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Hydro-geochemical study to evaluate the suitability of water for irrigation purpose at Qareh sou catchment, North of Iran

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ABSTRACT

In the present study, investigation of the chemical quality of water at the Qareh sou catchment has been carried out to evaluate the suitability of water for irrigation purpose. Water quality of the area has been studied based on physico- chemical analysis of six hydrometer stations during 2010. Various parameters, such as pH, EC, chloride, sulfate, bicarbonate, sodium, potassium, calcium and magnesium have been determined to evaluate this purpose. Irrigation water quality on the basis of Doneen's permeability index, residual sodium carbonate, sodium adsorption ratio, Magnesium adsorption ratio, Kelley's ratio, Corrosivity Ratio, potential soil salinity and Chadha's diagram have been computed. Results showed that the water was suitable for irrigation purpose. According to Chadha's diagram, the type of water is determined as Ca–Mg–HCO_3. Also, according to the Wilcox diagram water classified as 'excellent' and 'good', except for the Siah ab and Naharkhoran stations, but Corrosivity Ratio suggests that the Qareh sou water is not safe for Water Transmission. In shastkola and pol ordgogah stations, the value of MAR is harmfully over 50%.

Introduction

Increasing the scarcity of freshwater resources is driving many countries in the arid and semi-arid regions to use marginal quality water for agriculture and related activities (Srinivasan and Reddy, 2009). Agriculture is by far the largest water use at global level. Irrigation of agricultural lands accounted for 70% of the water used worldwide. In several developing countries, irrigation represents up to 95% of all water uses, and plays a major role in food production (Smith, 1994). Irrigation waters whether derived from springs, diverted from streams, or pumped from wells, contain appreciable quantities of chemical substances in solution that may reduce crop yield and deteriorate soil fertility (Phocaides, 2007). Water quality is intricately linked to agricultural production. Quality production is reliant upon clean source water. Water quality deterioration can occur in a number of ways, including land use impacts from industrial, urban and rural development (Little et al, 2010).The water quality used for irrigation is essential for the yield and quantity of crops, maintenance of soil productivity, and protection of the environment. For example, the physical and mechanical properties of the soil, ex. Soil structure (stability of aggregates) and permeability are very sensitive to the type of exchangeable ions present in irrigation waters. Globally around 200 thousand km^2 land is reported to be irrigated with wastewater and at least 10% of the world's population is thought to consume foods produced by irrigation with wastewater (Hamilton et al., 2007; WHO, 2006 a, b). In a semi-arid area, a city of 1 million people would produce enough water to irrigate approximately 15–35 km^2 (WHO, 2006a). Sustaining current agricultural production and agri-food processing is depended on quality water supplies. Irrigation requires good quality water in order to prevent damage to sensitive crops from pesticides, salts, and trace metals. In the long term, low sodicity in irrigation waters is necessary to maintain soil structural stability (Little et al, 2010).

The quality of water is largely controlled by discharge-recharge pattern, nature of host and associated rocks as well as contaminated activities. Moreover, the nature and amount of dissolved species in natural water is strongly influenced by mineralogy and solubility of rock forming minerals (Raymahasay, 1996). The chemical parameters of groundwater play a significant role in assessing water quality which is suitable for irrigation (Sadashivaiah et al, 2008). Irrigation with poor quality waters may bring undesirable elements to the soil in excessive quantities affecting its fertility. The quality of groundwater has definite command over the yield of crops through its effect on soil environment which is the soul of infinite life (Latha et al, 2002). Irrigated agriculture depends on an adequate water supply of usable quality. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available. This situation is now changing in many areas. Intensive use of nearly all good quality supplies means that new irrigation projects and old projects seeking new or supplemental supplies must rely on lower quality and less desirable sources. To avoid problems when using these poor quality water supplies, there must be sound planning to ensure that the quality of water available is put on to the best use (Ayers and Westcot, 1985). Hence this study was focused on evaluating of water quality for the purpose of irrigation at the Qareh sou catchment.

Materials and Methodology

Study of area

Qareh Sou catchment (Figure 1) is a 1637.65 km^2 area along the north mountainside of Alborz Mountain, regarded as the most important nutrients of Qareh Sou River and toward west it is extended to Gorgan and toward south reaches the Alborz Mountains, and finally in a village so called Qareh Sou with a length of 89kmgets to the Caspian Sea (Zarenejad, 2000). The bed of Qareh Sou River is different with composition and

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estuary which follows from geological status of this region and from the morphological point of view, the river is divided into mountain and leveled land (Hanafi, 1997).

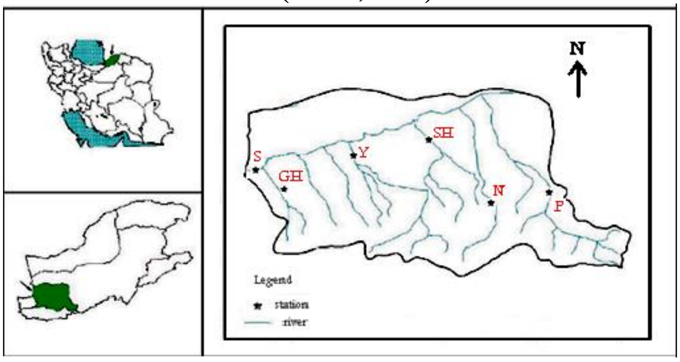

Figure 1: Qareh Sou catchment and sampling stations.

Sampling and Analysis

Six hydrometer stations were used for the sampling of Qareh Sou (table1). Topography of the area is shown in Figure 2. For examination of Qareh Sou's water quality during 2010, it was sampled in 10 stages in different seasons.

Electrical conductivity (EC) and pH were measured by hatch water checker portable meter. The bicarbonate (HCO_3^-) had been measured by Alkalinity measurements method. Sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chlorine (Cl^-) and sulfate (SO_4^{2-}) were measured by furnace 4100 Graphite atomic absorption using standard methods (APHA, 1998).

Table 1- Characteristics of hydrometric stations

Station	River	Altitude	X	Y
Naharkhoran	Ziarat	500	274664	4071765
Shastkola	Shastkola	150	263389	4068935
Siah Ab	Qare-Sue	-26	237291	4079672
Pol Ordogah	Garmabdasht	465	284254	4073732
Ghaz Mahale	Kurdkoy	5.5	241821	4075295
Yesaghi	Yesaghi	6	256827	4077110

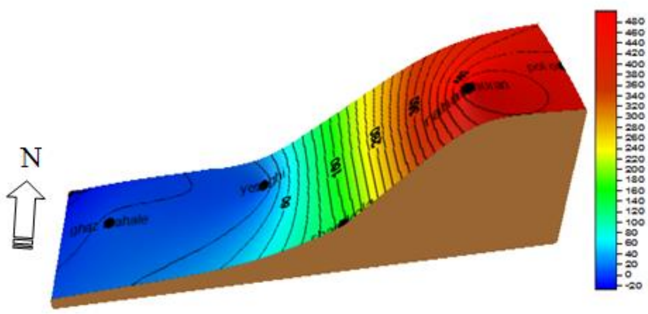

Figure 2: Topography of Qareh Sou catchment and hydrometric stations.

Irrigation water quality

Use of poor water quality can create four types of problems, namely toxicity, water infiltration, salinity and miscellaneous (Ayers and Westcot, 1985). To assess water quality for irrigation, there are four most popular criteria: TDS or EC, sodium adsorption ratio (SAR), chemical concentration of elements like Na+, Cl- and/or B- and residual sodium carbonate (RSC) (Michael, 1992 and Raghunath, 1987). For current irrigation water quality assessment, the following parameters were considered.

An important parameter to classify the groundwater samples for irrigation purpose is calculated by the formula proposed by Doneen (1962) as under:

$$Na\% = \frac{Na + K}{Ca + Mg + Na + K} * 100$$

Sodium along with carbonate forms alkaline soil; while sodium with chloride forms saline soil; both of these are not suitable for the growth of plants (Pandian and Shankar, 2007). The classification of irrigation water based on the values of sodium percentage as proposed by Wilcox (1955) has been applied.

The degree which the irrigation water tends to enter into cation exchange reaction in soil can be indicated by the sodium adsorption ratio (U.S. Salinity, 1954). According to Richards (1954), sodium adsorption ratio (SAR) is expressed as:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

Excess sodium in groundwater gets adsorbed on soil particles, thus change soil properties and also reduce soil permeability (Ayers and Bronson, 1975).

The classification of irrigation waters has been attempted on the basis of permeability Index, as suggested by Doneen (1962). It is defined as:

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} * 100$$

Magnesium adsorption ratio (MAR) (Raghunath, 1987) was calculated as:

$$MAR = \frac{Mg}{Ca + Mg} * 100$$

Kelley's ratio (KR) (Kelley, 1963) described as:

$$KR = \frac{Na}{Ca + Mg}$$

Corrosivity Ratio (CR) is defined as alkaline earth and alkaline and expressed as (Tripathi et al, 2012):

$$CR = \frac{Cl/_{35.5} + 2(\frac{SO_4}{96})}{2(\frac{HCO_3 + CO_3}{100})}$$

Residual Sodium Carbonate (RSC) refers to the residual alkalinity and is calculated for irrigation water by the following formula (Eaton, 1950; Richards, 1954):

$$RSC = (HCO_3 + CO_3) - (Ca + Mg)$$

The distribution of the potential soil salinity of the waters is governed by Doneen (1962):

$$PSS = Cl + \frac{1}{2} SO_4$$

All ionic concentrations are in milli equivalent per liter (meq/l).

Results and Discussion

General physico- chemical characteristics

If the anion-cation balance is less than 5%, the chemical analysis is assumed to be reasonable. If the balance is much greater than 5% then the analysis is poor (inaccurate), other constituents are present that were not used to calculate the balance, the water is very acidic and the H^+ ions were not included in calculation, or organic ions are present in significant quantities (Hounslow, 1995). The anion-cation balances of all water samples in the current research work ranged from -10.80% to 1.06% which is less than 5% that indicates the accuracy of the experimental chemical analyses, absence of either any other major chemical constituents, or high H^+ ion concentration and also absence of significant amount of organic ions. Height of the sampling stations is -26 to 500m from sea level and pH range from 6.72 to 8.47. Summary of statistical results of all parameters are shown in Table 1.

Table 1: Summary of statistical results of the parameters at the Qareh sou catchment

parameter	Total Count	Mean	Variance	Minimum	Maximum
Ca(epm)	58	3.062	1.379	1.4	5.8
Mg(epm)	58	2.855	1.614	1	6.8
Na(epm)	58	1.654	4.965	0.1	9.06
K(epm)	58	0.1005	0.0112	0.02	0.41
HCO_3(epm)	58	3.947	0.955	2	7.2
SO_4(epm)	58	1.864	2.958	0.42	9.5
Cl(epm)	58	1.736	4.492	0.2	9
pH	58	7.9002	0.1537	6.72	8.47
TDS(mg/l)	58	451	65238.8	205	1195

Water quality for irrigation purpose

TDS is important to be considered in the calculation of irrigation water quality, because many of the toxic solid materials may be imbedded in the water, which may cause harm to the plants (Matthess, 1982). In the absence of non-ionic dissolved constituents, TDS and EC are indicative of saline water (Michael, 1992). EC and Na^+ play a vital role in suitability of water for irrigation (Rao, 2005). High Na^+ contents can cause displacement of exchangeable Ca^{2+} and Mg^{2+} from the clay mineral of the soil (Matthess, 1982). Summary of statistical results of calculated important parameter are shown in Table 2. TDS values <450, 450-2000 and >2000 mg/l represent the irrigation water as 'none', 'slight to moderate' and 'severe', respectively (UCCC, 1974). According to this standard, the Qareh sou catchment water classified as 'none,' and 'slight to moderate'. Limits of some important parameters shown in Table 3.

Table 2: Summary of statistical results of calculated important parameters to assess the irrigation water quality in the Qareh sou catchment

Variable	Mean	Minimum	Q1	Median	Q3	Maximum
Na%	15.83	2.81	4.99	9.18	31.87	49.65
SAR	0.829	0.067	0.125	0.304	1.778	4.13
KR	0.211	0.022	0.042	0.0911	0.4253	0.95
PI%	46.634	32.5	43.41	46.864	50.891	63.6
MAR	47.74	29.41	38.72	47.02	54.84	72.6
CR	0.54	0.06	0.10	0.28	1.208	1.83
RSC	-1.971	-6.1	-3.025	-1.35	-0.7	-0.4
PSS	0.804	-2.88	-0.117	-0.02	1.27	6.505
EC(µs/cm)	644.3	292.9	377.5	512.9	895	1707.1

Table 3: Limits of some important parameters indices for rating water quality and its suitability in irrigation use.

EC(µS/cm) (Westcot ,1985)	SAR (Todd,1980)	Na% (Wilcox ,1955)	KR (Kelley, 1963)	MAR (Palliwal, 1972)	RSC (Eaton, 1950; Richards, 1954)	PSS (Doneen, 1962)	Suitable for irrigation
<700	<10	<20			< 1.25	<5	excellent
700-3000	10-18	20-40	<1	>50%	1.25-2.5	5-15	Good
>3000	18-26	40-80			>2.5	>15	Fair
	>26	>80					Poor

According to Ayers and Westcot (1985) for EC, the Qareh sou catchment water classified as 'excellent' and 'good' for irrigation (Table 3). This classification is shown in Figure 3 for all stations in the catchment.

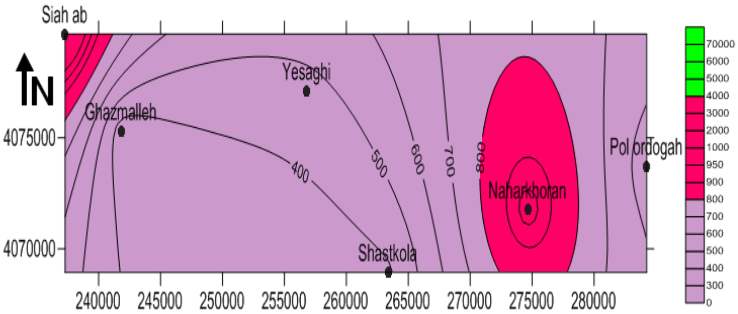

Figure 3: EC changes in sampling stations at the Qareh sou catchment.

An important chemical parameter for judging the degree of suitability of water for irrigation is sodium content or alkali hazard, which is expressed as the sodium adsorption ratio (SAR). SAR measures the potential dangers posed by excessive sodium in irrigation water (Alagbe, 2006). SAR value changes in the stations shown in Figure 4. As it can be seen, this parameter in the catchment is less than 2.5, and the water classified as 'excellent' for irrigation (Table 3).

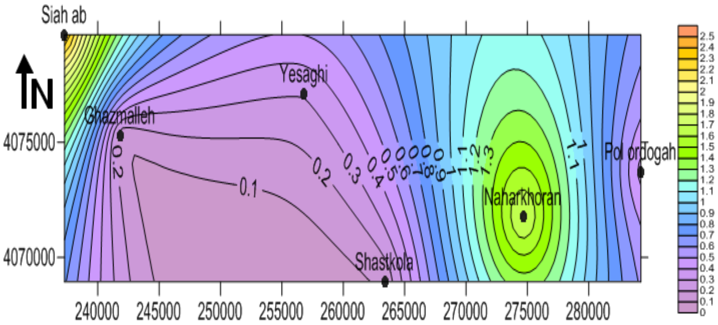

Figure 4: SAR value changes in sampling stations at the Qareh sou catchment.

According to the Plot of Sodium percent- Electrical conductivity as proposed by Wilcox (1955), water classified as 'excellent' and 'good', except for the Siah ab and Naharkhoran stations. Based on Figure 5 water qualities for irrigation are fair for two stations.

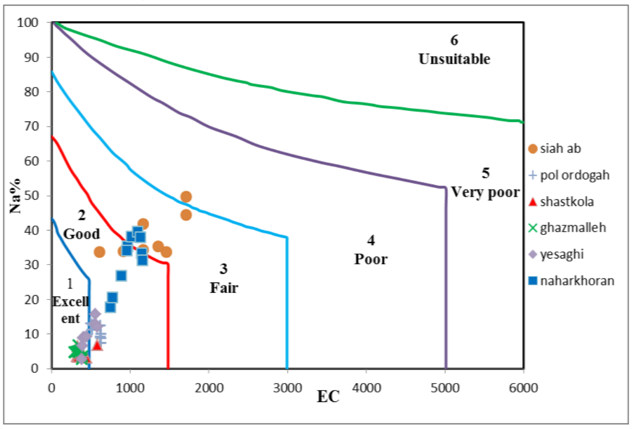

Figure 5: Plot of Sodium percent- Electrical conductivity at Qareh sou (after Wilcox 1955).

Although HCO_3^- is not toxic, it can cause zinc deficiency in rice and it can be severe when zinc exceeds 2meq/l in water used for flooding growing paddy rice (Ayers and Westcot, 1985). However, Kelly (1963) suggested that KR for irrigation water should not exceed 1. As shown in Figure 6, in all stations, Kelley's ratio has less than 1 and suitable for irrigation.

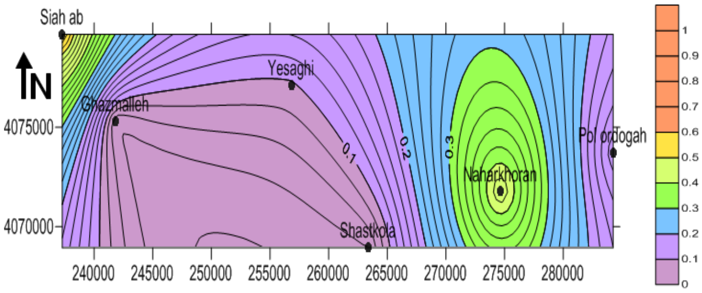

Figure 6: KR value changes in sampling stations at the Qareh sou catchment.

In present study area, MAR ranges from 29.41 to 72.6. MAR causes a harmful effect when it exceeds a value of 50 (Gupta and Gupta, 1987). Figure 7 shows that in shastkola and pol ordgogah stations the value of MAR is above 50%, which can be harmful.

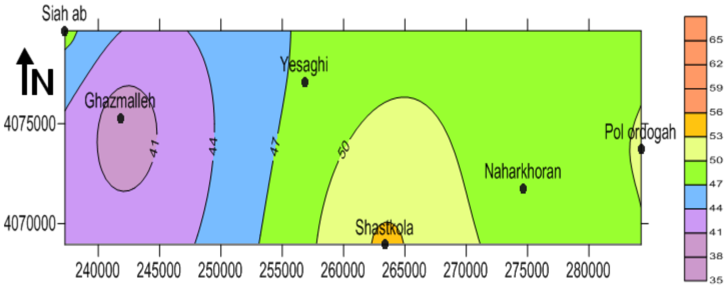

Figure 7: MAR value changes in sampling stations at the Qareh sou catchment.

The RSC values of samples of the study area ranges from -6.1 to -0.4. So, it is suitable for irrigation purpose. Figure 8 shows the variations of RSC in the sampling station.

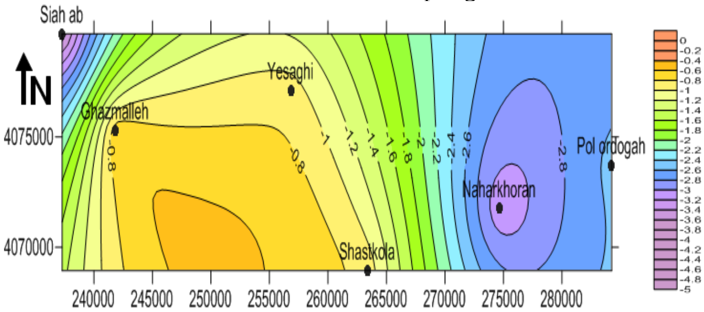

Figure 8: RSC value changes in sampling stations at the Qareh sou catchment.

Distribution of the PSS values in the study area is shown in Figure 9. As shown, the Qareh sou catchment water classified as 'excellent' for irrigation purpose (Table 3).

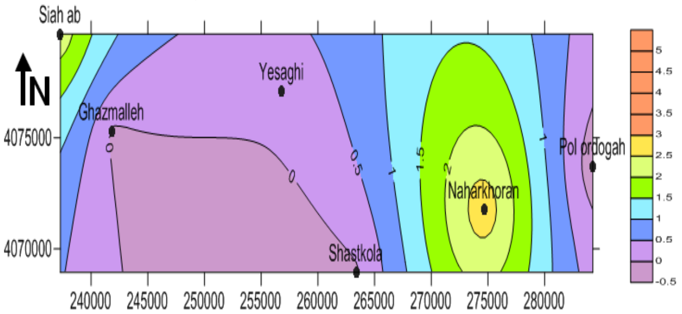

Figure 9: PSS value changes in sampling stations at the Qareh sou catchment.

To classify the water and identify the hydro-chemical processes, a Chadha diagram (Chadha, 1999) is used. This diagram is a somewhat modified version of the Piper diagram (Piper, 1944) and the expanded Durov diagram (Durov, 1948).

In Chadha's diagram (Figure 10), samples fall in 2 fields. Samples of Siah ab, Naharkhoran and pol Ordogah fall in field 1, which is Alkaline earths, exceed alkali metals. Samples of Yesaghi, Ghazmalleh and shastkola fall in field 5, which is Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively. The positions of data points in the proposed diagram represent Ca^{2+}–Mg^{2+}–HCO_3^- type.

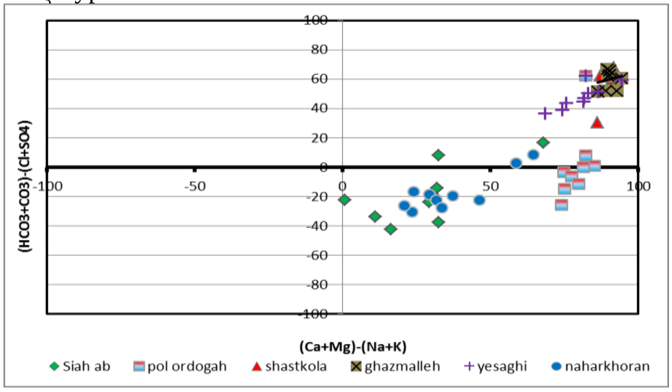

Figure10: Classification of samples as Per Chadha's at Qareh sou (1999) Scheme.

Accordingly, the PI is classified under class I (>75%), class II (25–75%) and class III (<75%) orders. Class I and class II waters are categorized as good for irrigation with 75% or more of maximum permeability. Class III waters are unsuitable with 25% of maximum permeability. The Qareh sou analytical data is plotted on the chart shown in Figure 11. The PI ranges from 32.5% to 63.6%, which comes under class I of Doneen's chart.

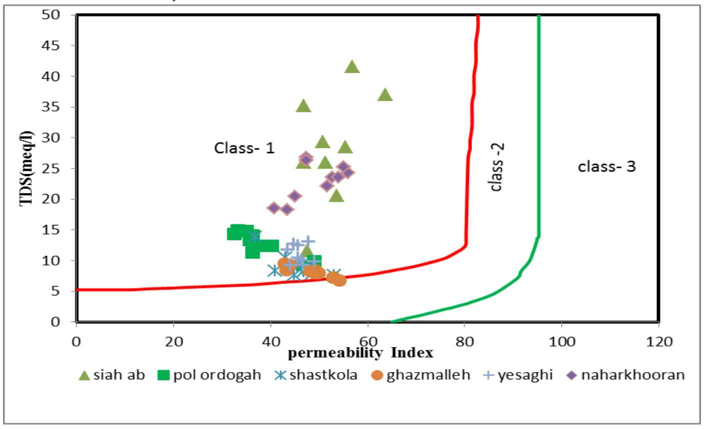

Figure 11: water irrigation Classification of Qareh sou (after Doneen, 1962)

The water with corrosivity ratio < 1 is considered to be safe for water transporting in any type of pipes. Whereas >1 indicates corrosive nature and hence it is not safe to be transported through metal pipes (Ryzner, 1944, Raman, 1985). The distribution of the CR index in the area is shown in Figure 12, suggesting that the Qareh sou water is not safe and needs noncorrosive pipe for transporting of water.

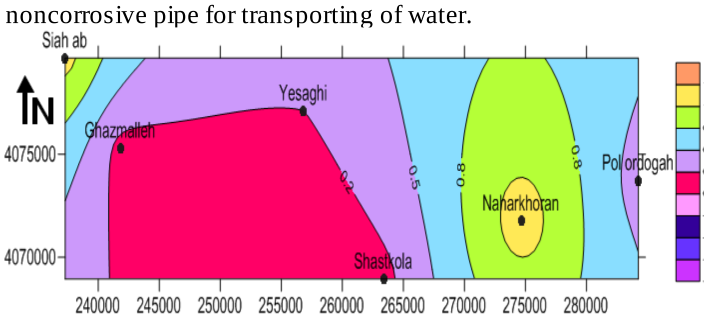

Figure 12: The distribution of the CR index in the study area

Conclusion

The chemical characteristics of water of the Qareh sou catchment have been studied on the basis of characteristics of water samples collected from six hydrometer stations during 2010. The following conclusions could be drawn in this study:

1. Ranging pH value from 6.72 to 8.47 shows that water is change from acidic to alkaline.
2. The Electrical conductivity values range from 292.9 to 1707.1 and classified as ‘excellent’ and ‘good’ for irrigation.
3. The SAR values range from 0.067 to 4.13. All of the SAR values are less than 10 and classified as ‘excellent’.
4. According to the Sodium percent - Electrical conductivity plot diagram, water classified as ‘excellent’ and ‘good’, except for the Siah ab and Naharkhoran stations.
5. In all stations, Kelley’s ratio is less than 1 and suitable for irrigation.
6. The MAR values range from 29.41 to 72.6. In shastkola and pol ordgogah stations, the value of MAR is above 50%, which can be harmful.
7. The RSC values range from -6.1 to -0.4. So, that is suitable for irrigation purpose.
8. The PSS values in the study area classified as ‘excellent’ for irrigation purpose.
9. According to the Chadha’s diagram, samples fall in 2 fields. Siah ab, Naharkhoran and pol Ordogah samples fall in field 1, which is Alkaline earths, exceed alkali metals and Yesaghi, Ghazmalleh and shastkola samples fall in field 5, which is Ca^{2+}–Mg^{2+}–HCO_3^- type.
10. According to the Doneen’s permeability index, the study area samples fall in Class I. It has shown that waters are categorized as good for irrigation.
11. The Corrosivity Ratio in the study area suggests that the Qareh sou water is not safe for transporting water.

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