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Assessment of groundwater quality and its suitability for irrigation using hydrogeochemical properties

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Abstract

Groundwater (GW) are important sources of fresh water for the agricultural sector in Tashk-Bakhtegan and Maharloo basin in Fars Province, Iran. In this study, data were collected from 420 groundwater samples to assess the suitability of groundwater for irrigation using hydrogeochemical properties. The groundwater quality (GWQ) was evaluated using 15 hydrogeochemical indices, namely Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Salinity Hazard (SH), Chloride (Cl^-), Permeability Index (PI), Total Dissolved Solids (TDS), Potential Salinity (PS), Total Hardness (TH), Kelley's Ratio (KR), Sodium Percentage (SP), Chloro-Alkaline Index I (CAI-I), Residual Sodium Bicarbonates (RSBC), Synthetic Harmful Coefficient (K), and Base Exchange Index ($\mathbf{r_1}$), along with Meteoric Genesis Index ($\mathbf{r_2}$). The results of these indices indicated that the GWQ was totally different in the north and south of the study area. Water sources were mainly acceptable for irrigation based on SAR, MH, SH, Cl^-, TDS, PS, TH, KR, SP, CAI-I, and K indices in the northern parts, while it showed limitations for use in the agricultural sector in most southern areas. Based on PI and RSBC indices, GWQ is entirely acceptable for irrigation all over the basin. According to the results of $\mathbf{r_1}$ and $\mathbf{r_2}$ indices, GWQ belongs to Na^+-HCO_3^- and shallow water percolating types in the northern parts, while it belongs to Na^+-SO_4^{2-} and deep water percolating types in the southern parts. Agriculture and rangelands are mainly located in the center toward north of the basin, where the GWQ is more suitable for irrigation. Besides, GWQ needs to be improved in southern parts and remediation measures are proposed to make it more usable for irrigation purposes.

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Introduction

Water is the most valuable sources for living organisms and a crucial factor to determine people's quality of life. The importance of this issue is even more higher in arid and semi-arid regions due to scarcity of rainfall and surface water. In arid areas, mostly groundwater (GW) is the main and reliable source of freshwater and its quality is as important as its quantity in these regions (Abbasnia et al., 2019).

The Tashk-Bakhtegan-Maharloo basin is located in an arid and semi-arid region (Pourghasemi et al., 2020) in south central

Iran with scarce surface water resources. Agriculture is the main profession of the people in this basin, which depends on groundwater. Hence, it is essential to determine groundwater quality (GWQ) accurately to use it more appropriately. A method for assessing GWQ is to analyze the hydrogeochemical properties of GW, which reflects its source of the main components, environmental condition, and suitability (Taheri et al., 2017).

Given the paramount importance of GW, it is necessary to study and monitor GW sources for better management of water resources. One of the most essential aspects of GW studies is the assessment of its quality. In arid and semi-arid regions, GW contains a large amount of soluble salts, a small amount of which provides the demands of plants and the rest accumulates in the soil. In the case of improper management of soluble salts in water, it will cause salinization of lands over time.

Many studies have assessed the hydrogeochemical properties of GW to evaluate its suitability for agricultural purposes. These properties can be evaluated using various indices, including Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH) (Abdalazem et al., 2020; Abdulhussein, 2018; Subbarao & Reddy, 2018; Xu et al., 2019; Zhou et al., 2020), Potential Salinity (PS) (Balamurugan et al., 2020; Deshpande and Narayanpethkar, 2019; Elsayed et al., 2020), Kelley's ratio (KR) (Hwang et al., 2017; Ibraheem & Mazhar Nazeeb Khan, 2017), Permeability Index (PI) (Ibrahim et al., 2019; Karakuş & Yıldız, 2019; Li et al., 2018; Li et al., 2016a; Madhav et al., 2018), and Sodium Percentage (NA%) (Nagaraju et al., 2014; Panaskar et al., 2016; Singh et al., 2020; Soleimani et al., 2018a; Soleimani et al., 2018b).

Priyanka et al., (2017) used Chloro-Alkaline Indices (CAI-I, CAI-II), SAR, Residual Sodium Carbonate (RSC), and KR indices to evaluate the suitability of GW in Chitradurga, Karnataka, India. The analysis of these indices showed that GW of this region was suitable for agricultural purposes. Li et al., (2018) assessed GWQ for domestic and irrigation purposes in Yan'an, a City in China, using several agricultural water quality indices, including Na%, SAR, KR, MH, and Salinity Hazard (SH), and found that GWQ was generally acceptable for agricultural purposes. Karakuş & Yıldız (2019) evaluated the GWQ in the vicinity of Sivas city center, Turkey, using SAR, KR, Na%, PI, RSC and MH. The results demonstrated that the majority of the GW is in "good" and "suitable" classes in terms of irrigation water quality. Xu et al., (2019) calculated SH, Na%, SAR, RSC, MH, PI, KR, PS, synthetic harmful coefficient, and irrigation coefficient to assess GW for agricultural purposes in the Central-Western Guanzhong Basin, China. These indices revealed that the average quality of GW samples in the southern parts, which were suitable for irrigation purposes, was higher than that of the northern parts. Balamurugan et al., (2020) adopted some indices, such as SAR, PI, RSC, Na%, KR, and MH, to evaluate GW for agricultural uses in the Sarabanga River region, Tamil Nadu, India. These indices indicated that the water in almost all samples was suitable for irrigation purposes. Elsayed et al., (2020) evaluated surface water for irrigation purposes in the Northern Nile Delta, Egypt, using SAR, PI, KR, and RSC indices, and observed that all surface water samples were suitable for agricultural uses.

Due to the lack of surface water in the Tashk-Bakhtegan-Maharloo basin in Iran, agricultural activities, which are the main profession of local people in this area, is dependent on groundwater. Hence, the present study aimed to assess the suitability of GWQ in this basin for irrigation purposes to plan and adopt proper GW management strategies.

Material and methods

Study Area

Tashk-Bakhtegan and Maharloo basin is located in south of Iran between latitudes 29° 01' 59" - 31° 11' 46" E and longitudes 51° 42' 12" - 54° 37' 12" N. The area includes the center and northern parts of Fars Province, covering 31.46 km^2. The highest and lowest points of this basin are 3922 and 1987 meters above sea level, respectively, and the elevation generally decreases from north to south. Annual rainfall varies from 200 mm in the south to 700 mm in the north (Choubin et al., 2016). Figure 1 depicts the location of the Tashk-Bakhtegan and Maharloo basin in Iran and the observation/monitoring wells.

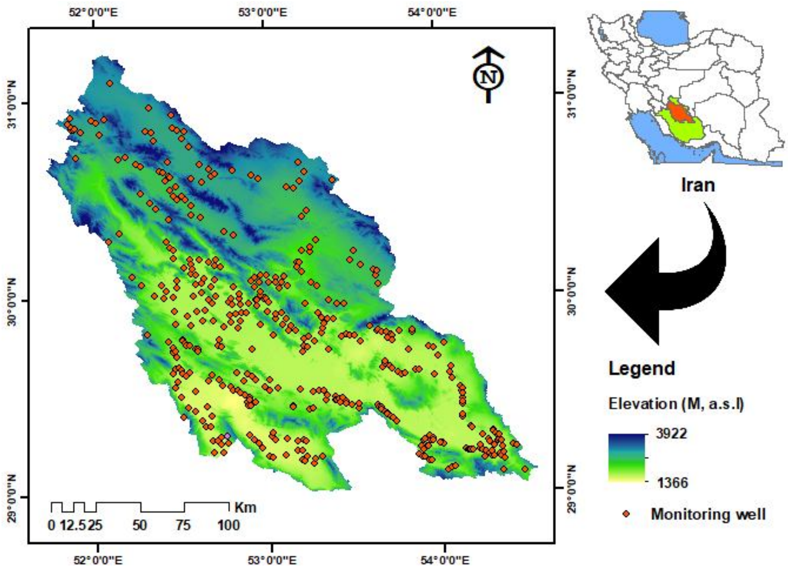


Figure 1. Location of the study area and monitoring wells in Iran

Land Use/ Land Cover Map

The type of land use can affect groundwater quality over time. Land use/cover (LULC) map of the study area was generated using MODIS Land Cover (MCD12Q1) images for the year 2019 and classified using the supervised classifications of MODIS Terra and Aqua reflectance data (Figure 2). The map was employed for comparison with the GWQ data. According to the land use/cover map, the area is mostly covered by bare lands, especially in the southern parts, but the northern and central parts mainly comprise croplands and rangelands. Croplands are located around urban areas, with about 15% of the total area.

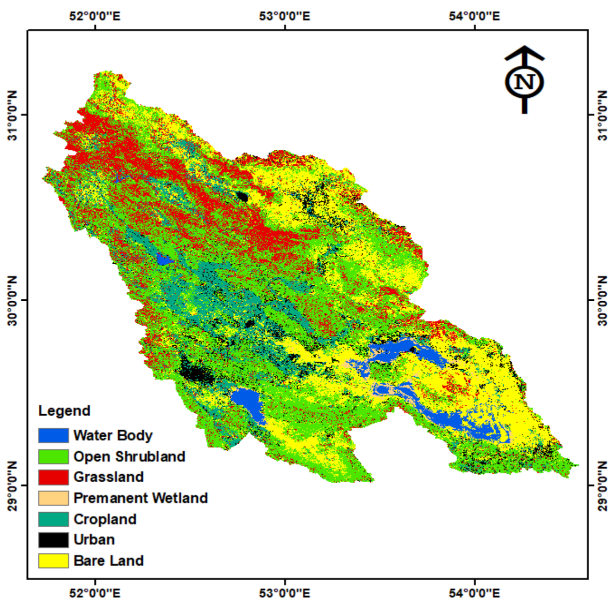


Figure 2. Land use map of the study area in 2019

Table 1. GWQ indices for irrigation purpose

Index	Equation	Range	Class	Description
Sodium Adsorption Ratio Ravikumar *et al.*, (2011)	$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+}+Mg^{2+})}{2}}}$	< 10 10 - 18 15 - 26 26 <	Excellent Good Injurious Unsuitable	SAR presents sodium hazard, which can reduce soil permeability and thus it causes inhibition for absorption of water by plants (Tahmasebi *et al.*, 2018). The sodium can substitute the calcium and magnesium in soil and in long-term causes the soil condition to be deteriorated (Panaskar *et al.*, 2016).
Magnesium Hazard Szabolcs (1964)	$MH = \frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})} \times 100$	< 50 50 <	Suitable Unsuitable	Excessive amount of Magnesium in the soil can cause alkalization and degrade soil structure and crop yield (Rao *et al.*, 2012).
Salinity Hazard Tahmasebi *et al.*, (2018)	*SH = EC (μmohs/cm)*	< 250 250–750 750–2250 2250 <	Excellent Good Doubtful Unsuitable	SH determines the existence of salt in GW. Excessive amount of salinity has osmotic effects on the plants (Subramani *et al.*, 2005) and subsequently it can effect on the intake of water and nutrients from soil (Palanisamy *et al.*, 2020).
Chloride Stuyfzand (1989)	*Cl⁻ (meq/L)*	< 0.14 0.14 – 0.85 0.85 – 4.23 4.23 – 8.46 8.46 – 28.21 28.21 – 282.06 282.06 – 564.13 564.13 <	Extremely Fresh Very Fresh Fresh Fresh Brackish Brackish Brackish - Salt Salt Hypersaline	Chloride toxicity can effect on the NaCl metabolism in body (WHO, 2004).
Permeability Index Doneen (1964)	$PI = \frac{(Na^+ + \sqrt{HCO_3^-})}{(Na^+ + K^+ + Ca^{2+} + Mg^{2+})} \times 100$	75 < 25 – 75 < 25	Suitable (I) Suitable (II) Unsuitable	PI evaluates the suitability of irrigation water and can be effected by the long-term exposure of irrigation water with a high compound of sodium, calcium, magnesium (Ravikumar *et al.*, 2011).
	TDS (mg/L)	< 1000	Non Saline	

Index	Equation	Range	Class	Description
Total Dissolved Solids Davis & DeWiest (1966)		1000 – 3000 3000 – 10000 10000 <	Slightly Saline Moderately Saline Very Saline	This parameter is mainly related to inorganic salts, organic matters and small amount of dissolver gases (Singh *et al.*, 2014). Excessive amount of TDS causes the high risk of a disease (Seth *et al.*, 2015).
Potential Salinity Doneen (1962)	$PS = Cl^{-} + \frac{SO_4^{2-}}{2}$	< 3 3 – 5 5 <	Excellent to Good Good to Injurious Injurious to Unsatisfactory	PS is primarily related to Cl^{-} and SO_4^{2-} concentration.
Total Hardness Sawyer (1960)	*TH (mg/L)*	< 75 75 – 150 150 -300 300 <	Soft Moderately Hard Hard Very Hard	The Total Hardness (TH) of GW can be resulted from divalent cations, mainly from calcium and magnesium (Boyd, 2015).
Kelley's Ratio Kelley (1963)	$KR = \frac{Na^{+}}{(Ca^{2+}+Mg^{2+})}$	< 1 1 <	Suitable Unsuitable	KR measures sodium against calcium and magnesium.
Sodium Percentage Wilcox (1955)	$Na\% = \frac{(Na^{+}+K^{+})}{(Na^{+}+K^{+}+Ca^{2+}+Mg^{2+})} \times 100$	< 20 20 – 40 40 – 60 60 – 80 80 <	Excellent Good Permissible Doubtful Unsuitable	Sodium percentage presents the GW suitability in term of soil permeability (Nagaraju *et al.*, 2006). Excessive concentration of Na^{+} can deteriorate the soil structure and permeability (Tijani, 1994).
Chloro-Alkaline Index I Aghazadeh & Mogaddam (2011)	$CAI\text{-}I = \frac{Cl^{-} - (Na^{+}+K^{+})}{Cl^{-}}$	0 < < 0	Equilibrium Disequilibrium	CAI-I presents nature of ion exchange process.
Residual Sodium Bicarbonates Gupta & Gupta (1997)	$RSBC = (HCO_3^{-} - Ca^{2+})$	< 5 5 - 10 10 <	Satisfactory Marginal Unsatisfactory	Water with high concentration of RSBC is relatively high pH prone (Singaraja, 2017) and calcium and magnesium will precipitate as carbonates (Ibraheem & Mazhar Nazeeb Khan, 2017).
	$K = 12.4 \times TDS + SAR$	< 25	Excellent	

Index	Equation	Range	Class	Description
Synthetic Harmful Coefficient Zhou *et al.*, (2009)		25 - 36 36 - 44 44 <	Good Injurious Unsuitable	Synthetic Harmful Coefficient comprehensively presets the salt and alkali hazards (Xu *et al.*, 2019).
Base Exchange Index Bokhari & Ali Khan (1992)	$r_1 = \frac{Na^+ - Cl^-}{SO_4^{2-}}$	< 1 1 <	Na^+-SO_4^{2-} Na^+-HCO_3^-	According to the Base Exchange Index, GW is classified into Na^+-SO_4^{2-} and Na^+- HCO_3^- types.
Meteoric Genesis Index Tarawneh *et al.*, (2019)	$r_2 = \frac{(Na^+ + K^+) - Cl^-}{SO_4^{2-}}$	< 1 1 <	Deep Meteoric Shallow Meteoric	Based on the Meteoric Genesis Index, GW is categorized into deep and shallow types.

Data Collection

In this study, data for GWQ were obtained from Iran Water Resources Management Company for 420 water quality monitoring wells in spring 2019. In order to assess the suitability of GW for irrigation purposes in Tashk-Bakhtegan and Maharloo basin, a dataset was created using hydrogeochemical parameters of GW including Potassium (K^+), Sodium (Na^+), Magnesium (Mg^{2+}) and Calcium (Ca^{2+}), as major cations, Chloride (Cl^-), Bicarbonate (HCO_3^-) and Sulfate (SO_4^{2-}), as major anions, and Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Total Hardness (TH).

Methodology

The GW suitability for agricultural activities is contingent on the effects of the mineral compounds in the GW (Hwang et al., 2017). Charge Balance Error (CBE) was initially computed to assess the standard error and suitability of ions concentration for all GW samples using Equation 1 below (Li et al., 2016b).

$$CBE\ \% = \frac{(TC-TA)}{(TC+TA)} \times 100 \qquad \text{Eq. (A.1)}$$

where TC and TA are total concentrations of cations and anions in meq/L, respectively. A zero CBE% represents ions balance, while positive and negative values indicate the excess of cations and anions, respectively. This error is widely considered perfect for hydrogeochemical analysis within a limit of ±5% (Li et al., 2014). For better understanding of the ions concentration distribution, bivariate diagrams were employed in SPSS Statistics 27.0.1.0.

Subsequently, the important indices including Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Salinity Hazard (SH), Chloride (Cl^-), Permeability Index (PI), Total Dissolved Solids (TDS), Potential Salinity (PS), Total Hardness (TH), Kelley's Ratio (KR), Sodium Percentage (SP), Chloro-Alkaline Index I (CAI-I), Residual Sodium Bicarbonates (RSBC), Synthetic Harmful Coefficient (K), Base Exchange Index (r_1) and Meteoric Genesis Index (r_2) were calculated based on equations in Table 1 to evaluate the GWQ for irrigation. All cations and anions were expressed in meq/L.

Afterwards, the spatial distribution maps based on sampling data were prepared using Inverse Distance Weighting (IDW) technique (Almodaresi et al., 2019; Asadi et al., 2020; Kawo & Karuppannan, 2018; Khosravi et al., 2017; Verma et al., 2020; Yang et al., 2020) in ArcMap 10.7.1. This technique is mostly used for geostatistical and mathematical interpolation (Yang et al., 2020) and estimates values of un-sampled cells based on nearby sampled locations.

Results

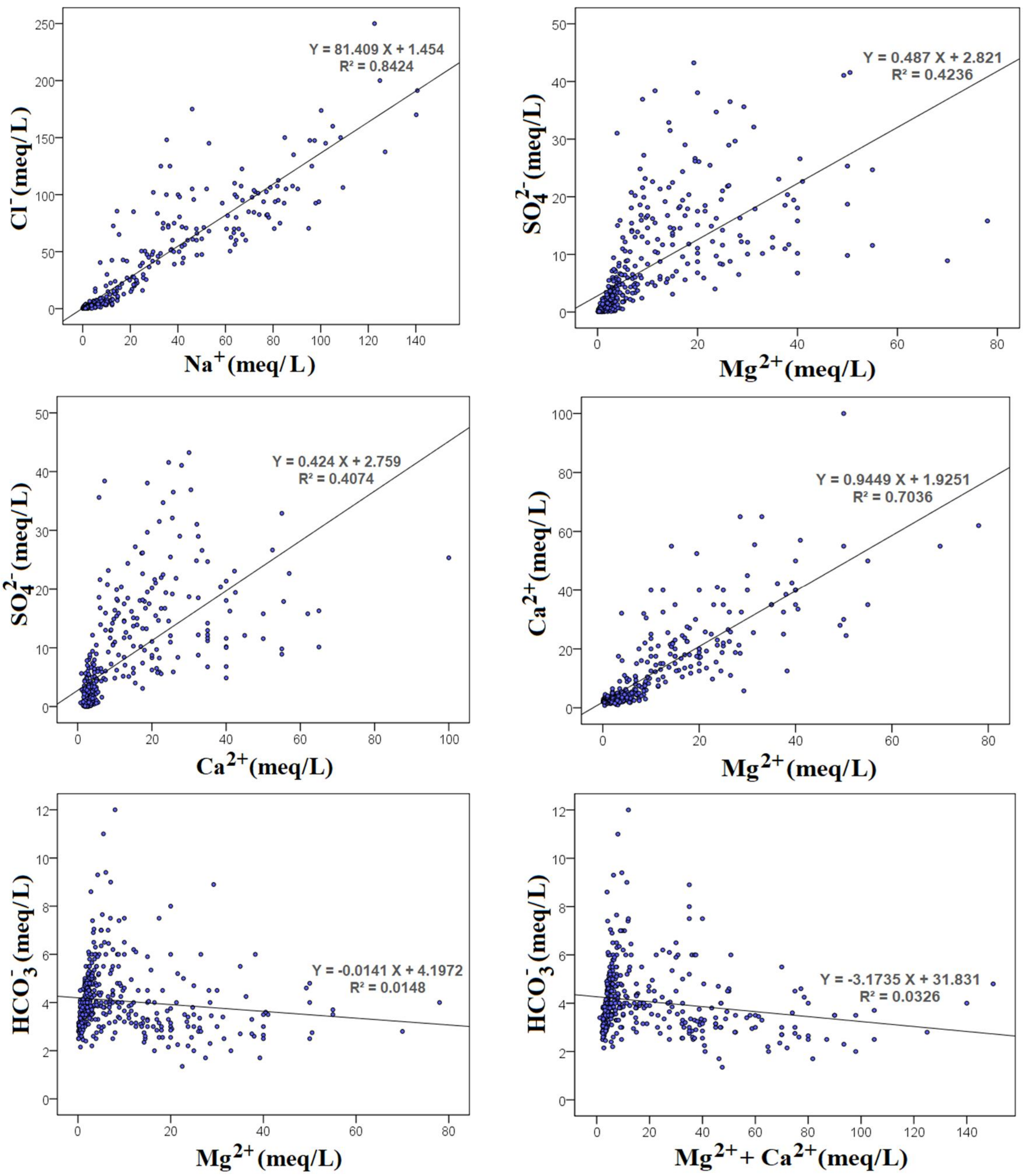
The CBE% values of all 420 samples ranged from -4.75 to +3.73, which confirm the reliability of the analysis. Determination of GWQ properties is important to accurately detect the GW suitability (Karakuş & Yıldız, 2019). The statistical summary of GWQ properties is presented in Table 2.

Table 2. Summary of GW quality properties

Parameter	Unit	Min	Mean	Max	Standard Deviation	Skew
K^+	meq/L	0.01	0.23	1.85	0.33	1.83
Na^+	meq/L	0.04	20.40	140.62	29.35	1.75
Mg^{2+}	meq/L	0.1	8.73	78	11.85	2.32
Ca^{2+}	meq/L	0.8	10.17	100	13.35	2.42
Cl^-	meq/L	0.15	28.13	250	43.36	1.80
HCO_3^-	meq/L	1.35	4.07	12	1.37	1.72
SO_4^{2-}	meq/L	0.02	7.072	43.23	8.86	1.67
EC	µS/cm	268	3710.16	22015	4593.92	1.45
TDS	mg/L	161	2403.85	15800	2982.34	1.60
TH	mg/L	60	945.10	7500	1207.99	2.15

Based on the mean value of ions concentration, the sequence of the abundance of the cations was found to be as $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, while the sequence of the abundance of the anions was as follows: $Cl^- > SO_4^{2-} > HCO_3^-$. Therefore, among the cations and anions Na^+ and Cl^- ions are dominant as the major ions. The average concentration of K^+-Na^+ was higher than average concentration of Mg^{2+}-Ca^{2+} and in terms of anions, the average concentration of Cl^- was higher than the average concentration of HCO_3^--SO_4^{2-}.

Among the individual ions, Na^+ and Cl^- had the highest correlation with a value of more than 0.84, while the correlation between HCO_3^- and Mg^{2+} and Ca^{2+} was the lowest and reverse. The correlation between all cations and anions was approximately +1, which represents that cations and anions are balanced (Figure 3).



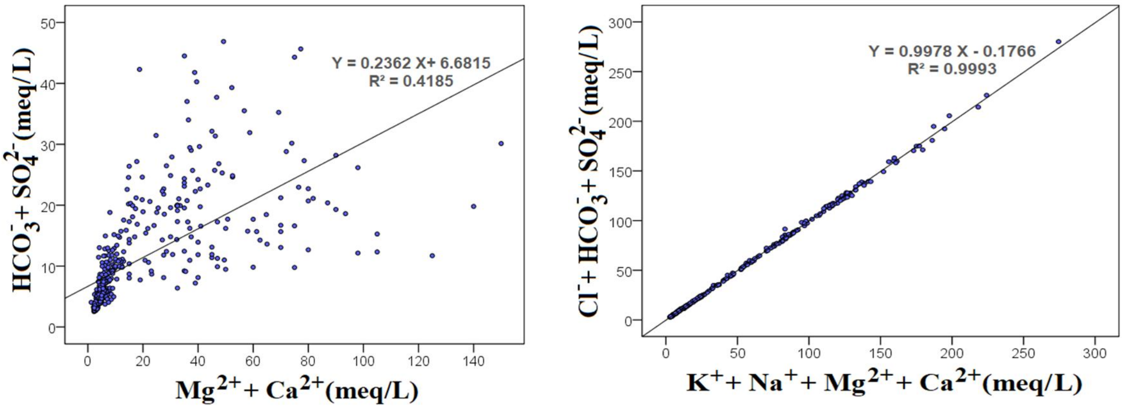


Figure 3. Bivariate diagrams of ionic concentrations in GW samples

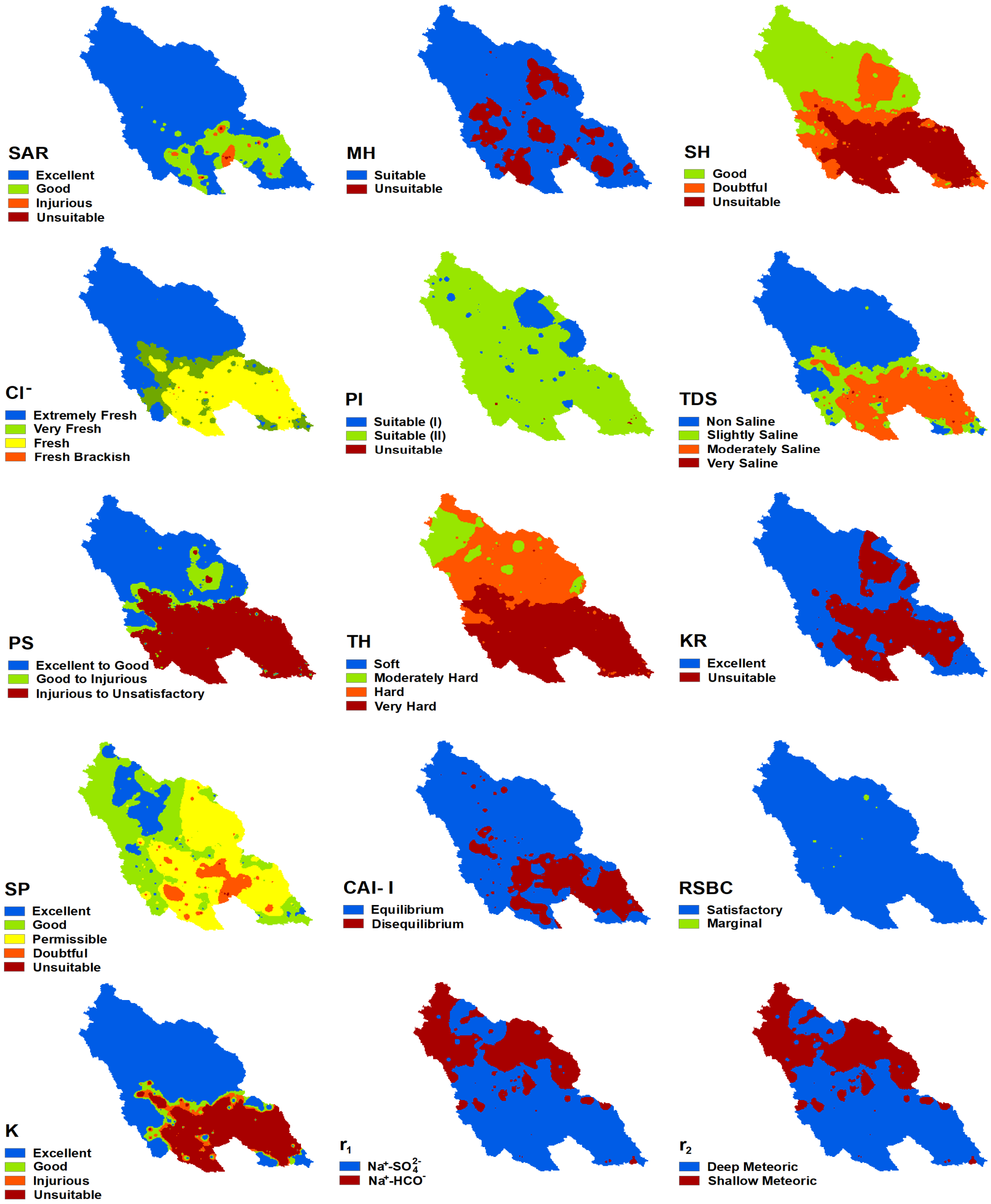


Figure 4. Classified maps of indices for irrigation purpose

After the statistical analysis of ions' concentration in each GW sample, hydrogeochemical parameters of GW were employed for computing GWQ indices to define irrigation water quality. The classified maps of indices for irrigation purpose are presented in Figure 4.

Sodium Adsorption Ratio (SAR)

The maximum and minimum values of SAR were 35.17 and 0.03, respectively. A number of 343 (81.5%) samples were categorized into "Excellent" class, 50 (12%) fell into "Good" class, 20 (5%) samples into "Harmful" class, 7 (1.5%) samples into "Unsuitable" class. According to the SAR classified map, most parts of the study area had "Excellent" and "Good" status in terms of SAR, and just a small part in the south had "Injurious" and "Unsuitable" status.

Magnesium Hazard (MH)

MH values ranged from 4.44 to 83.58. A total of 265 (63%) samples were classified into "Suitable" class and 155 (37%) samples were located in the "Unsuitable" class. The classified map of MH indicated that GW in most parts of the study area had "Suitable" condition and some areas in the center and south were "Unsuitable".

Salinity Hazard (SH)

SH values ranged from 268 to 22015 μS/cm and its average value was 3710.16 μS/cm. GW in terms of SH was found in "Good" class in 155 (37%) samples, "Doubtful" class in 108 (25.5%) samples and "Unsuitable" class in 157 (37.5%) samples. The SH classified map showed that the GW in northern parts of the study area had "Good" status, central parts had "Doubtful" status and southern parts had "Unsuitable" status.

Chloride (Cl^-)

The concentration of Cl^- in the GW samples varied between 0.004 and 7.03 meq/L, with an average value of 0.79 meq/L. GW samples were classified into "Extremely Fresh" (235 (56%) samples), "Very Fresh" (63 (15%) samples), "Fresh" (115 (27%) samples) and "Fresh Brackish" (7 (2%) samples) classes. The classified map of Cl^- illustrated that the northern parts of the study area were "Suitable" while southern parts scored lower GWQ.

Permeability Index (PI)

PI values ranged from 14.78 to 113.65 and among 420 GW samples in the study area, 68 (16%) belonged to "Suitable (I)" class, 342 (82%) belonged to "Suitable (II)" class and 10 (2%) belonged to "Unsuitable" class. The map of this index indicated that approximately the whole study area had suitable GW for irrigation.

Total Dissolved Solids (TDS)

TDS values ranged from 161 to 15800 mg/L with an average value of 2403.85 mg/L. GW samples were classified into "Non Saline" (236 (56%) samples), "Slightly Saline" (60 (15%) samples), "Moderately Saline" (114 (27%) samples) and "Very Saline" (10 (2%) samples). It can be observed in the spatial map of TDS that the northern parts had good condition and southern parts had higher values.

Potential Salinity (PS)

PS values ranged from 0.25 to 262.66 and GW in 170 (40%) samples were classified as "Excellent to Good", in 39 (10%) samples as "Good to Injurious" and in 211 (50%) samples as "Injurious to Unsatisfactory". According to the classified PS map, GW had "Excellent to Good" condition in northern parts, while southern parts had "Injurious to Unsatisfactory" condition.

Total Hardness (TH)

TH values varied from 60 to 7500 mg/L, with an average of 945.10 mg/L. GW in just one sample was classified in "Soft" class, 46 samples were classified as "Moderately Hard", 148 samples as "Hard" and 225 samples were classified as "Very Hard". TH map represented the hardness of GW is increasing from north to south of the basin.

Kelley's Ratio (KR)

KR ranged between 0.01 and 6.32 and were less than one for 282 samples (67%)

reflecting their suitability for irrigation, while GW in 138 samples (33%) were unsuitable. The classified map of KR (Figure 3) indicated that GW is within an acceptable quality level in northern and most central parts, while the southern areas were unsuitable in terms of GW for irrigation purposes.

Sodium Percentage (Na%)

The values of this index ranged from 1.09 to 85.77 and GW was “Excellent” to “Permissible” for irrigation in 354 samples (84%), while GW in 66 samples (16%) was “Doubtful” to “Unsuitable”. The map of Na% demonstrated that most parts of the study area had suitable status and just a small part in the south had unsuitable GWQ.

Chloro-Alkaline Index I (CAI-I)

The negative values of CAI_I reflect equilibrium condition, while the positive values represent the disequilibrium of condition. The CAI-I values varied from -10.2 to 0.838 and GW was in equilibrium status in 240 samples (57%) but 180 (43%) samples showed disequilibrium status. The CAI_I map indicated that most parts of the north had equilibrium status, while some parts in the south were in disequilibrium status.

Residual Sodium Bicarbonates (RSBC)

The RSBC values were found to be between 8.5 and 95.2 mg/L and 412 (98%) samples had GW with “Satisfactory” quality and 8 (2%) samples had GW with “Marginal” class. As it can be clearly recognized in the RSBC map, almost all of the study area had GW with “Satisfactory” quality.

Synthetic Harmful Coefficient (K)

K values varied from 2.20 to 213.76 and GW in 264 (63%) samples were classified as “Excellent”, 18 (4%) samples as “Good”, 16 (4%) samples as “Injurious” and 122 (29%) samples as “Unsuitable”. The map of K represented that GW had “Excellent” status in northern parts, while in the central parts it was “Good” to “Injurious” and in the southern parts was unsuitable.

Base Exchange Index (r_1)

The maximum and minimum values of r_1 were 12.6 and -12.66, respectively. Among the 420 GW samples, 312 (74%) belonged to Na^+-SO_4^{2-} type and 108 (26%) to Na^+-HCO_3^- type. The map of this index represented that most parts of the study area had Na^+-SO_4^{2-} GW type and some parts in the center and north of basin had Na^+-HCO_3^- GW type.

Meteoric Genesis Index (r_2)

r_2 values ranged from -12.53 to 13 and GW in 318 (76%) samples belonged to deep meteoric percolation type, while 102 (24%) samples had shallow meteoric percolation GW type. The map of this index indicated that most parts of the study area are classified as deep meteoric percolation and some central and northern parts are classified as shallow meteoric percolation.

Discussion

In the present study, statistical approaches and hydrogeochemical investigations were carried out using various indices to evaluate GW suitability for irrigation purposes in the Tashk-Bakhtegan-Maharloo basin, Iran. Due to the lack of surface water in this basin, GW is a major resource of water for irrigation; therefore, its suitability is important in terms of affecting agricultural activities. For this reason, hydrogeochemical indices, namely SAR, MH, SH, Cl^-, PI, TDS, PS, TH, KR, SP, CAI-I, RSBC, K, and r_1 and r_2 were measured in this research.

The results of ion concentrations revealed the balance of cations and anions, and ion abundances represented that the cations and the anions followed the $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and the $Cl^- > SO_4^{2-} > HCO_3^-$ sequences, respectively. Consequently, the concentrations of Na^+ and Cl^- were higher than the other cations and anions, suggesting that GW might flow through halite rocks and dissolute them (Anantha & Chandrakanta, 2014). Also, the concentrations and relationship of Mg^{2+} and Ca^{2+} against HCO_3^- indicated the dissolution of calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) (Wu *et al.,* 2020). Geological studies confirm the existence of the mentioned formations (Khosravi *et al.,* 2018).

The results of indices reveal that GWQ is acceptable for irrigation in the northern parts of the studied basin in terms of SAR, MH, SH, Cl^-, TDS, TH, PS, CAI-I, KR, and K. However, the GWQ declined from the central toward southern parts hence it has limitations for use in irrigation purposes based on the aforementioned indices.

Several studies have indicated that excessive use of GW in agricultural areas causes depleted levels and, consequently, decreased quality of GW (Harrington et al., 2007; Malki et al., 2017; Masoudi et al., 2015). Since irrigated agriculture is the most important activity in the Maharloo basin (Mahabadi et al., 2018) and more than 60% of these areas are dependent on GW resources (Delavar et al., 2020), agriculture has caused excessive and uncontrolled use of GW in this basin, potentially resulting in a decrease in GW quality.

Conclusion

The land use/cover map of the area indicated that most of the bare and croplands are located in the south towards the southeast, center, and west, respectively. GW was very saline and hard and not suitable for irrigation in the southern parts due to a high value of SH, which represents the concentrations of salts in GW, along with TDS and TH. A high amount of MH observed in some central parts towards the southern parts can alkalinize and degrade the soil and affect the crop yield. SAR and SP results illustrated that GW had better quality in the northern parts than the southern parts of the basin. This reflects that an excessive amount of sodium can reduce the permeability and degrade the soil and, if used for agricultural activities, it prevents water absorption by the plants in the southern parts. Therefore, it is crucial to implement remediation strategies to reduce these problems.

The findings of this study provide information to better manage and decide on plans for use and rehabilitation of GW resources in the study area. Especially, GW can be made more usable through remediation measures to improve its quality in southern parts of the study area.

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