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Long-term assessment of water quality and soil degradation risk via hydrochemical indices of Gharasoo River, Iran

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ABSTRACT

The suitability of Gharasoo River water for irrigation uses was evaluated in Kermanshah city, Iran. Long-term datasets including major cations, anions and other parameters such as electrical conductivity (EC), total dissolved solids (TDS) were analyzed. Sodium absorption ratio (SAR), magnesium ratio (MR), % sodium (%Na), residual sodium carbonate (RSC), permeability index (PI) and Ca^{2+}/Mg^{2+} ratio were calculated to evaluate the suitability of Gharasoo River water for irrigation purposes. Piper trilinear diagram reveals that the water is the alkaline earth than alkaline type. Based on the SAR values plotted in the U.S. Salinity Laboratory Staff diagram, Gharasoo River water belongs to class medium-salinity hazard and low-sodium hazard (C_2S_1) which indicates that there is no limitation to use water for irrigation. According to FAO method, soil degradation risk was low in the study area and potential plant nutritional disorders will not be expected. Different indices showed the regional sodicity problems: the high risks for %Na, PI, Ca^{2+}/Mg^{2+} and magnesium ratios for soil and clogging of irrigation systems only at one station.

1. Introduction

Rivers play an important role in human development. They are important natural potential sources of irrigation water particularly for agricultural production in semiarid regions where rainfall is not sufficient to uphold crop growth (Sundaray, Nayak et al. 2009, Jafar Ahamed, Loganathan et al. 2013). Agriculture is the single largest user of water throughout the world. The productivity of irrigated agriculture is significantly higher than the productivity of rained agriculture, particularly in arid and semiarid regions. The water quality for irrigation plays a very important role for agricultural production and environment protection (Ağca 2014). Water quality or suitability for agricultural use is evaluated by the potential severity of problems that may be occurred during long-term use (Ayers and Westcott 1994, Ağca 2014). The water quality is depend on the concentration and composition of solutes, which can not only enrich soil with soluble salts, but also cause to precipitate insoluble salts and affect its exchangeable cation composition or even increase sodicity (Keren 2012, Keren and Levy 2012). In order to avoid plant toxicity problems, the presence of potentially toxic elements, nitrate amount, should also be evaluated. An imbalanced N supply to crops or algal development in irrigation reservoirs should be also considered. These factors are all included in the FAO practical guidelines for assessing irrigation water quality (Ayers and Westcott 1985, Peragóna, Delgadob et al. 2015).

In irrigated agriculture especially in arid climatic conditions, irrigation water with poor quality is of concern due to constant threat of the hazard of salt water. Crop yield, soil physical conditions, fertilizers needs, irrigation system performance and longevity as well as how the water can be applied are affected by irrigation water quality (Ayers and Westcot 1994). Natural and anthropogenic pollution processes cause rapidly decline water quality globally and mostly in developing countries (Zhou, Wang et al. 2013, Ağca 2014). Rezaei and Sayadi (2014) reported the point and non-point source pollutions for Gharasoo River water. Sayadi, Rezaei et al. (2015) with reference to multivariate statistical analyses revealed that there are some sources which release the pollutants into the Gharasoo River. Despite these researches indicated water quality of Gharasoo River for drink purpose, there is no detailed information about the water quality assessment for agricultural purposes based on physico-chemical parameters. Since water quality for irrigation is not a minor problem in Kermanshah city, virtually no local research has been conducted. This work was undertaken in order to evaluate Gharasoo River suitability for irrigation. In addition, attempts were made to identify potential degradation risk of soil irrigated by Gharasoo River via some calculated hydrochemical parameters and graphical representations.

2. Materials and methods
2.1. Study area

The Gharasoo River in length 20.7 km runs through the Kermanshah city after joining two its branches of Merek and Raz Avar Rivers. The study area lies between latitudes 47˚ 36´- 47˚ 47´ N and longitudes 34˚00´- 34˚91´ E with the height of 1322 meters above sea level. The mean annual temperature and rainfall are 13.7˚C and 424.4 mm, respectively.

2.2. Datasets

Datasets of this study consist of four sampling stations data which included 10 water quality characteristics monitored monthly over a period over than 15 years (Anonymous 2009). Different durations of available data series rose from various establishment times of the stations. The monitoring stations geographical positions are presented in Table 1. The 10 analyzed parameters according to standard methods (Eaton, Clesceri et al. 1994) are presented in Table 2.

In this study focused on hydrochemical properties of water and the subsequent indices can be appropriate explaining the following undesirable effects which categorized by (Peragóna, Delgadob et al. 2015) as below:

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(a) Soil degradation through accumulation of soluble salts and sodicity, and infiltration risks. Salinity problem can be evaluated by electrical conductivity (EC) (U.S. Salinity Laboratory Staff 1954, Ayers and Westcott 1985). While sodicity and attributed infiltration risks can be estimated from EC, adjusted sodium adsorption ratio (SAR_{adj}) and residual sodium carbonate (RSC) (Suárez 1981, Ayers and Westcott 1985), percent sodium (%Na) and permeability index (PI). According to piper method (Fig.1), it was revealed that in one station water type was Mg^{2+} dominant. Although the potential effect of Na^{+} may be slightly in Mg-dominated water ($Ca^{2+}/Mg^{2+} < 1$), but sufficiently enhances a higher than normal soil exchangeable sodium percentage (ESP) at a given SAR (Rahman and Rowell 1979, Ayers and Westcott 1985, Peragóna, Delgadob et al. 2015). In addition to Ca^{2+}/Mg^{2+} ratio, the magnesium ratio (MR) can also show the Mg hazard.

Table 1. Contributed stations detailed information.

Station	Latitude	Longitude	Height (m)	Data series of different durations
Station 1 (S_1)	47˚ 44´ N	34˚ 30´E	1338	1992-2009
Station 2 (S_2)	47˚ 47´ N	34˚ 33´E	1290	1972-2009
Station 3 (S_3)	47˚ 00´ N	34˚ 29´ E	1300	1978-2009
Station 4 (S_4)	47˚ 15´ N	34˚ 14´E	1380	1972-2009

Table 2. The average of chemical composition and irrigational quality parameters of water of stations.

Parameter	EC	pH	TDS	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	SAR	SAR_{adj}	pH_c	RSC	%Na	PI	Ca/Mg	MR	French degrees	Langelier index (Is)
Stations	dS m^{-1}	-	mgL^{-1}	$meqL^{-1}$						$(meqL^{-1})^{½}$		-	$meqL^{-1}$	%				◦fH	-
S_1	0.54	8.0	346.8	0.46	0.7	1.11	2.19	3.65	1.69	0.99	1.29	8.1	-5.38	28.9	86.3	0.6	62.5	2.1	-0.1
S_2	0.46	7.8	299.0	0.16	0.3	0.68	2.96	1.29	0.36	0.25	0.17	8.7	-4.09	8.5	35.4	2.3	30.3	1.3	-0.9
S_3	0.35	7.9	225.7	0.27	0.2	0.23	2.33	0.96	0.35	0.27	0.25	8.5	-3.02	10.6	45.6	2.4	29.2	1.0	-0.6
S_4	0.51	7.8	325.4	0.23	0.5	0.63	2.82	1.51	0.76	0.52	0.41	8.6	-4.10	17.6	54.9	1.9	34.9	1.3	-0.8

(b) Nutritional disorders. Elements such as B^-, Na^+ and Cl^- can be toxic to plants. Also, bicarbonate, HCO_3^- can decrease micronutrients uptake (specially Fe^{2+} and Zn^{2+}) (Ayers and Westcott 1985). Zn^{2+} uptake and translocation to the shoot are inhibited by high concentrations of HCO_3^- (Marschner 1995). Also, a Ca^{2+}/Mg^{2+} ratio < 1 can decrease Ca^{2+} uptake via an antagonistic effect (Ayers and Westcott 1985, Peragóna, Delgadob et al. 2015).

(c) Clogging of irrigation systems. French degrees (◦fH), Langelier index (Is), RSC and Ca^{2+}/Mg^{2+} ratio will be considered as useful indices to assess the participation of Ca^{2+} and Mg^{2+} compounds and carbonate precipitation (Peragóna, Delgadob et al. 2015).

To assess the suitability of water for irrigation uses, the following irrigational quality parameters were computed by the ensuing equations:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad (1)$$

$$SAR_{adj} = SAR \times [1 + (8.4 - pH_c)] \quad (2)$$

$$pH_c = (pK_2' - pK_s') + p(Ca^{2+} + Mg^{2+}) + p(Alk)$$

$$(pK_2' - pK_s') = f\ (\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+}); \quad (3)$$

$$\mathrm{p}(\mathrm{Alk}) = f\ \left(\mathrm{CO_3}^{2-} + \mathrm{HCO_3}^{-}\right)$$

$$RSC = (HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (4)$$

$$\%\ \mathrm{Na} = \frac{(Na^{+} + K^{+})}{\sqrt{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})}} \times 100 \quad (5)$$

$$PI = \frac{(Na^{+} + \sqrt{HCO_3^{-}})}{\sqrt{(Ca^{2+} + Mg^{2+} + Na^{+})}} \times 100 \quad (6)$$

$$MR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (7)$$

$$^{\mathrm{o}}\mathrm{fH} = \left(2.5\ \mathrm{Ca}^{2+} + 4.12\ \mathrm{Mg}^{2+}\right)/10 \quad (8)$$

$$\mathrm{Is} = p\mathrm{H} - p\mathrm{H_c} \quad (9)$$

All the ionic concentrations in the above equation are expressed in meq L^{-1}, and % Na and PI in %.

3. Results and discussion

The results of physico-chemical parameters and calculated irrigation water quality parameters are given in Table 2. The pH of water in the study area ranges from 7.8-8.0. EC in all stations is lower than permissible limit of FAO classification (Table 3). Total dissolved solid (TDS) values varied from 225.7 to 346.8 mg L^{-1}.

Measured cations and anions, include Ca^{2+}, Mg^{2+}, Na^+, K^+,HCO_3^-, Cl^- and SO_4^{2-} were plotted in piper trilinearpiper by AquaChem (2011) shown in Fig. 1. The plot showed that the dominant water types for station 1 was Mg^{2+}-Ca^{2+}-Na^+, while stations 2 and 3 were identified as Ca^{2+}-Mg^{2+} and station 4 classified as Ca^{2+}-Mg^{2+}-Na^+ type. This result revealed that water was mostly alkaline earth (Ca^{2+}+Mg^{2+}) than alkaline (Na^++K^+).

3.1. Salinity problems

Irrigation water has relatively small amounts salts. The origination of water salts is from dissolution or the rocks and soil weathering, including dissolution of lime, gypsum, and other soil minerals. These salts are carried with the water to agricultural lands. Salts remain behind in the soil as irrigation water evaporates or is used by the crops (Ayers and Westcott 1994). The appropriate range of EC for agricultural uses is defined as 0.25 to 3 dS m^{-1}. If EC is greater than 3

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dS m^{-1}, water intake by the plant significantly decreases and then crop productivity is affected very much (Ayers and Westcott 1985). In the study area, EC varied from 0.46 to 0.54 dS m^{-1}, is present in the medium-salinity hazard class (C_2), indicated the moderate-to-low crop productivity (Jafar Ahamed, Loganathan et al. 2013). Therefore, Gharasoo River water can be used without any special practices for salinity control.

3.2. Sodicity problems
3.2.1. SAR and USSL diagram

The excessive Na^+ content in water reduces the permeability of soils, consequently, the available water for the plant. Na^+ replacing adsorbed Ca^{2+} and Mg^{2+} causes damage to the soil structure resulting in compact and impervious soil (Arveti, Sarma et al. 2011). The excess of Na^+ with Ca^{2+} and Mg^{2+} is evaluated by SAR. According to the SAR values plotted in the USSL diagram (Fig. 2), all stations fall under C_2S_1 (moderate-salinity hazard and low- Na^+ hazard) class. Al-Bassam and Al-Rumikhani (2003) reported that the relatively low to medium sodicity level of water is due to chemical amendments which are used frequently. The previous reports about Gharasoo River pollution sources (Rezaei and Sayadi 2014, Sayadi, Rezaei et al. 2014) showed industrial and domestic waste, agricultural runoff, as anthropogenic activities and hydro-geochemical sources.

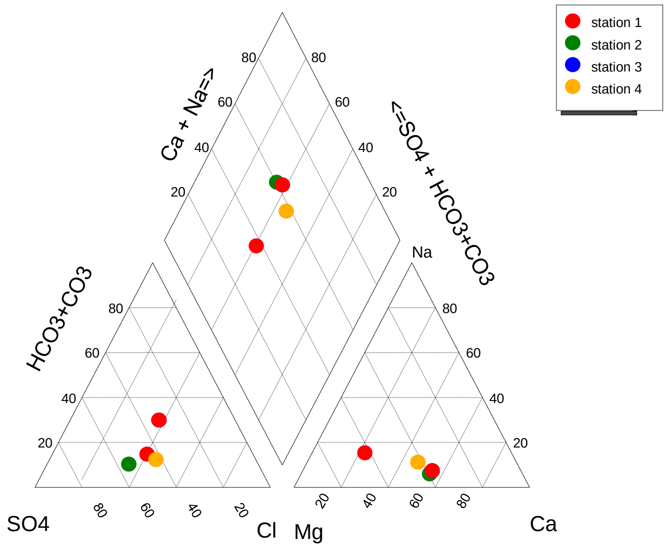

Fig. 1. Piper diagrams for water type classification by (Back and Hanshaw 1965).

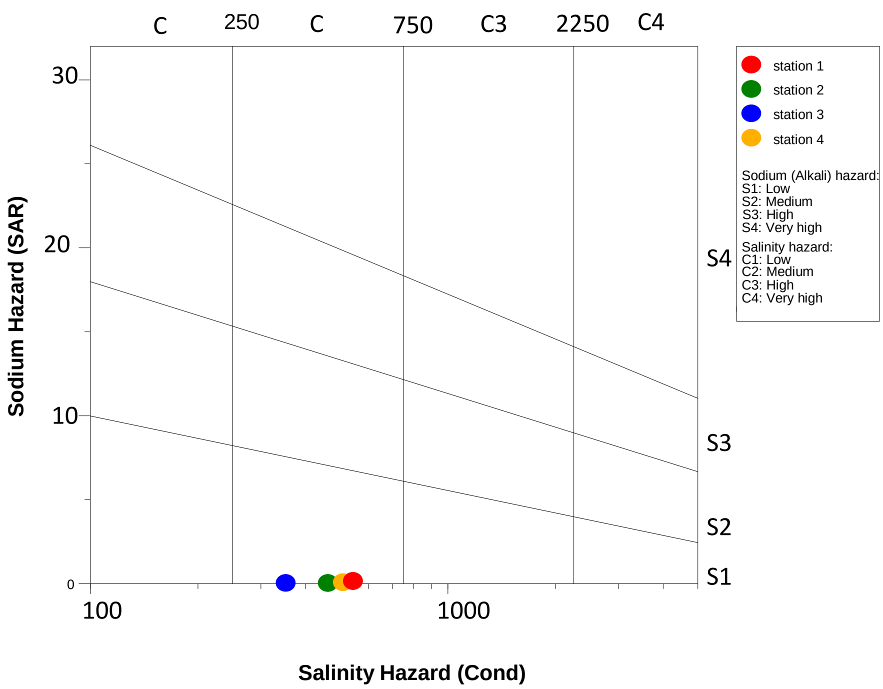

Fig. 2. Plotting SAR against Electrical Conductivity (U.S. Salinity Laboratory Staff 1954).

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3.2.2. Residual sodium carbonate (RSC)

The RSC values were calculated to determine the hazardous effect of CO_3^{2-} and HCO_3^- on the water quality for agricultural purpose. Water quality may be diminished when total CO_3^{2-} and HCO_3^- levels exceed the total amount of Ca^{2+} and Mg^{2+}. At high magnitude of excess (residual) CO_3^{2-} concentration, CO_3^{2-} combine with Ca^{2+} and Mg^{2+} and form a solid material. The suitability of water for irrigation is affected by the relative abundance of Na^+ with respect to alkaline earths and the quantity of CO_3^{2-} and HCO_3^- in excess of alkaline earths. This excess is denoted by 'residual sodium carbonate' (RSC) and is determined as suggested by (Richards 1954). According to Wilcox, Blair et al. (1953), an RSC value <1.25 meq L^{-1} is probably safe for irrigation. If it is >2.5 meq L^{-1}, it is not suitable for irrigation (Table 3). Hence, in the study area, all the values fall in the safe zone.

3.2.3. Percent sodium (%Na^+)

For irrigation purpose, the percentage of Na^+ is highly important. % Na^+ ranges from 8.5 to 28.9 % which is attributed to stations 2 and 1, respectively. These results show that all stations fall in low-risk gradation (Table 3). Based on average %Na^+, water is classified as excellent (< 20 %), good (20-40 %), permissible (40-60 %), doubtful (60-80%) and unsuitable (> 80 %) (Wilcox (1955). According to this classification, only station 1 fall in the good class and the rest stations fall in the excellent category. Thus, Gharasoo River water is suitable for irrigation purposes (Table 3).

Table 3. Classification of the Gharasoo River water quality according to the FAO method and other water quality indices.

Potential irrigation problems	Units	Risk-gradation		
		Low	Medium	High
Soil degradation				
Salinity (effects on crop water availability)				
EC	dS m^{-1}	<0.7	0.7-3.0	>3.0
Infiltration (effects on infiltration rate of water into the soil)				
SAR and EC=				
0-3	dS m^{-1}	>0.7	0.7–0.2	<0.2
3–6	dS m^{-1}	>1.2	1.2–0.3	<0.3
6–12	dS m^{-1}	>1.9	1.9–0.5	<0.5
12-20	dS m^{-1}	>2.9	2.9–1.3	<1.3
20-40	dS m^{-1}	>5.0	5.0–2.9	<2.9
RSC	meq L^{-1}	<1.25	1.25-2.5	>2.5
% Na	%	<20	4-60	>80
PI	%	<25	25-75	>75
MR	%			>50
Ca^{2+}/Mg^{2+} ratio	-	>1		<1

3.2.4. Permeability index (PI)

Continuous usage of water for irrigation will affect the soil permeability quality. Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- contents in soil influence PI. Doneen (1964) results showed the suitability of water for irrigation considering the permeability index (PI). According to PI values as classified by Ragunath (1982), the Gharasoo River in station 1 fall under class III (>75 %), in rest stations falls under class II (25–75).

3.2.5. Ca^{2+}/Mg^{2+} ratio

The Ca^{2+}/Mg^{2+} ratio will be also considered in the evaluation of sodicity problem. Since at similar ◦fH or RSC values, high Ca^{2+}/Mg^{2+} ratios can increase precipitation of Ca^{2+} phosphates and carbonates, which are less soluble than their Mg^{2+} counterparts (Peragóna, Delgadob et al. 2015). The Ca^{2+}/Mg^{2+} ratio of Gharasoo River water in all stations showed no special problems (Table 2) with the exception of station 1 (Table 3).

Table 4. Different risks related to the irrigation water quality for Gharasoo River water according to the FAO method and water quality indices.

Potential irrigation problems	Units	Risk-gradation		
		Low	Medium	High
Nutritional disorder				
Sodium (Na^+)				
Surface Irrigation	meq L^{-1}	<3.0	3.0–8.7	>8.7
Sprinkler Irrigation	meq L^{-1}	<3.0	>3.0	
Chloride (Cl^-)				
Surface Irrigation	meq L^{-1}	<4.0	4.0–10.0	>10.0
Sprinkler Irrigation	meq L^{-1}	<2.9	>2.9	
Bicarbonate (HCO_3^-)				
Overhead Sprinkling	meq L^{-1}	<1.5	1.5–8.5	>8.5
Ca^{2+}/Mg^{2+} ratio		>1	-	<1
Clogging irrigation systems				
French degrees	° fH	<1. 7	1.7–12	≥ 12
RSC	meq L^{-1}	<1.25	1.25–2. 5	> 2.5
Langelier index (pH-pH_c)		<0		>0
Ca/Mg ratio		>1	-	<1

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3.2.6. Magnesium ratio (MR)

Generally, Ca^{2+} and Mg^{2+} maintain a state of equilibrium in waters. In equilibrium, more Mg^{2+} in the water will adversely affect crop yields (Sundaray, Nayak et al. 2009). MR>50 is considered as unsuitable for irrigation purposes. In all stations, MR ranges from 29.18 to 62.50 which are lower than the permissible limit with the exception of station 1. High MR may be due to the passage of surface water through limestone formation in the study area.

3.3. Nutritional disorder

In addition to assessment of irrigation water quality on soil properties, potential nutritional disorders derived from Cl^-, HCO_3^- and Na^+ concentration or Ca^{2+}/Mg^{2+} ratio of Gharasoo River water were also evaluated. Nutritional disorders will not be expected for all stations (Table 4) with the exception of station 1 due to the high Ca^{2+}/Mg^{2+} ratio.

3.4. Potential irrigation problems

The surface water-irrigated lands of study area were under low-risk of irrigation problems by considering of Langelier index (Is). Although, negative Langelier index in all stations indicated a low-risk of clogging irrigation systems through irrigation, other properties such as ◦fH, RSC, and Ca^{2+}/Mg^{2+} ratio exhibited the moderate risk rating for ◦fH and high risk for Ca^{2+}/Mg^{2+} ratio in station 1 (Table 4). Therefore, a moderate risk of precipitation of Ca^{2+} and Mg^{2+} compounds will be expected (Peragóna, Delgadob et al. 2015). The precipitation of Ca^{2+}(and/or Mg^{2+}) with HCO_3^-, will result in a relative increase of Na^+ in solution accompanied by an increase in pH (due to the hydrolysis process where OH^- ions dominate) (Al-Bassam and Al-Rumikhani 2003).

To sum up, Gharasoo River water quality evaluation according to USSL and FAO methods is excellent for irrigation purposes. However, more indices showed the high risks for %Na, PI, Ca^{2+}/Mg^{2+} and MR in station 1. Therefore, based on the information to diminish the sodicity problem for land irrigated with water from station 1 specific practices are required. Leaching requirements (LR) should be considered to avoid deleterious salt accumulation with application of water amendments (e.g. gypsum, Ca^{2+}-containing fertilizers) and manure application instead of fertilizer chemicals to lower the risk of infiltration.

4. Conclusion

Different methods and indices were evaluated for the assessment of the Gharasoo River quality for irrigation usage purposes. While USSL and FAO methods classified water for all stations as C_2S_1 and unrestricted. Water quality indices introduced more precise definition to categorize water quality in regional scales. Water quality indices indicated that water in the station 1 has sodicity problems. Soil degradation risk was low in the study area and potential nutritional plant disorders arising from the use of irrigation will not be expected. To avoid soil degradation and plant disorders in this place by continuous irrigation, the use of water amendment and manure application may be suggested.

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