is an ionic exchange between sodium and potassium in the groundwater and the magnesium or calcium found in the host rock, the CAI value is negative. As shown in Table 7, this index is negative in the studied samples and varies from -0.32 to -1.57 with the average of 0.795, except for sample 11 which is 0.03 and represents a lack of sodium and potassium exchange of water with calcium or magnesium in the aquifer material resulting in the reduction of the amount of sodium in water.

Considering calcium to magnesium ratio and chlorine and alkaline disequilibrium index, it can be said that the type of rock reservoir in samples W01, W05, W07, and W10 is dolomitic limestone, in samples W02, W03, W04, and W06 is calcareous dolomite, and lastly in samples W08, W09, and W11 is also dolomitic.

### 3.3.2. Saturation Index

With regards to the impact of lithological formations on the groundwater resources, the saturation indexes (SI) are studied for different minerals. For these purposes, PHREEQC software (Parkhurst and Appelo, 1999) was used (Piper, 1944). The following equation was used to evaluate saturation index for different minerals:

$$SI = \log \frac{IAP}{K_{sat}} \quad (3)$$

where  $SI$  is the saturation index,  $IAP$  is the level of dynamics and immobility of minerals, and  $K_{sat}$  is solubility constant. When the water is saturated ( $SI = 0$  and  $IAP = K_{sat}$ ), and  $SI < 0$ , there is an under-saturation condition. For  $SI > 0$ , it indicates super-saturation in relation to a mineral. Saturation index depending on the type of mineralogy, pH, TDS, and temperature can be changed.

Saturation index for various minerals have been used to assess whether there is a balance between water and minerals. This means that the changes in water saturation with respect to various minerals identify geochemical reactions controlling water chemistry (Jalali, 2006; Langmuir, 1997).

According to Figure 8, saturation index for the common minerals such as halite, calcite, dolomite, magnetite, gypsum, and anhydrite, in a number of studied samples were lower than zero and water samples were under-saturated in relation to the mentioned minerals. In the samples W03, W04, W05, W06, W07 and W09, dolomite saturation index was 0.44, 0.22, 0.73, 0.19, 0.66, and 0.28 while calcite saturation index was 0.43, 0.34, 0.52, 0.28, and 0.39 which represents the super-saturation of water in relation to calcium, bicarbonate, and magnesium.

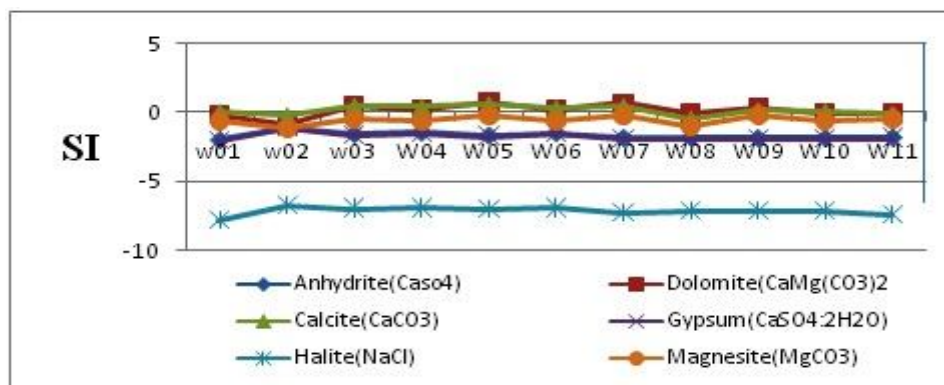


Figure 8. The main minerals saturation index of water samples in the study area

### 3.4. Heavy Metals' Assessment in the Water Resources

#### 3.4.1. Concentration of the Heavy Metals

Table 8 shows the correlation matrix of the main heavy elements with EC and pH. As shown in Table 8, chromium has a positive correlation with copper (0.657) and EC (0.747) which represents the high effect of these ions and other elements on chromium in the course of change.

Chromium is closely related to many anions and cations in water such as calcium, sodium, chlorine, and sulfate and it shows close proximity with TDS and EC. Correlation of chromium with the mentioned parameters indicates its non-settlement or non-absorbency by different materials in the water flow. So, it

appears that low concentration of chromium in the water is derived from the sedimentary rocks under the crossing water i.e. carbonate, sandstone, and shale.

**Table 8.** The heavy metals correlation matrix of water resources in the study area

	pH	EC	Fe	F	Cr	Mn	Ni	Pb	Cd	Zn	Cu
pH	1										
EC	-0.816	1									
Fe	0.238	-0.385	1								
F	-0.094	0.254	0.527	1							
Cr	-0.463	<b>0.747</b>	-0.215	0.269	1						
Mn	0.197	-0.235	<b>0.822</b>	0.524	-0.060	1					
Ni	0.548	-0.306	-0.140	-0.157	0.164	-0.003	1				
Pb	0.237	-0.164	0.445	0.044	-0.073	0.610	0.319	1			
Cd	0.228	-0.117	0.17	-0.084	-0.168	0.224	0.466	<b>0.740</b>	1		
Zn	-0.256	-0.102	-0.232	-0.397	-0.558	-0.143	-0.613	-0.246	-0.341	1	
Cu	-0.463	0.371	0.33	0.565	<b>0.657</b>	0.381	-0.235	-0.073	0.254	-0.804	1

Ratio of cadmium to lead (equal to 0.765) shows a high correlation. Cadmium in an oxidizing environment with pH of 5 to 8 has less relative mobility. It also lacks close proximity between cadmium with some of the main elements dissolved in water such as chlorine and sodium; it is an indication of a centralized source for this element that is found more in areas of shale and schist (Mason and Moore, 1994).

Iron just shows a high correlation with manganese (0.822). Iron and manganese oxides are the most absorbents in aquatic environments and are slightly related with fluorine; hence manganese as a minor mineral can be in the form of magnetite that shows high resistance to weathering. Hence, iron presence in the areas due to sedimentary rocks.

### 3.4.2. Heavy Metals Contamination of Water Resources

To assess the groundwater pollution level in relation to the heavy metals, WHO 2008 standard was used. Comparison of the concentration of the main heavy metals with the international standards shows that the iron concentration in about half of the samples is higher than 0.2ppm and the high concentration of iron is due to ferro-sandstones of Lalunand Zaigun formations that are just located up streams of the springs. The concentration of fluoride, cadmium, nickel, zinc, lead, manganese, copper, and chromium is lower than the standards in most of the samples.

In order to evaluate heavy metals' pollution in ground waters of the study area, the metal index (MI) and the heavy metal pollution index (HPI) have been used. Using these indicators, the amount of contamination of the groundwater resources and potability or non-potability can be determined.

### 3.4.3. Metal Index (MI)

Metal Index is a convenient feature to assess the level of pollution in water with regard to metals. The index is calculated using the following formula:

$$MI = \sum_{i=1}^n \left( \frac{C_i}{C_0} \right) \quad (4)$$

where,  $C_i$  is the given metals concentration, and  $C_0$  is the concentration of the metals in the standard level (WHO, 2008). In this study, metal index for chromium, copper, lead, cadmium, iron, manganese, and nickel were calculated (Figure 9).

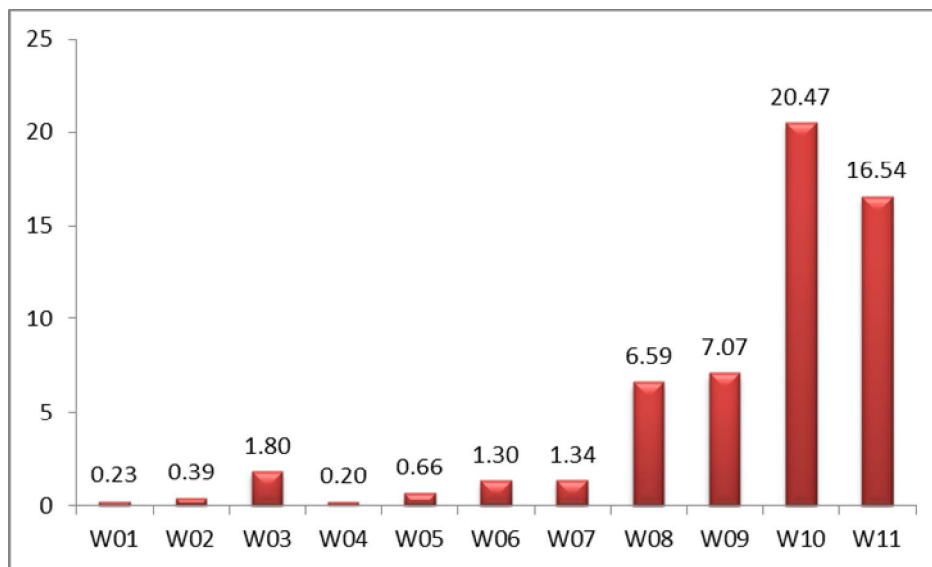


Figure 9. Metal index of water resources in the study area

According to Figure 9, samples W03, W06, W07, W08, W09, W10 and W11 contain low concentration of the mentioned metals, so they must show the bottom level of the metal index, but due to the high concentration of iron, even higher than WHO 2008 standard, their metal index values are higher than 1. High metal index in the samples indicates metal pollution in these environments, making them unsuitable for drinking. Therefore, presence of the elements with lower concentration but close to the maximum level decreases water quality due to the increasing effect of metals.

### 3.4.3. Heavy Metals Pollution Index (HPI)

Heavy metal pollution index has been introduced by Mohan *et al.*, (1996) as the following:

$$HPI = \frac{\sum_{i=1}^n W_i Q_i}{\sum_{i=1}^n W_i} \quad (5)$$



where  $Q_i$  is the heavy metal index,  $W_i$  is the weight of the desired parameter, and  $Q_i$  is expressed as:

$$Q_i = \sum_{i=1}^n \frac{|M_i - I_i|}{(S_i - I_i)} \times 100 \quad (6)$$

where  $M_i$  is the calculated heavy metal concentration,  $I_i$  is the ideal value of the parameter, and  $S_i$  is the parameter value as the standards. This is the index to estimate contaminants in drinking waters and the pollution critical index for this is 100. Using the mentioned index, the level of water contamination with iron, nickel, cadmium, zinc, lead, manganese, copper, and chrome were examined. Table 9 shows the measured amount of the HPI for 11 samples of water resources in the study area. The highest and lowest HPI is related to w10 and W2, respectively.

**Table 9.** HPI index of water resources in the study area

Sample No.	HPI	Sample No.	HPI	Sample No.	HPI
W1	2.8	W5	27.94	W9	39.78
W2	1.963	W6	74.91	W10	97.952
W3	83.14	W7	3.25	W11	60.12
W4	2.226	W8	38.664	-	-

The results suggest that HPI for the water resources is lower than the critical limit (HPI = 100). So, considering HPI values, the water resources in the study area are drinkable (Ameh *et al.*, 2011; Bably Prasad, 2008). However, investigation of the MI and HPI indices show the samples W03, W06, W07, W08, W09, W10, and W11 are contaminated due to their high concentration of iron.

#### 4. Conclusion

Study of the geological units from the standpoint of their impact on water resources indicates that Soltanieh dolomites, shales, and sandstones scattered by Zaigun, Lalun, and Mila formations and low to middle Triassic dolomites and upper Triassic limestones and limestones of Qom formation in the study area have direct impact on the quality and quantity of the groundwater.

Hydro chemical reviews of the groundwater in Hastijan area indicate that the groundwater resources are hard to very hard and frequently have Ca, Mg - HCO<sub>3</sub> type. So, based on the concentration of the main ions, cationic and anionic conditions are ordered as Mg<sup>2+</sup>>Ca<sup>2+</sup>>Na<sup>+</sup>>K<sup>+</sup> and HCO<sub>3</sub><sup>-</sup>>SO<sub>4</sub><sup>2-</sup>>Cl<sup>-</sup>.

The results of Gibbs's diagram also show the reciprocal effect between the chemistry of surrounding rocks and ground waters originated from meteoric waters. The evaluation of the saturation index shows that the water resources tend toward the dolomite and calcite super-saturated; these waters are also super-saturated in relation to calcium, magnesium, and carbonate while under-saturated regarding anhydrite, gypsum, and halite. The ground waters' quality is influenced by lithology and the feed water quality.

Investigation of the drinking water shows that its quality is in accordance with the existing standards and the concentration of ions in the majority of samples does not exceed the permitted level, therefore, the majority of the region's water is suitable for drinking. Moreover, evaluation of the ground waters in the study area shows that their quality is mostly suitable for agricultural uses.

Calculation of the Langelier coefficient for water samples of Hastijan showed that about 73% of the water samples are corrosive, and the remaining 27% have sedimentation property. In this study, chromium had a positive correlation with copper, 0.657 and EC, 0.747 which represents the effect of the ions and the elements in the process of chromium change. This indicates that chromium is not sedimented or absorbed by different materials on the water flow path. Iron has a high correlation with manganese, 0.822 and shows a relatively low association with fluorine. On the other hand, manganese can be the secondary element in the form of magnetite that shows high resistance to weathering. The presence of iron in the area is the result of sedimentary rocks.

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