

Hydrogeochemical Characteristics of Groundwater in the Bassit Ophiolitic Area, Northwestern Syria

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How to cite this paper: Adra, A. (2022). Hydrogeochemical Characteristics of Groundwater in the Bassit Ophiolitic Area, Northwestern Syria. *Journal of Geoscience and Environment Protection*, 10, 373-392.
<https://doi.org/10.4236/gep.2022.1012021>

Received: November 15, 2022

Accepted: December 27, 2022

Published: December 30, 2022

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Abstract

In order to evaluate the hydrogeochemical properties and the quality of groundwater in the Bassit ophiolitic area (Northwestern Syria), 27 groundwater samples were collected from springs and wells during dry and wet seasons. Physical-chemical parameters and heavy metal concentrations of groundwater samples were measured. The analytical results showed that the groundwater is very hard and slightly alkaline in nature. The concentrations of major ions are in the following order: $Mg^{2+} > Ca^{2+} > Na^+ > K^+$ and $HCO_3^{2-} > Cl^- > SO_4^{2-} > NO_3^-$. The magnesium ion (Mg^{2+}) has exceeded the permissible limit for drinking purpose, reflecting an influence of ophiolitic rocks on the local groundwater chemistry. The hydrogeochemical facies are mainly (Mg- HCO_3) and (Mg/Ca- HCO_3) types with a minor occurrence of Ca- HCO_3 type. According to Gibbs diagrams, all samples fall in the rock dominance field and the chemical quality of groundwater is related to the lithology of the area. The maximum concentrations of some heavy metals in groundwater samples for two seasons are relatively low (16.9 $\mu g/l$ Cr, 19.27 $\mu g/l$ Ni, and 1.78 $\mu g/l$ Co), which are under the permissible limit for a drinking purpose. Also to evaluate the groundwater suitability for irrigation purposes, Salinity hazard (EC), Sodium hazard (SAR, Na%) and magnesium hazard (MAR) were appraised. It is found that 89% of groundwater samples in two seasons were mainly classified as high salinity/low sodium, which suggests that this groundwater is unsuitable for irrigation. Only (11%) of samples were classified as medium salinity/low sodium and as such suitable for irrigation. The magnesium hazard showed that 82% of the samples had high values ($MAR > 50\%$) and as such unsuitable for irrigation. Soil irrigated with such groundwater will not be exposed to any alkali hazard, but will suffer from salinity and magnesium hazard.

Keywords

Hydrogeochemistry, Groundwater Quality, Heavy Metals, Ophiolitic Area

1. Introduction

Groundwater is an essential part of water resources for drinking, irrigation, and industrial purposes around the world. The groundwater quality could reveal important information on the geological formation of the aquifers and the suitability of groundwater for various purposes (Nagaraju et al., 2016). Generally, the chemical composition of groundwater is controlled by several factors, including hydrogeochemical process, degree of rock weathering, hydrodynamic conditions, residence time, and soil inputs when water infiltrates (Appelo & Postma, 1996). The interaction of these factors results in various hydrogeochemical types of groundwater (Shvartsev, 2008). Therefore, the study of hydrogeochemistry is a useful tool for identifying the origin of the groundwater chemical composition and the process responsible for groundwater chemistry (Singh et al., 2011), especially in a complex geological setting, exemplified by an ophiolitic area. Ophiolite is an oceanic crust and upper mantle fragments that have been tectonically uplifted and emplaced onto the continental crust (Brooks, 1987). It typically includes ultramafic and mafic rocks (largely peridotites, dunites, and gabbros) with varying degrees of serpentinization (Barnes et al., 1978). These rocks are composed of ferromagnesian minerals (e.g. olivine, pyroxene, and serpentine) with an elevated level of heavy metals, such as Cr, Ni, Zn, Co, V and Sr (Al-Riyami et al., 2002). Ophiolites present important groundwater resources in some areas (e.g., in Greece (Voutsis et al., 2015) and in Italy (Segadelli et al., 2017)). However, ophiolites may impact strongly the chemical composition of the water (e.g., in Oman (Paukert Vankeuren et al., 2019)) because of the high reactivity of the rock-forming minerals, which makes some water sources unsuitable for human use. In a general manner, the chemical weathering of ophiolitic rocks results in the formation of clays and iron oxides minerals and a release of dissolved constituents such as heavy metals to soil and waters (Tashakor et al., 2018; Critelli et al., 2015). Previous studies showed that the Cr and Ni contents in some springs in ophiolitic areas exceed the maximum permissible limit for total Cr and Ni of drinking water (WHO, 2011) in Italy, Greece and Turkey (Fantoni et al., 2002; Voutsis et al., 2015; Hatipoglu-Bagci & Bayari 2020). Although ophiolite may host one of the groundwater resources in Syria, few studies on its groundwater quality have been carried out (Adra et al., 2020), contrasting to other aquifers (e.g. karstic and alluvial) (Kassem, 2001; Asmael et al., 2021). Because of the climate change, the urbanization with insufficient infrastructure, and an inadequate water resources management (Asmael et al., 2021) in recent, the problem of water scarcity in Syria has been exacerbating. Thus, the exploration of new water resources and the assessment of its quality and quantity are necessary in

Syria. Since the Bassit is a large drainage area in Syria, which consists of extensive outcrops of ophiolitic rocks, it was selected as the study area. The aim of this work is to 1) investigate the hydrogeochemical characterization and to assess the quality of groundwater in Bassit area and 2) to determine the concentration of certain heavy metals (Cr, Ni, and Co) in the groundwater.

2. Study Area

The Bassit region (**Figure 1**) lies in the northwestern Syria along the Latakia coast

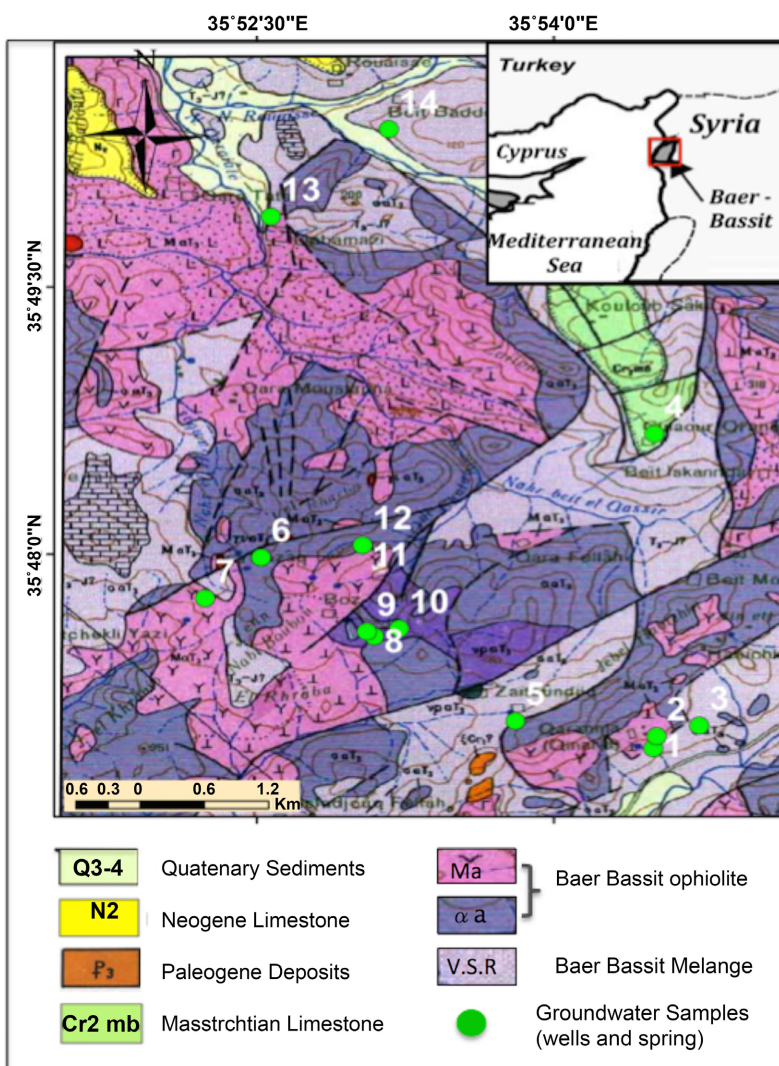


Figure 1. Geological map of the Baer-Bassit ophiolite (NW Latakia-Syria) showing the outcrops of the ophiolite and the sites of groundwater sampling. N2: Neogene deposits (Clays, sandstone, conglomerates). Pg: Paleogene deposits (Clayey bedded limestones). Cr2 mb = upper cretaceous (Masstrchtian) dolomite and dolomitic limestone. Baer-Bassit ophiolite: (upper Triassic T₃ – upper cretaceous Cr₂) Ma: Basic rocks, Gabbro, diabase, sheeted diabase dykes, lava and pillow lava. aa: Ultra basic rocks, Serpentinites (Dunit-Harzburgites). Baer-Bassit melange (V.S.R): T₃ – Cr₂ Volcano-sedimentary rocks, Radiolaries, limestones, sandstones, silt, marl, lavas and tuffs. Map is based on [Kazmin & Kulakov \(1968\)](#) (1/50,000).

for approximate 40 km and rises gradually to an average height of 1000 m above sea level, the forest covers more than 70% of the region. The Bassit is separated from the Coastal Mountains in south by the El-Kabir river valley. The study area is characterized by Mediterranean climate type with a long dry summer and rainy winter. The annual average of rainfall ranges from 700 to 1000 mm/year. The villages are located in the western and southern parts of the study area and the majority of people depend on the agriculture in their livelihood and use groundwater for their domestic and irrigation purposes. No industrial activities exist in the region.

Geological Setting

The Bassit ophiolite association is a part of the periarabic Arc (**Figure 1**), which consists of ophiolite allochthones thrust over the sedimentary cover of the African-Arabic platform and extending from Oman through the central Zagros (Iran) and the foothills of the Eastern Taurus (Turkey) to northwestern Syria and Cyprus (**Knipper et al., 1986**). The Bassit ophiolite complex makes up the Baer-Bassit nappe, which represents the upper structural stage of the allochthon section. The Tamima nappe represents the lower nappe of the section which is composed of Upper Triassic–Lower Cenomanian volcanic and sedimentary rocks (**Parrot, 1980; Knipper et al., 1986**). The obduction of the ophiolite complex in late Maastrichtian resulted in the emerging of these rocks and their lateritic weathering. At the end of the Cretaceous period, the folded-nappe allochthon structures again submerged beneath sea level and were covered by Upper Maastrichtian-Pliocene carbonate sediments 300 - 1200 m thick. According to **Knipper et al. (1986)**, The Bassit ophiolite nappe consists from bottom to top of 1) Gabbro–hyperbasite complex which ranges up to 1.5 km in thickness and composed of serpentized dunites and harzburgitic tectonites; 2) diabase-gabbro complex which is widespread in the region and consists of norites, gabbros, diabases and diorites; 3) Two pillow-lava horizons (tholeiite basalts and boninitic rocks). Hydrogeologically, very few studies were done about the hydrogeological properties in Bassit area. Generally, the region is lack of available water resources, the ophiolitic rocks may represent the main aquifer in the study area, which is exploited through few bore and dug wells with depths ranging from 40 to 75 m. The ophiolitic complex aquifer is impermeable and highly fractured by faults (**Poisson, 1977; Critelli et al., 2015**). Recharge to the aquifers takes place through the snowmelt, rainfall events, and lateral and downward groundwater flow from overlying strata (like karstic). Springs are the main way of groundwater discharge, which are mainly associated with the ophiolitic complex. However, the flow of springs depends on the annual precipitation, which increases in wet season and may ceases in dry season.

3. Sampling and Methods

To analyze the physico-chemical properties of groundwater in the study area,

a total of (27) groundwater samples were collected from (6) springs and (8) hand-dug wells with a buried depth between (40 - 75 m) during the wet season (April 2020) and the process was repeated during the dry season (August 2020). The sampling sites are illustrated in (Figure 1). Standard methods (APHA, 1998) were adopted in the collection, preservation, and analyses of samples. The parameters, i.e. temperature, electrical conductivity (EC), pH, and total dissolved solid (TDS), were measured using a multiparameter WP600 series in the field immediately after pumping out for 10 - 20 minutes. The groundwater samples were taken and stored in the acid-washed polyethylene bottles. The collected samples were kept in the refrigerator at 4°C for test. The determinations of Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, and NO₃⁻ were performed by an ion chromatography (Shimadzu-IC). The content of HCO₃⁻² was measured using an acid-base titration. Total hardness (TH) was calculated as TH = 2.49 Ca²⁺ + 4.11 Mg²⁺ (Todd, 1980). Determination of some heavy metals (Cr, Ni, and Co) was performed by a graphite furnace atomic absorption spectroscopy (Shimadzu AA-6800) using certified Cr, Ni, and Co standard solutions. The suitability of groundwater for drinking purposes was evaluated by comparing different parameters with those reported by the World Health Organization (WHO, 2011), and for irrigation purposes were evaluated by the following parameters: 1) Soluble sodium percentage (SSP or Na%) is an indication of sodium hazard in soil. A high Na% in soil can have dangerous impacts on soil aeration, structure and infiltration. It was calculated by the following equation (Equation (1)) (Todd, 1980):

$$\% \text{Na} = [(\text{Na}^+ + \text{K}^+) \times 100] / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+) \quad (1)$$

2) Sodium adsorption ratio (SAR) is used to express alkali hazard, when the concentration of sodium is high in irrigation water, Na⁺ ions tend to be absorbed by clay particles in the soil, displacing Ca²⁺ and Mg²⁺ ions, which reduce the soil permeability (Selvakumar et al., 2014). SAR is calculated by the following equation (Equation (2)) (Richards, 1954):

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

3) Magnesium adsorption ratio (MAR) also recognized as magnesium hazard (MH) and is calculated as per method suggested by Ragunath (1987) as (Equation (3)):

$$\text{MAR} = \frac{\text{Mg}^{2+} \times 100}{\text{Ca}^{2+} + \text{Mg}^{2+}} \quad (3)$$

4. Results and Discussion

4.1. Physical Chemical Parameters

Results of physical and chemical parameters of groundwater samples for the dry (August 2020) and wet (April 2020) seasons are shown in Table 1. These parameters including statistical measures, such as minimum, maximum, mean concentrations, and standard deviation (SD) that are compared with World Health

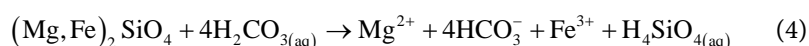
Table 1. Statistics of parameters of groundwater samples for dry and wet seasons. The concentrations of major elements in mg/l and heavy metals (Cr, Ni, and Co) in µg/l.

Parameters	Dry season (August, 2020)				Wet season (April, 2020)			
	Min	Max	Mean	SD	Min	Max	Mean	SD
pH	7.21	8.17	7.53	0.31	7.4	8.67	8.03	0.30
EC (µS/cm)	710	1090	949	112.8	750	1360	1055	163.7
TDS (mg/l)	476	780	639	84.91	502	911	670	109.7
TH (mg/l)	457	764	577.2	120.7	394	739.6	547.4	118.7
Mg ²⁺ (mg/l)	42.90	179	109.6	41.5	33.9	170.4	96.8	41.8
Ca ²⁺ (mg/l)	10.70	112.3	50.5	30.1	15.5	111.7	59.6	33.2
Na ⁺ (mg/l)	10.20	68.8	35.5	17.4	12.5	67.0	35.9	15.7
K ⁺ (mg/l)	0.16	1.28	0.91	0.89	0.14	4.91	0.86	0.7
HCO ₃ ⁻ (mg/l)	289	600	432.7	112.3	325	770	543.6	223.6
Cl ⁻ (mg/l)	16.01	99.9	45.0	21.4	16.8	102.8	45.8	20.8
SO ₄ ²⁻ (mg/l)	9.01	117.4	33.8	33.8	6.3	127.4	36.9	37.2
NO ₃ ⁻ (mg/l)	4.00	50.0	19.1	14.0	5.00	50.0	20.8	13.0
Cr (µg/l)	0.75	16.91	4.76	4.6	1.02	14.82	4.36	3.7
Ni (µg/l)	2.19	19.27	5.63	4.9	1.32	17.3	4.52	4.2
Co (µg/l)	0.49	1.25	0.40	0.4	0.11	1.78	0.50	0.5

Organization standards for drinking water (WHO, 2011). The pH of the groundwater samples varies from 7.21 to 8.67, with average values (7.53 and 8.03) for dry and wet seasons, respectively, which indicates a slightly alkaline nature of the groundwater. The electrical conductivity (EC) varies from 710 to 1090 µS/cm, with an average value of 949 µS/cm in samples of dry season, and from 750 to 1360 µS/cm, with an average value of 1055 µS/cm in samples of wet season. The total dissolved solid (TDS) ranged from 476 to 780 mg/l, with an average value of 639 mg/l for dry season, and from 502 to 911 mg/l with an average value of 670 mg/l for wet season. The most desirable limit of TDS in drinking water is 500 as per WHO standard while all the samples exceed this limit and belong to permissible category for drinking (Davis & Dewiest, 1966). The total hardness (TH) of groundwater samples ranged from 457 to 764 mg/l, with an average value of 577.2 mg/l for dry season, and from 394 to 739.6 mg/l, with an average value of 547.4 mg/l for wet season as shown in (Table 1). The maximum permissible limit of TH for drinking purposes is 500 mg/l (WHO, 2011). It implies that the groundwater in the study area is higher than permissible limit. The classification of groundwater based on TH shows that a majority of the groundwater samples fall in the very hard water category (Todd, 1980). Generally, there are no significant differences in pH, TDS, TH, and EC of the groundwater samples between dry and wet seasons.

4.2. Major Ions Content in Groundwater

Magnesium (Mg^{2+}) is the first cation predominant in the groundwater samples of the study area. The concentrations of Mg^{2+} ranged from 42.9 to 179 mg/l, with a mean value of 109.6 mg/l, for dry season and from 33.9 to 170.4 mg/l, with a mean value of 96.8 mg/l for wet season as shown in (Table 1, Figure 2). The permissible limit of Mg^{2+} in the drinking water is 30 mg/l (WHO, 2011). It implies that the groundwater in the study area is higher than recommended value. Mg^{2+} is derived from ferromagnesian minerals (olivine, pyroxene, and serpentine) in ophiolitic rocks, as the alteration (serpentinization) of these minerals (e.g olivine) in presence of water associated with carbon dioxide (CO_2) as follows (Garrels, 1967):



Calcium (Ca^{2+}) is the second cation predominant in the groundwater samples of the study area. The concentrations of Ca^{2+} ranged from 10.7 to 112.3 mg/l, with mean values of 50.5 and 59.64 mg/l for dry and wet seasons, respectively (Table 1, Figure 2). The desirable limit of Ca^{2+} in the drinking water is 100 mg/l therefore, the amount of Ca^{2+} is in safe limit (WHO, 2011), Ca^{2+} is derived mainly from weathering of Ca-rich minerals like feldspars, pyroxenes, and amphiboles of gabbroic and basaltic units in the bedrocks (Mason & Moore, 1982). Sodium (Na^+) varied from 10.2 to 68.8 mg/l, with a mean value of ~35 mg/l in the groundwater samples for the two seasons as shown in (Table 1, Figure 2). The amount of Na^+ is less than desirable limit 200 mg/l according to (WHO, 2011). The molar Na/Cl ratios for the majority of the groundwater samples range from 1.0 to 2.07 as shown in (Figure SI-1), which suggest that the main source of sodium in groundwater is the feldspar dissolution with ($\text{Na}/\text{Cl} \geq 1$) (Arnorsson & Stefansson, 1999).

In contrast to Na^+ , the amount of potassium (K^+) in the groundwater samples is very low (mean values of 0.91 and 0.86 mg/l for dry and wet seasons, respectively), which is in safe limit according to (WHO, 2011). Low concentrations of

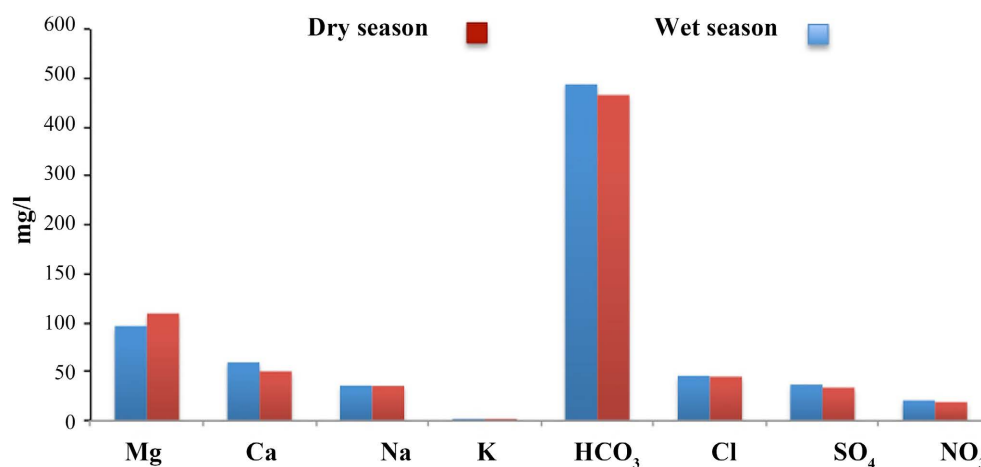


Figure 2. Mean concentration of major ions in groundwater samples for dry and wet seasons.

potassium are attributed to the lack of potassium-bearing minerals such as K-feldspar in ophiolitic rock and that K-feldspar is more resistant to weathering than plagioclase-feldspar (Robertson & Eggleton, 1991). Bicarbonate (HCO_3^-) is the dominant anion in the groundwater samples ranged between 289 and 600 mg/l with the mean value of 432.7 mg/l for dry season and between 325 and 770 mg/l with the mean value of 543.6 mg/l for wet season. The abundance of ophiolite rocks in the area suggests that the major source of HCO_3^- in groundwater is weathering of ferromagnesian minerals according to equation (4). The Cl^- and SO_4^{2-} concentrations in the groundwater for two seasons ranged from (16.01 - 102.8 mg/l Cl^-) and (6.3 - 17.4 mg/l SO_4^{2-}), respectively. The amounts are lower than desirable limit (250 mg/l for Cl^- and 250 mg/l for SO_4^{2-}) (WHO, 2011). The main source of Cl^- and SO_4^{2-} in groundwater is associated with evaporate deposits, which their outcrops in the northern mountain of the study area are visible. The nitrate (NO_3^-) concentrations in groundwater samples ranged from (4 - 50 mg/l) with mean values of (19.1 mg/l) for dry season and (20.8 mg/l) for wet season, which are in safe limit according to (WHO, 2011). The source of nitrate in area is N fertilizers (e.g urea, nitrate or ammonium compounds) that are used for agricultural practices. The abundance of the major ions in groundwater is in following order: $\text{Mg}^{2+} > \text{Ca}^{2+} > \text{Na}^+ > \text{K}^+$ and $\text{HCO}_3^{2-} > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^-$. The scattered plots for $\text{Na}/(\text{Na} + \text{Ca})$ and $\text{Cl}/(\text{Cl} + \text{HCO}_3)$ as a function of TDS (Gibbs, 1970) can be used to identify of rock-water interaction processes. According to Gibbs's diagrams, the functional sources of dissolved chemical constituents include evaporation dominance, rock dominance, and precipitation dominance. Most of the groundwater samples are plotted in the middle part of the diagram (Figure 3), indicating that rock weathering is the dominant processes controlling the major ion composition of groundwater in the study area.

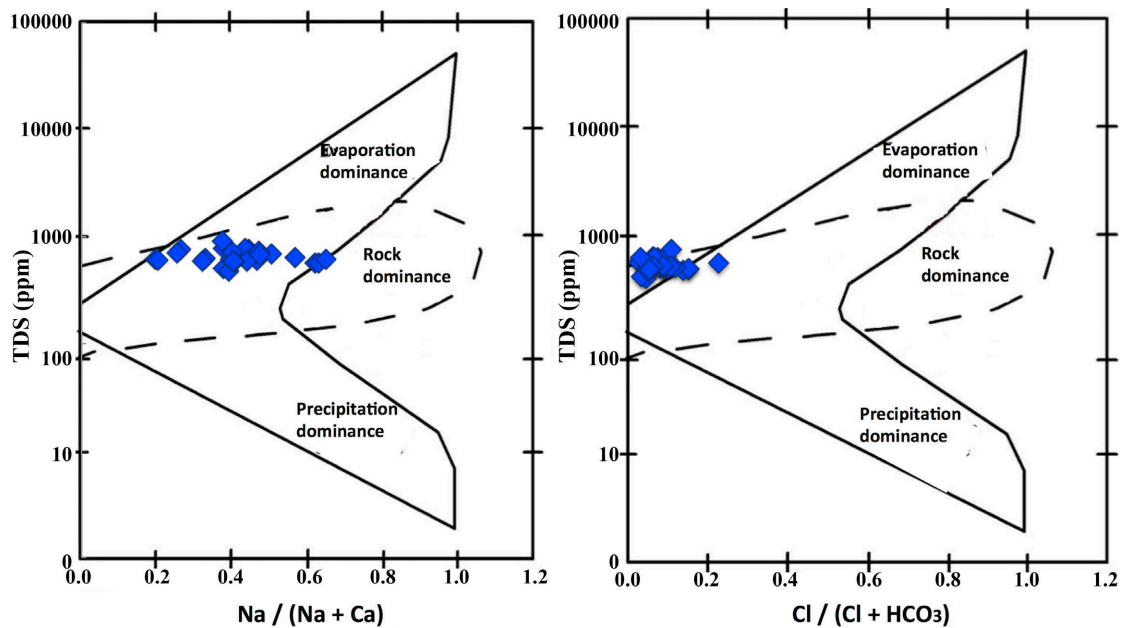


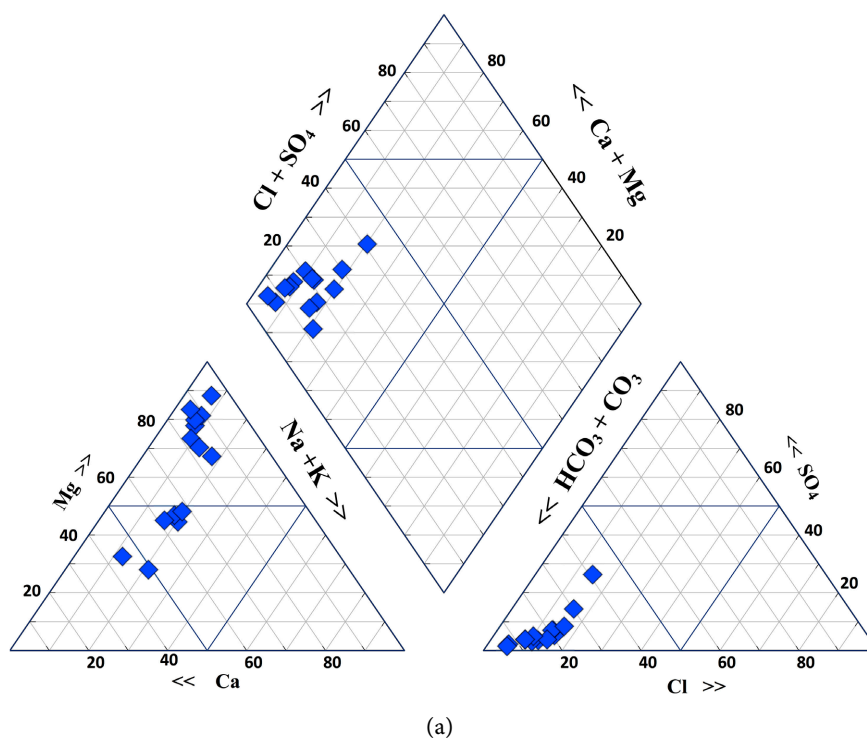
Figure 3. Gibbs diagram for all groundwater samples collected in wet and dry seasons.

4.3. Hydrogeochemical Facies

Hydrogeochemical facies identification is a good tool for determining the groundwater chemistry based on the dominant cations and anions. The concentrations of major ions determined in groundwater samples as shown in (Table SI-1 and Table SI-2) were plotted on the Piper diagrams (Piper, 1953) (Figure 4), to distinguish the different waters types in the study area. The diagram revealed that the magnesium/calcium bicarbonate (Mg/Ca-HCO₃) is the most common hydrochemical facies, which is typical of ophiolitic terrains (Neal & Stanger, 1984). Most of the groundwater samples (~90% of the total samples) for two seasons have more Mg²⁺ concentration as compared to other cations, indicating a higher degree of serpentinization in the study area. On the Ca vs. Mg binary plot for two seasons (Figure 5), Mg-HCO₃ type waters from serpentinites fall below the 1:3 line of Ca/Mg ratios present 60% of the groundwater samples, whereas the Ca-HCO₃ type waters are above 1:1 only present 10% of the samples. Samples that plot between the 1:1 and 1:3 lines indicate mixing of the Ca-HCO₃ and serpentine derived Mg-HCO₃ type waters present 30% of the groundwater samples. Generally, the main type water associate with outcrops of ultramafic rocks in the study area is Mg-HCO₃, which are slightly alkaline, and this corresponds to results in other ophiolitic area of the world, e.g. Oman and Greece (Neal & Stanger, 1984; Kanellopoulos et al., 2015).

4.4. Heavy Metals (Cr, Ni, Co) Content in Groundwater

The summary of the heavy metals concentrations in groundwater samples along with standard permissible limits is presented in Table 1. The concentrations of



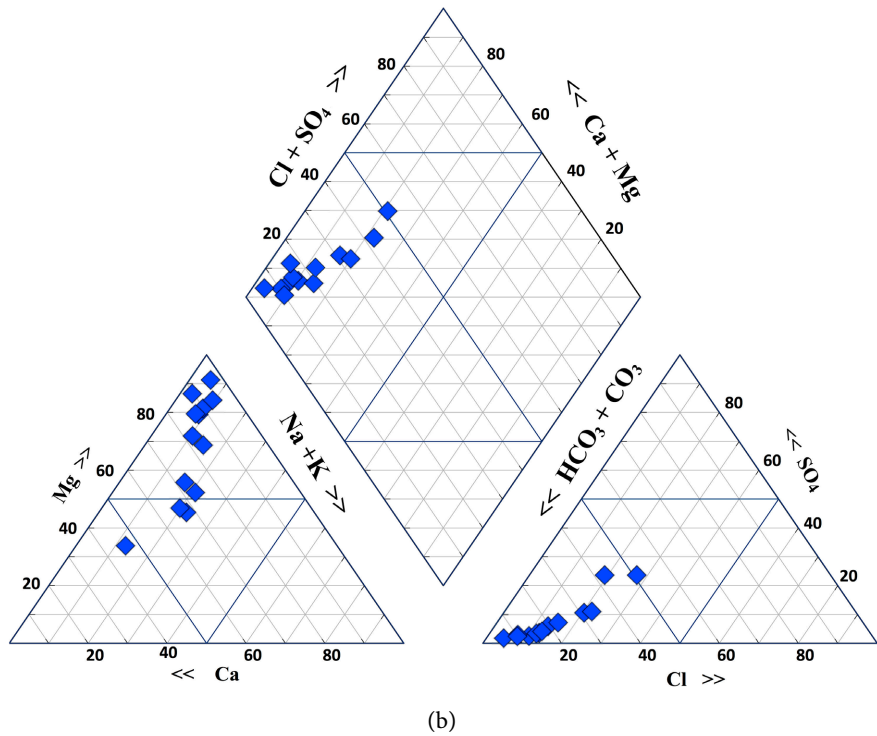


Figure 4. Piper diagram of the groundwater samples in wet season (a) and dry season (b).

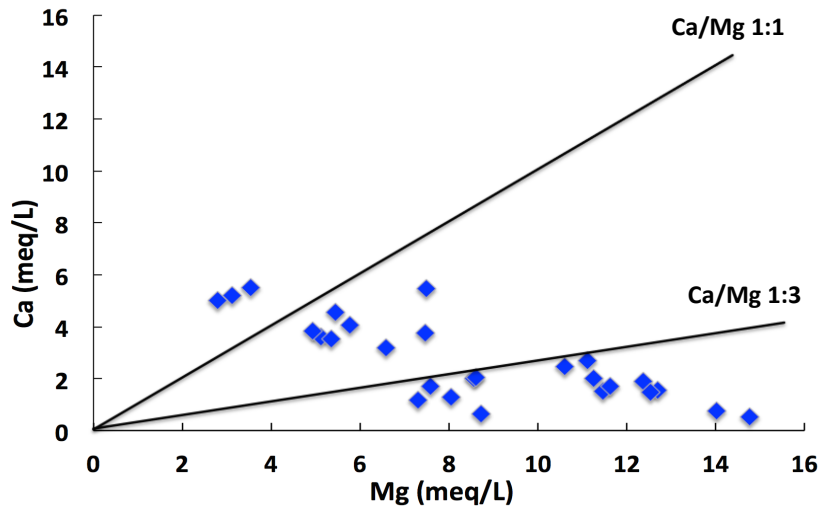


Figure 5. Bivariate plot of Ca vs. Mg for all groundwater samples in dry and wet seasons.

Cr in groundwater samples range from 0.75 to 16.91 $\mu\text{g/l}$ with a mean of 4.67 $\mu\text{g/l}$ for dry season and from 1.02 to 14.82 $\mu\text{g/l}$ with a mean of 4.36 $\mu\text{g/l}$ for wet season as shown in (Table 1). This is comparable to reported values from Greek ophiolites in Greece (Voutsis et al., 2015). The average of two seasons is much higher than the natural average in groundwater (1 $\mu\text{g/l}$) (DFPC, 2015), but less than the maximum permissible limit of Cr_{tot} in drinking and irrigation water, respectively (50,100 $\mu\text{g/l}$) according to (WHO, 2011). The presence of Cr in the groundwater samples is related to the ophiolitic rocks in the study area which

contain high concentration of Cr(III) between (17 - 449 mg/kg) in gabbro rocks in ophiolitic dykes and between (100 - 1663 mg/kg) in ophiolite sole amphibolites (Al-Riyami et al., 2002). The rock weathering is possibly the main responsible processes for the Cr mobility from the bedrock to sediments, soils and water. Cr(III) rich minerals may be oxidized to Cr(VI) by natural oxidants such as manganese oxides, which are the most effective electron acceptors for Cr(III) oxidation under certain environmental conditions of groundwater (Oze et al., 2007). Such phenomena take place in several areas worldwide, in Italy (Fantoni et al., 2002) and in Greece (Megremi, 2010). The concentrations of Ni(II) in the groundwater samples range from (2.19 - 19.27 µg/l) with a mean value of 5.63 µg/l for dry season and from (1.32 to 17.3 µg/l) with a mean value of 4.52 µg/l for wet season (Table 1). The amounts are less than the maximum permissible limit of Ni in drinking and irrigation water, (20, 200 µg/l) respectively according to (WHO, 2011) and this is comparable to mean Ni value reported from Greek ophiolites in Greece (3.11 µg/l) (Voutsis et al., 2015). Ni concentration depends on groundwater pH, which are relatively low in the case of neutral and alkaline groundwater, due to its enhanced adsorption and incorporation onto clays and/or Fe and Mn (hydr)oxides (Dublet et al., 2012). The origin of nickel is the ophiolitic rocks of the study area which contain from (33 - 190 mg/kg) in gabbro and from (100 - 829 mg/kg) in amphibolites (Al-Riyami et al., 2002). Cobalt is normally associated with nickel, the majority of groundwater samples have low concentration of Co below 1 µg/l, exceptionally it is high in the sample S2 (1.25, 1.78 µg/l) for the dry and wet seasons, respectively as shown in (Table SI-3). However, the values still less than the maximum permissible limit of Co in drinking and irrigation water (50, 50 µg/l) respectively (WHO, 2011). In general, the maximum concentrations of heavy metals in groundwater samples for two seasons (Cr 16.91 µg/L, Ni 19.27 µg/L, Co 1.78 µg/L) (Table 1) were less than the maximum permissible values for drinking water (Cr 50 µg/L, Ni 200 µg/L, Co 50 µg/L) proposed by (WHO, 2011). The lower concentration of (Cr, Ni) could explain by the solubility of Cr and Ni in water is pH dependent to some degree; the chromium is soluble at pH values of less than 4 and the solubility of nickel occurs only at pH value of less than 5.5 (Rahim et al., 1996). The pH values of the groundwater samples for two seasons range from (7.21 to 8.67) which indicates circumneutral to slightly alkaline preventing significant metal solubility.

4.5. Irrigation Water Quality

Assessment of groundwater quality for irrigation was accomplished using salinity hazard (EC), sodium adsorption ratio (SAR), soluble sodium percentage (SSP or % Na), and magnesium adsorption ratio (MAR) (Aghazadeh & Mogaddam, 2010). Summary of irrigation-water parameters for groundwater samples in wet and dry seasons are shown in Table 2. These parameters including statistical measures, such as minimum, maximum, mean concentrations, and standard deviation (SD).

4.5.1. Soluble Sodium Percentage (SSP)

The SSP% of groundwater samples for dry and wet seasons were ranged from 5.61% to 29.83% and from 7.01% to 27.23%, with mean values were 18.28% and 18.83%, respectively as shown in (Table 2). The Wilcox (1955) diagram (Figure 6(a)) relating electrical conductivity (EC) and sodium percentage shows that 95.6% of the samples fall in the good to permissible range and the remaining samples fall under excellent to good range. This makes the groundwater in the study area suitable for irrigation.

4.5.2. Sodium Adsorption Ratio (SAR)

The mean SAR values of groundwater samples are 0.66 and 0.69 for dry and wet seasons, respectively as shown in (Table 2), indicating water suitability for

Table 2. Summary of irrigation-water parameters for groundwater samples in wet and dry seasons.

Parameters	(Dry season, August 2020)				(Wet season, April 2020)			
	Min	Max	Mean	SD	Min	Max	Mean	SD
SAR	0.17	1.26	0.66	0.35	0.21	1.15	0.69	0.32
SSP	5.61	29.83	18.28	7.65	7.01	27.23	18.83	6.92
MAR	25.41	96.56	73.81	21.71	25.43	94.87	67.20	25.02
EC ($\mu\text{S}/\text{cm}$)	710	1090	949	112.8	750	1360	1055	163.7

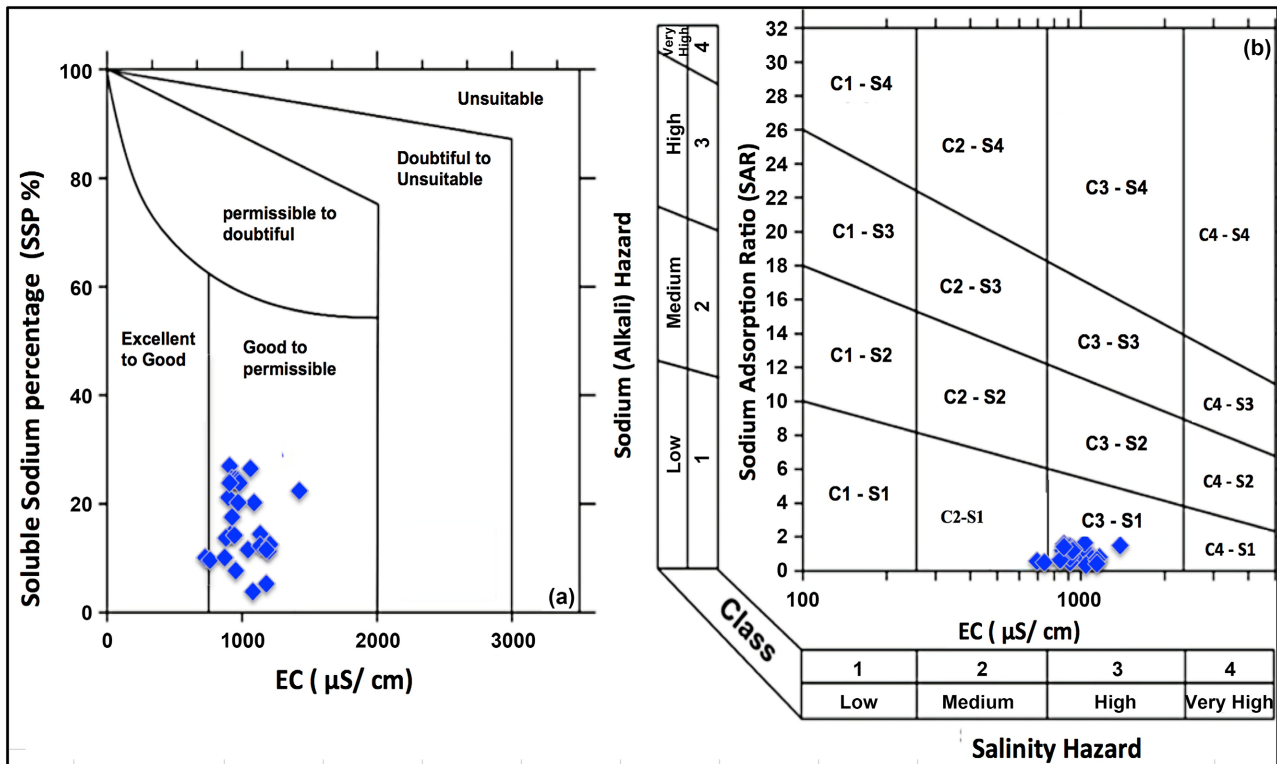


Figure 6. Suitability of groundwater quality for irrigation purposes based on (a) The Wilcox diagram (Wilcox, 1955) and (b) US salinity diagram indicate the ratio of SAR versus EC ($\mu\text{S}\cdot\text{cm}^{-1}$) (Richards, 1954) for all groundwater samples in two seasons.

irrigation according to the classification (Todd, 1980). To develop the suitability of water for irrigation purposes, Richards plot (SAR versus EC) was used (Figure 6(b)) (Richards, 1954). It was shown 89% of samples were classified as (C3-S1) indicating the high-salinity-low sodium, which suggests that this groundwater is not suitable for irrigation due to its high salinity. It could only be used to irrigate certain semi-tolerant crops (Ahamed et al., 2013). Only ~11% of samples were classified as (C2-S1) indicating medium salinity-low sodium, which could be used for irrigation for all types of soil.

4.5.3. Magnesium Adsorption Ratio (MAR)

MAR values of groundwater samples in dry and wet seasons range from 25.4 to 96.56% (mean = 73.81%) and from 18.4% to 94.87% (mean = 67.2%), respectively as shown in (Table 2). A value of MAR > 50 indicates harmful groundwater and unsuitable for irrigation, while a value of MAR < 50 indicates suitable groundwater (Gupta & Gupta, 1987). Furthermore, 22 samples (~82% of the total samples) had MAR values high of 50% for dry and wet seasons and as such unsuitable for irrigation, and only 5 samples (~18% of the total samples) had (MAR) values below 50% for dry and wet seasons and as such suitable for irrigation as shown in (Table SI-4).

5. Conclusion

The present work reveals adequate background information on hydrogeochemical properties and contamination levels of some heavy metals in the groundwater in the Bassit ophiolitic area (northwestern Syria). The results demonstrate that the groundwater is very hard and slightly alkaline in nature. The concentrations of major ions are in the following order: $Mg^{2+} > Ca^{2+} > Na^+ > K^+$ and $HCO_3^{2-} > Cl^- > SO_4^{2-} > NO_3^-$. The dominant hydrogeochemical facies of groundwater in the study area are Mg-HCO₃ (up to 60% of the samples), Mg/Ca-HCO₃ Mixing type (~30% of the samples) and Ca-HCO₃ type (~10% of the samples), which reflect an influence of ophiolitic rocks on the local groundwater chemistry. No change in groundwater type was recorded temporally (in dry and wet seasons). The maximum concentrations of some heavy metals for two seasons were (Cr_{tot} 16.9, Ni 19.27, Co 1.78 all in µg/L), which are less than the permissible limits for drinking purpose. Generally, the sampled groundwater was found to meet drinking water quality guidelines for most of the physicochemical quality properties. However TDS, TH and Mg²⁺ concentrations in most groundwater samples were in excess of maximum permissible limits, that could lead to health problems. Groundwater quality for irrigation was classified based on SAR, SSP% and MAR indices, SAR has indicated that all the samples belong to the excellent category. The Wilcox diagram shows that 95% of the samples fall in the field of good to permissible and the remaining samples fall in the field of excellent to good range. The analytical data plotted on the US salinity diagram illustrates that 89% of the groundwater samples fall in the field of C3-S1, indicating high salinity and low sodium water and the remaining samples fall in the field of

C2-S1, indicating medium salinity and low sodium water. The magnesium hazard (MAR) shows that 82% of the samples had MAR values high (>50%) and as such unsuitable for irrigation, and the remaining samples classified as such suitable for irrigation as shown in (Table SI-4). Land irrigated with such groundwater will not be exposed to any alkali hazard, but will suffer from a salinity hazard and magnesium hazard. Thus, most of the groundwater in the study area can be used for soils with good drainage conditions which control salinity.

Acknowledgements

I would like to thank Dr. Hajar Nasser and Dr. Omar Jaafar in the Faculty of science at Tishreen University for their support during the field exercise and for their suggestions that improved the scientific soundness of this manuscript.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Supporting Information

Table SI-1. Concentrations of selected elements and physico-chemical parameters of groundwater samples in dry season.

Name Sample	Groundwater (Dry season, August 2020)							NO ₃ mg/l	EC μS/cm	TDS mg/l	pH
	Cation				Anion						
	Ca ²⁺ mg/l	Mg ⁺² mg/l	K ⁺ mg/l	Na ⁺ mg/l	SO ₄ ²⁻ mg/l	Cl ⁻ mg/l	HCO ₃ mg/l				
Spring S1	38.56	150.33	0.22	29.74	14.09	41.74	600	13	1010	780	7.36
Spring S2	54.65	135.12	0.93	36.71	17.96	46.21	532	15	1090	719	7.21
Spring S3	41.28	104	0.73	42.00	26.16	44.22	450	6	1053	695	7.73
Spring S4	112.3	42.97	2.26	28.79	29.45	46.62	400	12	890	597	7.22
Spring S5	31.89	154.15	3.19	28.35	15.98	42.01	514	22	1090	731	7.46
Well S6	26.45	97.87	0.31	17.09	11.51	21.03	440	7	710	476	7.86
Well S7	30.12	152.16	0.65	10.19	9.01	16.01	591	4	1040	698	7.66
Well S8	73.44	62.3	0.16	57.54	93.87	55.85	289	50	880	590	7.4
Well S9	76.53	90.66	0.55	68.79	117.38	99.99	311	40	1030	680	7.36
Well S10	65.30	79.9	0.84	44.49	38.58	55.036	320	26	870	574	7.27
Well S11	13.02	106	0.29	22.19	11.25	25.87	527	6	855	564	7.98
Spring S12	10.73	179.36	0.37	19.91	13.40	30.81	340	28	922	608	8.17
Well S13	82.39	70.18	1.28	55.59	40.36	59.78	311	19	901	595	7.22
Spring S14	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry

Table SI-2. Concentrations of selected elements and physico-chemical parameters of groundwater samples in wet season.

Name sample	Groundwater (Wet season, April 2020)							NO ₃ ⁻ mg/l	EC μS/cm	TDS mg/l	pH
	Cation				Anion						
	Ca ²⁺ Mg/l	Mg ²⁺ mg/l	K ⁺ mg/l	Na ⁺ mg/l	SO ₄ ²⁻ mg/l	Cl ⁻ mg/l	HCO ₃ mg/l				
Spring S1	41.01	136.87	1.35	25.93	15.91	41.39	493	18	1150	771	7.98
Spring S2	50.52	128.82	0.42	30.54	22.73	49.90	443	20	1160	777	7.67
Spring S3	41.34	104.48	0.42	36.08	30.40	44.59	429	10	901	604	7.97
Spring S4	106.23	37.97	2.37	25.75	30.97	45.23	442	18	918	615	7.65
Spring S5	30.48	139.15	4.91	24.31	17.72	43.16	600	23	1140	764	7.99
Well S6	24.21	88.87	0.39	14.62	13.32	23.32	700	5	750	502	8.67
Well S7	34.94	141.16	0.83	12.45	6.26	16.8	510	28	1140	764	8.45
Well S8	78.11	59.95	0.14	51.53	113.82	46.64	325	50	922	618	7.78
Well S9	111.71	90.928	0.45	67.01	127.39	102.83	785	42	1360	911	7.76
Well S10	71.81	64.90	0.914	49.55	48.24	69.24	550	20	940	630	7.4
Well S11	34.41	92.00	0.20	45.27	12.20	33.69	333	20	948	635	8.45
Spring S12	15.45	170.36	0.51	25.26	19.26	32.35	564	25	850	570	8.01
Well S13	92.69	66.18	1.20	45.42	35.39	53.79	770	7.21	941	630	7.98
Spring S14	102	33.96	0.54	48.30	22.59	38.48	666	5	881	590	7.61

Table SI-3. Concentrations of heavymetals (Cr, Co, Ni) for the groundwater samples in dry and wet seasons.

Sample name	Groundwater (Dry season, August 2020)			Groundwater (Wet season, April 2020)		
	Cr (ppb)	Co (ppb)	Ni (ppb)	Cr (ppb)	Co (ppb)	Ni (ppb)
S1	16.91	0.55	19.27	14.82	0	17.3
S2	9.19	1.25	5.78	13.65	1.78	4.2
S3	2.03	bdl	2.62	5.02	0	2.1
S4	9.48	0.87	5.96	4.21	0.81	5.2
S5	3.55	0.55	2.54	1.23	bdl	1.32
S6	3.6	0.49	10.55	1.02	0.52	8.61
S7	4.39	0.55	3.81	6.09	0.51	3.03
S8	0.75	bdl	4.11	5.31	bdl	3.8
S9	0.95	0.68	2.19	bdl	0.67	2
S10	1.39	0.71	4.29	3.01	bdl	3.52
S11	1.07	bdl	6.88	1.09	bdl	4.94
S12	2.81	bdl	5.22	3.91	0.11	4.52
S13	4.62	0.3	bdl	1.65	0.37	2.8
S14	dry	dry	dry	bdl	0.98	bdl

Table SI-4. Result of irrigation-water parameters for groundwater samples in dry and wet seasons.

Sample name	Groundwater (Dry season, August 2020)			Groundwater (Wet season, April 2020)		
	SAR	MAR * 100	SSP%	SAR	MAR * 100	SSP%
S1	0.48	86.74	13.69	0.44	84.9	13.30
S2	0.61	80.58	16.55	0.52	81.1	14.72
S3	0.79	80.87	22.73	0.68	80.9	20.02
S4	0.59	39.10	16.66	0.55	37.5	16.32
S5	0.46	89.03	14.50	0.42	88.5	13.58
S6	0.34	86.13	12.28	0.31	86.0	11.72
S7	0.17	89.45	5.61	0.21	87.1	7.01
S8	1.20	58.74	29.83	1.07	56.3	27.23
S9	1.26	66.53	29.32	1.15	57.7	24.98
S10	0.88	67.25	23.79	1.02	60.3	26.96
S11	0.45	93.18	15.89	0.92	81.8	26.45
S12	0.31	96.56	9.64	0.40	94.9	12.18
S13	1.09	25.41	27.15	0.88	25.4	22.69
S14	dry	dry	dry	1.06	18.4	26.43

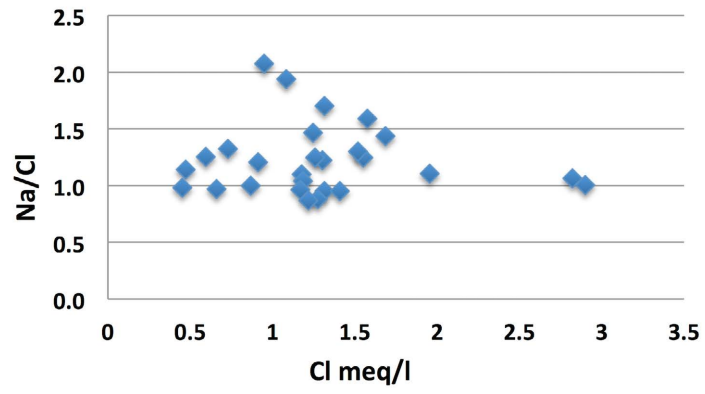


Figure SI-1. The Na/Cl ratios versus Cl (meq/L) for the groundwater samples in wet and dry seasons.