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EVALUATION OF GROUNDWATER QUALITY OF THE UPPER ALLUVIAL FAN AQUIFER AND ITS POTENTIAL USES FOR DIFFERENT PURPOSES IN THE TERSAQ AREA, EAST IRAQ

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ABSTRACT

The present study is devoted to evaluate groundwater quality and its suitability for different purposes in the Tersaq Area. The study area is an arid region located in eastern Iraq at the border between Iraq and Iran, covering an area of 1730 Km^2, mainly covered by the Quaternary sediments (alluvial fans and sheet run off sediments). It suffers water scarcity exacerbated lately by climate change, and increasing control of river water flow from the Iranian side by hydraulic structures. Forty water samples are collected from wells penetrating the alluvial fan, springs gushing at the up and down slope of the fan and water appearing in the course of the perenneil streams in the area during wet and dry seasons. The samples are analyzed for major cations and anions as well as for minor ions: hydrogen sulfide gas, fluoride, and physiochemical properties and trace elements (Ba, Zn, Cu, P, Ni, Cd, Co and Cr). The results show that most water samples are brackish with either chloridic or sulphatic water type that are suitable to irrigate some salt-tolerant crops such as wheat, barley and palms, and only so due to the good infiltration capacity of the soil and its low sodium absorption ratio. They are also suitable for livestock drinking. However, the water of the springs spreading along the Himreen Mountain flank is of fresh type suitable for human drinking. The main factors affecting water chemistry are evaporation process and the dissolution of the evaporitic rocks such as gypsum and anhydrite.

تقييم نوعية المياه الجوفية لخزان المروحة الغرينية العلوي وصلاحيته للاستخدامات المختلفة في منطقة ترساق، شرق العراق

حسين عبد جساس و يونس ابراهيم اسماعيل الساعدي

المستخلص

هذه الدراسة مكرسة لتقييم نوعية المياه في منطقة ترساق واستخداماتها لمختلف الأغراض. منطقة الدراسة من المناطق شبه الجافة التي تقع شرق العراق قرب الحدود العراقية – الإيرانية بمساحة تقدر بـ 1730 كم^2 مغطاة بشكل رئيسي بترسبات العصر الرباعي (ترسبات المراوح الغرينية وترسبات الجريان السطحي). تعاني المنطقة من شحة في المياه نتيجة التغيرات المناخية واحكام السيطرة على كمية المياه المتدفقة نحو المنطقة من قبل الجانب الإيراني والذي قام بإنشاء المزيد من المشاريع الإروائية في الجانب الإيراني. تم التقاط أربعين نموذج مائي خلال موسمي الجفاف والوفرة المائية من 8 آبار محفورة ضمن ترسبات المراوح الغرينية و 8 ينابيع تنبع من أعلى وأسفل منحدر المراوح الغرينية و 4 نماذج من الوديان الموسمية. تم إجراء التحليلات المختبرية اللازمة لتحديد تراكيز الأيونات الرئيسية الموجبة والسالبة، غاز كبريتيد

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الهيدروجين، الفلورايد، والعناصر الشحيحة (Ba، Zn، Cu، Pb، Ni، Cd، Co و Cr) في حين تم قياس بعض الخصائص الفيزيوكيميائية في الحقل. بينت النتائج ان أغلب عينات المياه هي مياه معتدلة الملوحة (مسوسة) ذات نوعية كلوريدية وبعضها الآخر كبريتية، وهي مناسبة لسقي بعض المحاصيل التي تتحمل الملوحة (كالنخيل، الشعير والحنطة)، حيث ان سعة ترشيح التربة العالية وقيمة نسبة امتزاز الصوديوم المنخفضة تقلل من مخاطر تسبخ التربة. وهذه المياه مناسبة أيضاً لشرب الحيوانات. من ناحية أخرى فإن الينابيع على امتداد سفح جبل حمرين مياهها عذبة، في حين ان الينابيع على امتداد الحافة الجنوبية للمروحة الغرينية الفعالة ذات مياه معتدلة الملوحة. أهم العوامل التي تؤثر على نوعية المياه في منطقة الدراسة هو التبخر وإذابة الصخور التبخرية كالجبس والأنهيدرايت.

INTRODUCTION

Arid regions which include arid, hyper-arid, semi-arid and dry sub-humid regions, cover about 41% of the Earth’s surface and are considered the most vulnerable regions to water crisis particularly in Asia, Sub-Saharan Africa, and Latin America where the poor and underdeveloped countries are located (Mortimore, 2009). These regions face the greatest pressures on their limited freshwater resources and this continues to get wores (UNESCO, 2015). Studies on arid and semi-arid regions showed the importance of water management and assessment in any integrated development strategy (Kolsi *et al*., 2013; Ramadan, 2015; El Alfy, *et al*., 2015). Challenges facing water managers in arid regions include food security, climate change, population growth, salinity increase and pollution from various sources. Accordingly, the results of the hydrogeological and environmental studies conducted in these regions could serve as a scientific background for sustainable water resources management. In this regard, accurate assessment of the available and renewable water resources is essential to improve the scientific understanding to facilitate enhancing water governance and to reach to integrated management of water resources in these regions.

The quality of water is as important as its quantity. The required quality of water supply depends on its purpose; thus, the needs for drinking, industrial, and irrigation water vary widely (Todd, 1980). Major factors that control the evolution of groundwater and surface water quality are aquifer mineralogy, water rock interactions, flow velocity, distance along flow paths, residence time, and mixing processes (Hudak, 2000).The study of water quality involves a description of the occurrence of various constituents and the relation of these constituents with the surrounding materials. In addition, groundwater quality gives important clues to the geological history of rocks and indications of groundwater recharge, discharge, movement, and storage (Walton, 1970). The concentration of different constituents varies spatially and temporally, due to the fact that the concentration of different ions increases along the flow path and the duration of water contact with rocks through which it flows (Domenico and Schwartz, 1998). Trace elements which are defined as metallic, metalloids and radionuclide elements present in minute concentrations, occur naturally as a result of the weathering of the rocks or as a result of anthropogenic activities (Drever, 1997). These elements affect animals and plants, even though they are in very small concentrations (Davis and Deweist, 1966). Therefore, measuring the concentration of trace elements in water is important, especially when evaluating drinking water.

The study area is considered as a part of the zone that extends along the eastern Iraq – Iran border between Khanaqin and Al-Teeb, which has the same nature and circumstances. This zone is characterized by arid to semi-arid climate with limited water resources to meet the agricultural, industrial and domestic requirements. Many geological and hydrogeological studies have been conducted on this zone covering part or the entire area of interest. Parsons (1955) documented primary information about water resources of Badra – Jassan area including wells, springs, and kihreez and delineated the main water bearing formations.

Macdonald and Partners (1970) evaluated the surface- and groundwater of Galal valley to irrigate Badra, Jassan and Zurbatiyah areas. Khalil *et al*. (1972) conducted a hydrogeological investigation in Badra – Jassan area. Hassan *et al*. (1977) introduced an integral hydrological study, depending on the available information, to characterize the hydraulic parameters of the aquifers, hydrochemistry, and river system of Gala Badra Basin. Yacoub (1983) prepared the geological map of Mandili Quadrangle (NI-38-11), scale 1: 250 000, as a part of the Mesopotamian Plain project. Barwary (1991) prepared a geological report including the geological map of Mandili Quadrangle (NI-38-11), scale 1: 250 000. Al-jiburi (2004) conducted a hydrogeological and hydrochemical study of Mandili Quadrangle to produce hydrogeological map of the area, scale 1: 250 000. The current study is an attempt to assess the groundwater quality and to evaluate its suitability for different uses in Tersaq area which suffers water resources scarsity.

STUDY AREA

The study area extends along Iraq – Iran border, eastern Iraq, 30 Km southeast of Mandili City and 35 Km northwest of Badra City, covering an area of about 1730 Km^2 (Fig.1). The area is bounded by the Himreen structure from the northeast and the edges of alluvial fans from the southwest. It is covered mainly by the Quaternary sediments, while the pre-Quaternary rocks, are exposed along the Himreen structure (Fig.2). According to Barwary (1991), the stratigraphic sequence involves different geological formations, ranging in age from the Middle Miocene to Pliocene represented by the Fatha, Injana, Mukdadiya and Bia Hassan formations.

The Fatha Formation (Middle Miocene) consists of claystone followed by marl, thin limestone and thick gypsum. The Injana Formation (Upper Miocene) consists of monotonous alternation of sandstone, claystone, and siltstone. The Mukdadiya Formation (Pliocene) is composed of alternation of medium-coarse grained sandstone, siltstone and claystone beds. The sandstone beds contain very often pebbles (scattered in lenticels). The Bia Hassan Formation (Pliocene) consists mainly of conglomerate, sandstone and clay. The Quaternary sediments involve three main types: **i)** Alluvial Fan Sediments (Pleistocene – Holocene) form a continuous belt along the southwestern limb of Himreen structure, and consist of poorly sorted clastic sediments, usually gravels and boulders with subordinate amount of sand, silts and clays; secondary gypsum is usually associated with alluvial fan sediments **ii)** Slope Sediments (Pleistocene – Holocene) which are usually developed on foothill slopes and composed generally of gypsiferous sand or loam with rock fragments and gravels **iii)** Sheet-run-off Sediments (Pleistocene – Holocene) occupy wide areas between the alluvial fans; floodplain and shallow depression fill units within the study area, and is built up of silty clays, silts and sands. The most prevailing sediments are silty clay and clayey silt with some sand admixture.

Structurally, the study area lies in the eastern part of the Mesopotamian Zone and the southeastern part of the Foothill Zone (Buday, 1980). The late regional intensive tectonic movements caused the uplifting of the Himreen structure in the Foothill Zone and the development of asymmetrical syncline in the Mesopotamian Zone. The major part of the study area lies within the Foothill Zone (Mukdadiya Zone) which is characterized by the still rising Himreen Anticline (Fouad, 2010). The Himreen Anticline runs almost parallel to Iraq – Iran border, with the southwestern limb of the anticline is within the study area and the main axis is in Iran (Buday, 1980).

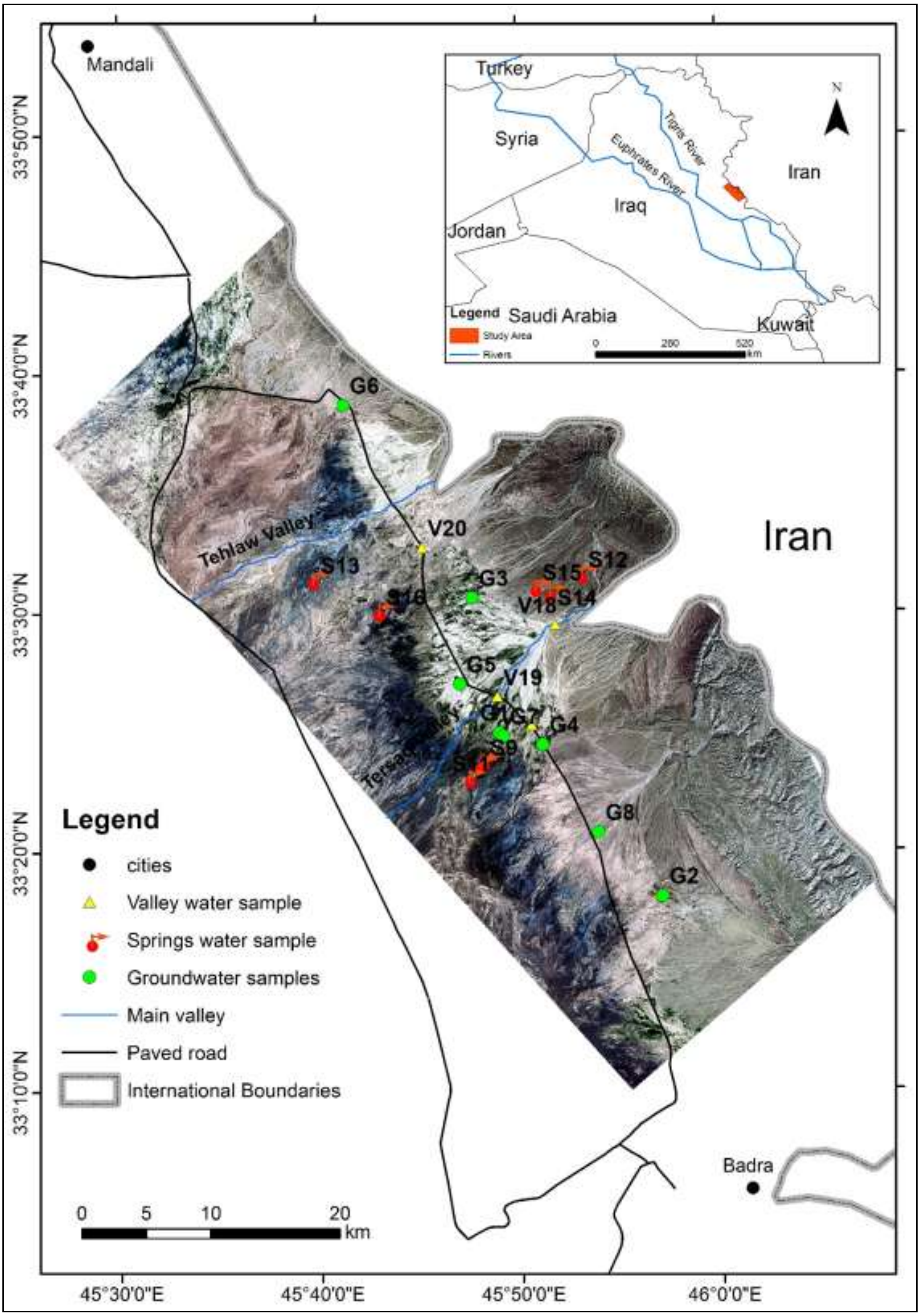

Fig.1: Location map of the study area, showing the sampling sites, 4 valley water samples (yellow triangle), 8 spring samples (red circle), and 8 groundwater samples (green circles)

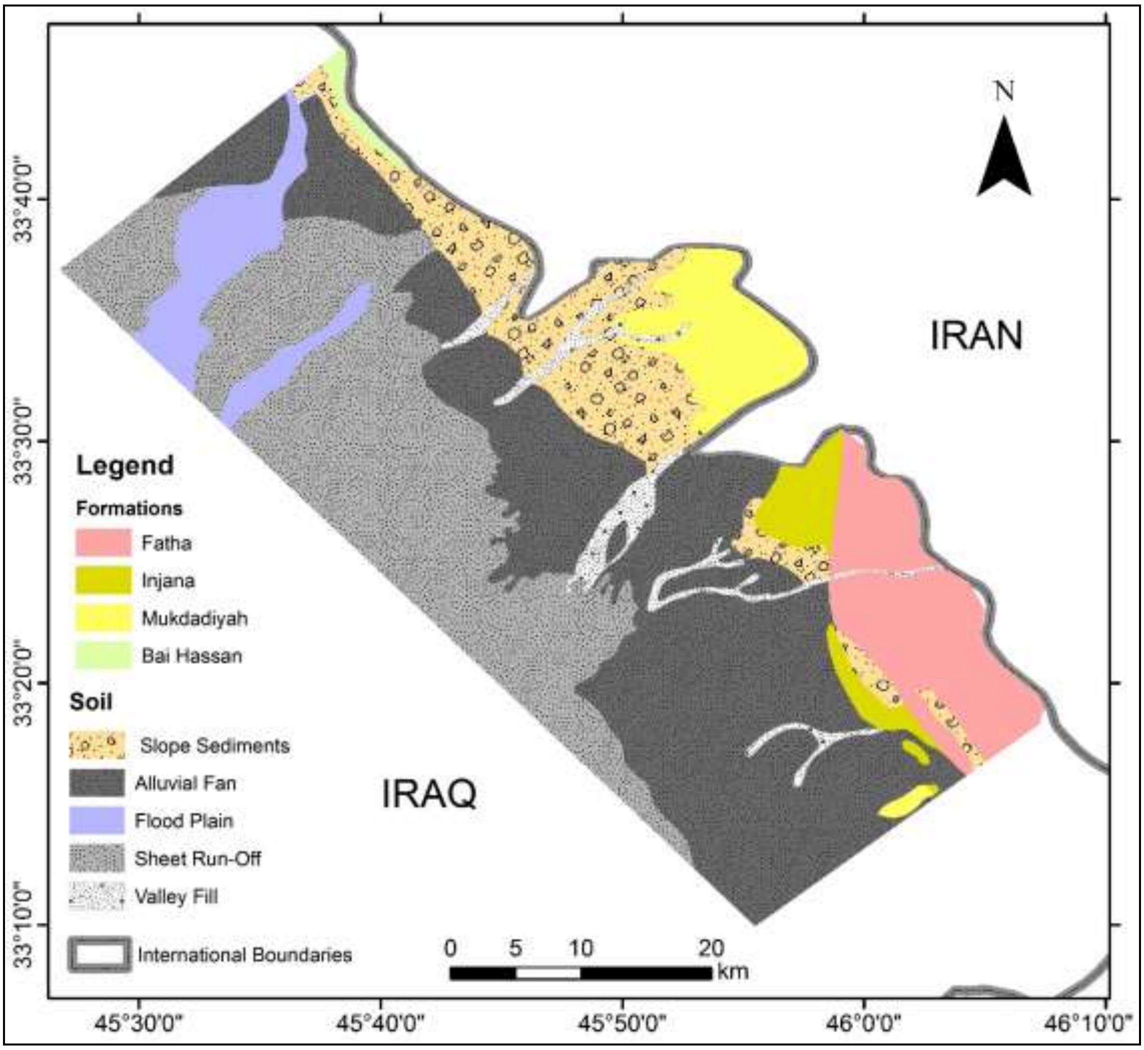

Fig.2: Geological map of the study area (modified after Barwary, 1991)

The study area is a part of the Foothill Zone which is characterized by hilly terrain in the eastern and northeastern parts and gently sloping pediment plain in the central and southwestern parts. The topography of the study area is mountainous in the northeastern parts, with elevations not more than 707 m.a.s.l., and not more than 40 m.a.s.l in the south eastern plains. Two main valleys cross the Tersaq area, Galal Tersaqe at the south and Galal Tehlaw at the north. The geomorphological development in the study area is controlled basically by structure, climate and lithology (Buday, 1980).

CLIMATE

The climate, controlled by altitude and geographic location, is considered as the main factor affecting the hydrogeological system of an area (Wilson, 1983). Within the geological frame, the climate variability beside the topographical factors can affect the rate of groundwater recharge, the intensity of groundwater flow, and water losses by evaporation and evapotranspiration (Krasny *et al*., 2006). Therefore, understanding the climate is vital to evaluate the availability and sustainability of groundwater. In this study, the Badra meteorological station is selected to evaluate the climate in the Tersaq area, where it is the nearest station. The meteorological data of the Badra station is available for the period (1992

– 2005). For this station, the average annual temperature, precipitation, and pan evaporation are 24 ºC, 185 mm, and 3127 mm, respectively (Fig.3). The study area is characterized by a continental climate (Mediterranean type), being cold rainy in winter and hot dry in summer, and according to the aridity index (UNEP, 1992) the study area is classified as an arid region.

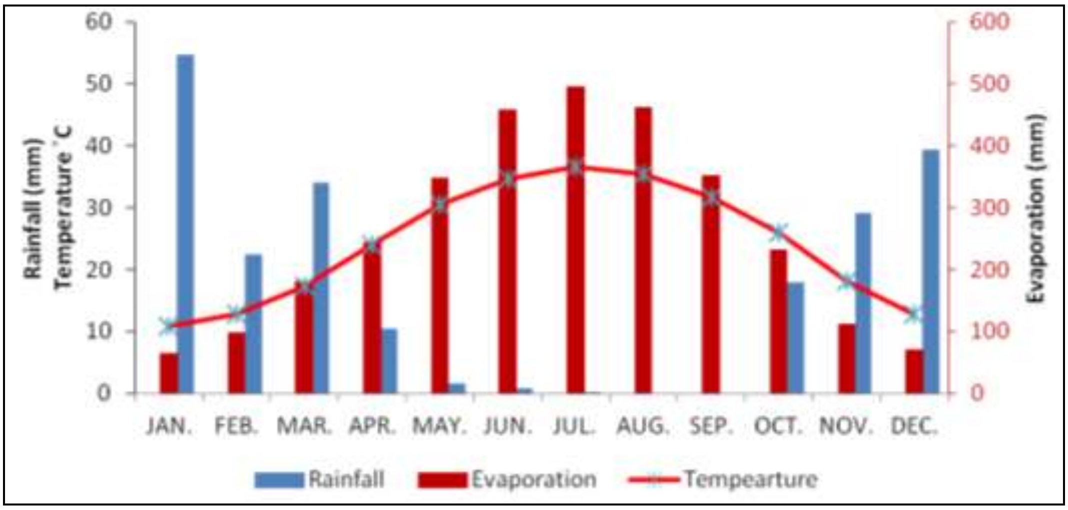

Fig.3: Long-term mean monthly climatic parameters in the Badra meteorological station

HYDROGEOLOGY

The Quaternary sediments (alluvial fan sediments) represent the main upper aquifer in the study area. These sediments cover vast portion of the study area except at the slopes of the Himreen Mountain where the Bai Hassan and Mukdadiya formations appear. These formations represent the main pre-Quaternary aquifers and composed of a belt of gravel and sand sediments, extending along the Iran – Iraq borders (Al-Jiburi, 2004). These aquifers are not yet developed in the region due to their high dissolved salts content (> 1000 mg/l). Sedimentologically, the Quaternary aquifer is composed of discontinuous lenticular bodies of fine – coarse gravels and sand, which vary vertically and horizontally (Barwary, 1991). Besides, there are variations in the hydraulic parameters, but in general the sediments have good permeability and high infiltration capacity. The thickness of the gravel and sand sediments is about 100 m within the Mandili region (Parsons, 1955) and about (65) m within the Badra region (Hassan *et al*., 1977). Therefore, these sediments form good aquifer in the study area, especially for the uppermost shallow aquifer, where the deeper aquifer seems to be of higher salinity. The Transmissivity of the alluvial fan sediments within the study area ranges between 32 – 153 m^2/day, the permeability ranges between 13m – 24 m/day (Parsons, 1955) and the water level depth ranges between 2.8 – 21 m below ground surface.

Many springs in the study area form an important source of water supply, practically the perennial springs which occur as natural ponds. The sub-ground flow of rainfall is the main source of the highland springs which are characterized by fresh water where the Total Dissolved Solids (TDS) is < 1000 mg/l. The lowland springs southwest the study area are of brackish water and represent natural discharge of groundwater along the margins of the active alluvial fans. Groundwater is recharged mainly from the upstream catchment outside the study area, and from some small watersheds inside the Iraqi border. Groundwater flows generally from northeast to south and southwest. The Tersaq and Tehlaw valleys are the main seasonal valleys in the study area (Fig.1), and most of their watersheds are in the Iranian side. The flow in these valleys are controlled by some hydraulic structures in the Iranian side leading to flow rate reduction even in wet seasons, although few flash floods occur after heavy rainfall. However, floodwater and even low river flow percolate into adjacent shallow Quaternary aquifers through the valley bed consisting of mainly gravel and sand, reappearing as baseflow in the downstream part of the river.

METHODOLOGY

Field trips were organized in 2010 during wet season (April) and dry season (October) to collect 40 water samples (in each season: 8 groundwater samples from wells (G1, G2, G3, G4, G5, G6, G7, G8), 8 samples from springs (S9, S10, S11, S12, S13, S14, S15, S16), and 4 valley samples (V17, V18, V19, V20) as shown in Figure 1. A GPS (Garmin eTrex Vista) handheld unit was used to determine the locations. Samples were collected in plastic bottles; cleaned 2 – 3 times by water samples before sampling.

The hydrochemical study involved analyzing the major cations and anions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-}, HCO_3^{-}), minor compounds (NO_3^{-}, P_2O_5, H_2S and F), and in situ measurements of TDS and pH. Two samples (G3 and S11) where further analyzed for the following trace elements: Ba, Zn, Cu, Pb, Ni, Cd, Co and Cr. The analyses were carried out in the laboratory of Iraq Geological Survey according to the standard procedure (Al-Janabi *et al*., 1992). The Ca^{2+} and Mg^{2+} ions were measured by titration with 0.05 EDTAN, whereas K^{+} and Na^{+} were measured using Flame Atomic Emission Spectrometry. The SO_4^{2-} and P_2O_5 were determined by the spectrophotometric device, and HCO_3^{-} was determined by titration with HCl, while the Cl^{-} was determined by titration with silver nitrate. The Spectroquant Analytical Test Kit Method was used to determine NO_3, while the ion selective method was used to determine F. The TDS was measured by gravimetric analysis. To determine the dissolved H_2S gas in water, the gas was preserved in the field by adding 10% Zn-acetate, then determined in the laboratory by titration with sodium thiosulphite. The trace elements were analysed by atomic absorption spectrometry. The degree of water hardness is an important factor for operational, aesthetic, and economic considerations. Therefore, the total hardness (TH) was calculated using the formula given by Todd (1980). To define the hydrochemical facies, a trilinear diagram (Piper, 1944) was used with the help of AquaChem 2011.1 software.

RESULTS AND DISCUSSION

- **Major cations and anions**

The analysis of TDS and major catios and anions are presented in Table 1 for wells (Table 1a), springs (Table 1b), and valley samples (Table 1c). For each group of samples and parameter, range and median values are given for wet and dry seasons.

The source of Na^{+} and Cl^{-} high presence is meteoric water and the dissolution of halite precipitates in the depressions as a result of high evaporation rate under the arid condition. Another source of Na^{+} in the groundwater is ion exchange and weathering of alumino-silicate minerals (Davis and Dewiest, 1966). Dissolving of the evaporite rocks (gypsum and anhydrite) increases Ca^{2+} and SO_4^{2-} in groundwater and surface water. The main source of calicium and magnisium is the weathering of carbonate cement material and weathering of carbonate rocks (limestone and dolomite). As mentioned before, the additional source of Ca^{2+} is the dissolving of evaporate rocks. The presence of Mg^{2+} in water causes, as in the case of Ca^{+}, hardening of water (Todd, 1980). Potassium has rather low concentration due to the low solubility of potassium bearing alumino-silicate minerals in water (e.g. orthoclase and muscovite). The main source of HCO_3^- is the dissolution of carbonate cementing material by the infiltrating water. The domination of major cations in groundwater is in the following order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, and anions $Cl^- > SO_4^{2-} > HCO_3^- > NO_3$. The classification of water samples was studied by plotting the concentrations of major cations and anions in the Piper diagram (Fig.4). The Trilinear plots show that among anions and cations, Cl^- and Na^+ have clear dominance followed by SO_4^{2-} and Ca^{2+}, where most of the samples are distributed in two types: Na – Cl and Ca – Cl, and occasionally Ca-SO_4.

Table 1: Range and median values of major chemical parameters in the water samples (mg/l)
Table 1a: Water wells samples

Chemical Parameter	Wet Season		Dry Season	
	Range value	Median value	Range value	Median value
TDS	1236 – 12630	4003	1280 – 12680	4124
Ca^{2+}	253 – 990	413	277 – 986	400
Mg^{2+}	17 – 151	55.5	7 – 156	86.5
Na^+	60 – 3186	987.5	45 – 3198	892.5
K^+	2 – 21.5	5.5	2.35 – 25.11	4.4
Cl^-	142 – 4722	1456	71 – 4730	1331
SO_4^{2-}	589 – 3120	1176	600 – 3127	1225
HCO_3^-	46 – 287	116.5	42.7 – 291.6	102.5

Table 1b: Springs water samples

Chemical Parameter	Wet season		Dry Season	
	Range Value	Median value	Range Value	Median Value
TDS	595 – 6260	1605	656 – 3328	1450
Ca^{2+}	136 – 721	216.5	140 – 687	212.5
Mg^{2+}	2 – 114	41	16 – 122	55.5
Na^+	48 – 1376	242.5	52 – 1182	220.5
K^+	1.41 – 6.65	2.9	1.4 – 5.4	3.3
Cl^-	53 – 2024	442.5	71 – 1864	433
SO_4^{2-}	192 – 1920	696	238 – 1889	596
HCO_3^-	40 – 243	85.5	40 – 177	109

Table 1c: Valley water samples

Chemical Parameter	Wet Season		Dry Season	
	Range Value	Median Value	Range Value	Median Value
TDS	2024 – 2708	2392	3036 – 3264	3150
Ca^{2+}	170 – 208	192.5	154 – 186	170
Mg^{2+}	19 – 36	29.2	47 – 48	47.5
Na^+	477 – 741	613.5	849 – 957	903
K^+	5.47 – 5.87	5.67	5.73 – 6.41	6.07
Cl^-	710 – 1101	923.2	1349 – 1509	1429
SO_4^{2-}	480 – 552	516	433 – 452	442.5
HCO_3^-	85 – 143	106.7	57 – 157	107

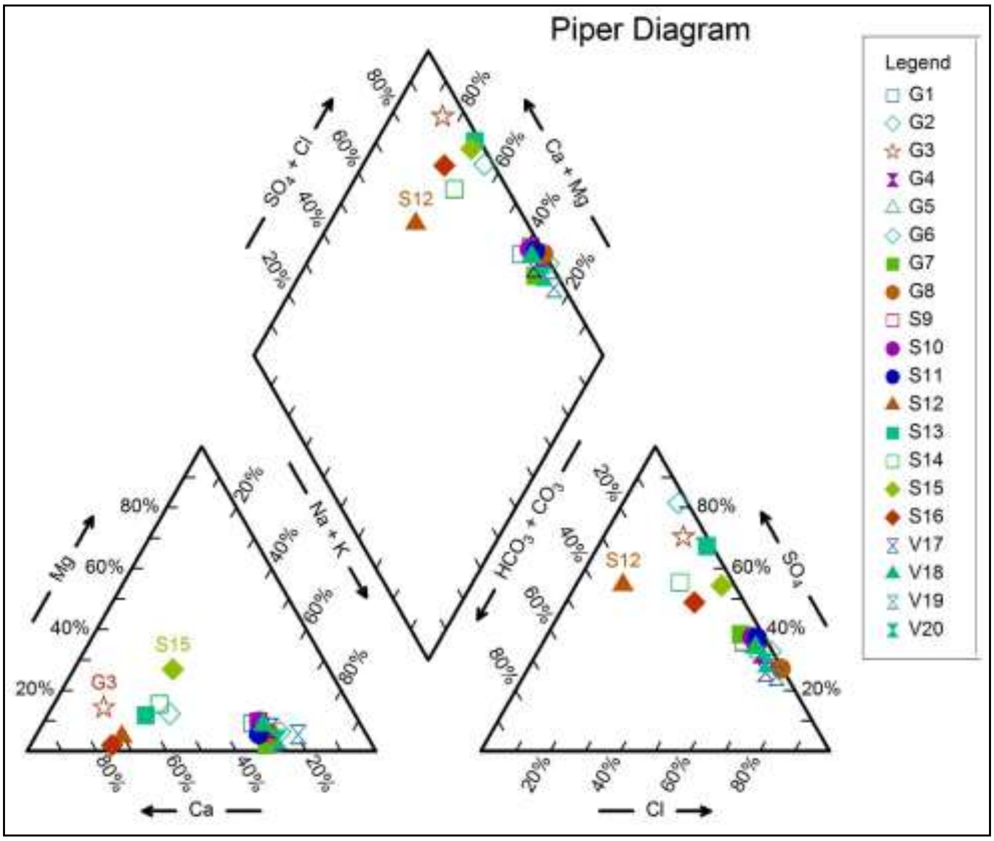

Fig.4: Piper diagram of groundwater (G), spring water (S), and valley water (V) samples

– **Physical Properties:** Odor and color in natural water come from organic material like algae, and from humus compounds (Pierce *et al*., 1998). All the analysed samples are odorless and colorless, whereas, the wells samples have slightly salty taste, except sample G3, valley water samples and some spring samples. Groundwater samples G2 and G8 are of saline type, where the TDS exceeds 10000 mg/l. The springs and Galal water also have slightly salty taste, except four springs located in the foothill area (samples S12, S14, S15 and S16), which are of fresh water type. The pH of all water samples was in the range 7.1 – 8.5; the springs water tends to be alkaline, and the pH was slightly higher during wet season than those in dry season. Moderately high pH values are commonly associated with water of high bicarbonate concentrations (Davis and Dewiest, 1966).

– **Total dissolved Solid (TDS):** TDS is a measure of the total amount of minerals dissolved in water, and it is a very useful parameter in the evaluation of water quality. It represents the total sum of cations and anions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, and SO_4^{2-}) and small amount of organic matter thatdissolved in water (WHO, 2006). According to Davis and Dewiest (1966) and Drever, (1997) classifications (Table 2), most of the water samples in the study area are brackish, as most of them have TDS in the range of 1000 – 10000 mg/l.

Figure 5 shows the spatial distribution of TDS in the groundwater of the alluvial aquifer. Only slight difference in TDS values are noticed in the wells samples taken in the wet season as compared to dry season. However, the valley water shows a remarkable difference as the TDS value ranges from (2024 – 2708) mg/l in the wet season climbs to (3036 – 3264) mg/l in the dry season. The brackish type of the valley water samples indicates that the source of that water is not only surface run off. Its presence in the valley during dry seasons reveals that it is a baseflow and its origin is either springs flow or groundwater seepage. During the wet season however, occasional runoff introduces fresh water that causes a temporary improvement of valleys water quality.

Table 2: Classification of water according to TDS values (mg/l)
(after Dewiest, 1966; and Drever, 1997)

TDS	Class According to Davies & Dewiest 1966	Class According to Drever 1997	Water type distribution ratio (%)		
			Wells	Springs	Valley Water Samples
< 1000	Fresh	Fresh	-	50	-
1000 – 2000		Brackish	12.5	-	-
1000 – 10000	Brackish		75	50	100
10000 – 100000	Salty water		12.5	-	-

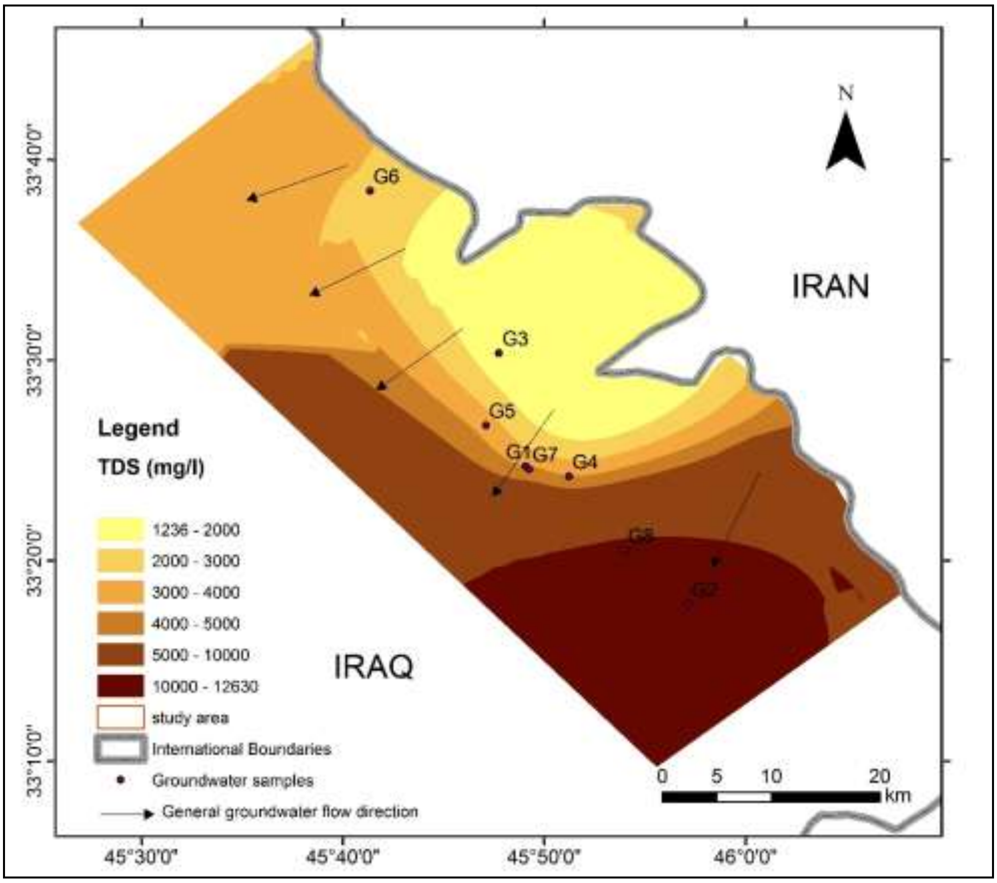

Fig.5: Spatial distribution of the TDS (mg/l) in groundwater samples (black dots) and the general groundwater flow direction (black arrows)

According to the classifications given in Table 2, four of the springs located in the Foothill Zone (S12, S14, S15 and S16) are classified as fresh water while the other four samples located at the discharge zone of the fan (S9, S10, S11, and S13) are of brackish water class as well as all valley and most of the wells water samples. Two wells (G2 and G8), which are believed to tap the older alluvial fan sediment, have salty groundwater. Salinity increases in the southeastern part of the study area and decreases towards northwest (Fig.5). The relatively low salinity in the middle part of the study area (sample G3) could be explained by the fact that the recharge source is the fresh water that discharges from the nearby springs. Salinity increases in the southeastern part due to the exitence of water within old and inactive alluvial fan with low recharge rate, and may be due to the leakage of the salty water from the deeper pre-Quaternary aquifers. A slight decrease in salinity occurs during wet season due to the dilution of groundwater by recharge. The fresh water of the foothill springs belongs to seepage of rainfall within the clastic sediments of the Mukdadiya Formation. The springs distributed along the alluvial fan edges are considered as natural discharge points.

– **Total Hardness (TH):** Total hardness mainly reflects water content of calcium and magnesium ions, and it is expressed by its equivalent from calcium carbonate according to the following equation (Todd, 1980):

$$TH = 2.497\ Ca + 4.115\ Mg$$

Where TH, Ca, Mg are expressed in (mg/l)

TH values during dry season of valley, springs and wells water are in the ranges of 585 – 627, 418 – 2219 and 720 – 3102 respectively with higher values during wet season. Water of the study area is therefore classified as very hard water according to Todd (1980) (Table 3). The main sources of Ca and Mg ions are the carbonate sediments (limestones, dolomite and the calcareous cementing material).

Table 3: Classification of Water Hardness (TH) according to (Todd, 1980)

TH (mg/l)	Class (Todd 1980)	Distribution ratio of TH (%)		
		Wells	Springs	Valley Water samples
7 – 75	Soft	-	-	-
75 – 150	Moderately Hard	-	-	-
150 – 300	Hard	-	-	-
> 300	Very Hard	100	100	100

- **Minor hydrochmical parameters**

Table 4 presents the range and average values of pH and some minor hydrchemical parameters, that affect water quality including NO_3, PO_4, H_2S and fluoride (F) during dry and wet seasons for all water samples. The pH is in the range 7.1 – 8.5, which means that the majority of dissolved inorganic carbonate is HCO_3^- (Drever, 1997).

The low concentration of nitrate (< 8 mg/l in average), which is below the background level of (<10 mg/l) (EEA, 2000), refers to low anthropogenic effect. The fuoride concentration in the groundwater varies with the type of rock in contact with the flowing water, but does not usually exceed 10 mg/l (WHO, 2006). The mean of measured concentrations of F in all samples is less than 0.4 mg/l. Phosphours is a rather common element in igneous rocks, and it is also a fairly abundant in sediments (Hem, 1991). The most common host mineral is apatite, which is calcium phosphate. Moreover, phosphorous compounds are present in many detergents, fertilizers and food products. Orthophosphate, polyphosphate and organic phosphate represent the usual forms of phosphorous found in aqueous solutions (Mckenzie *et al*., 2001). In spite of agricultural activities, the concentration of the P_2O_5 is below the detection limit (< 1 mg/l) for all samples. The relatively low concentration of nitrate, fluoride and phosphate could be attributed to the low application of fertilizer and relatively thick unsaturated zone and renewable groundwater.

Table 4: Range and mean values of pH and some minor chemical parameters that affect water quality (in mg/l)

	Dry Season (October)						**Wet Season (April)**					
	Wells water		**Valley water**		**Spring water**		**wells**		**Valley water**		**Spring water**	
	Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**
pH	7.1 – 7.6	7. 39	8.1 – 8.5	8.3	7.3 – 8.1	7.7	7.10 – 7.7	7.42	8 – 7.9	7.9	7.8 – 8.3	7.9
NO_3^-	2 – 8.7	3	1 – 1.2	1	2.8 – 15	9	0 – 25	8.6	5 – 2	2.5	4 – 27	13
PO_4^{3-}	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	2.5 – 3.7	3.1	0.7 – 8.7	3.2
H_2S	2.7 – 6.80	4.46	8.5 – 8	8.3	1.7 – 8	6.3	-	-	-	-	-	-
F	0.21 – 0.65	0.33	0.01 – 0.14	0.08	0.02 – 0.37	0.24	0.21 – 0.65	0.42	0.25 – 0.54	0.33	0.13 – 54	0.35

The "rotten eggs" odor of hydrogen sulfide is particularly noticeable in some groundwaters and stagnant drinking-water in the distribution system, as a result of oxygen depletion and the subsequent reduction of sulfate by bacterial activity (WHO, 2006). H_2S should not be detectable in drinking water by taste or odor. The concentration of dissolved H_2S gas was only measured in dry season, and it was for groundwater samples in the range 2.72 – 6.80 mg/l with an average of 4.46 mg/l, and in spring and valley samples in the range 1.7 – 8.5 mg/l with an average of 6.76 mg/l. It is obvious that there is pollution by H_2S gas, and that might cause diarrhea and nausea, and breathing this gas causes Blocking Oxidative Metabolism (WHO, 2006). The source of the H_2S could belong to gypsum metabolized by specialized sulfate-reducing bacteria via fermentation.

The concentration of trace elements (ppm) was determined for only two samples collected during dry season from a well used for drinking porpuse (sample G3) and a spring located at the edge of the active alluvial fan (sample S11). As shown in Table 5, the concentration of some trace elements is below the detection limit of the atomic absorption spectrometry device. It is therefor recommended to use Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for their low detection limits.

Table 5: Concentrations of the trace elements of two samples (G3 and S11) in ppm

Sample No.	**Ba**	**Zn**	**Cu**	**Pb**	**Ni**	**Cd**	**Co**	**Cr**
G3	N.D	0.2	N.D	N.D	< 0.2	< 0.1	N.D	N.D
S11	N.D	0.28	N.D	N.D	< 0.2	< 0.1	N.D	N.D

N.D: not detected

– **Water Suitability:**

- **For Human Drinking Purpose:** Water quality can be defined and standardized by means of indications expressing the limiting concentrations of relevant constituents and other water properties with regard to their health effect. The Iraqi standard (IRS, 1996) and the international standard (WHO, 2006) have been used as guides for drinking purpose (Table 6). All wells and valley waters are not suitable for drinking purpose because their TDS and concentration of most constituents are higher than the recommended levels of both standards. Sample (G3) has a close TDS value to the upper standard limlt but the concentration of its calcium sulfate is higher by far. On the other hand, the water quality of four spring water samples (S12, S14, S15 and S16) could be classified as suitable for human drinking according to the used standards, while the other four samples (S9, S10, S11 and S13) are not suitable due to their locations in the discharge zone of the fan.

Table 6: Mean of wet and dry seasons values of hydrochemical parameters for wells, springs, and valleys water samples in mg/l compared to IRS (1996) and WHO (2006) standards for human drinking purpose

Variables	pH	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CL^{-}	SO_4^{2-}	HCO_3^{-}	NO_3^{-}
IRS (1996)	6.5 – 8.5	1000	500	150	50	200	-	250	250	-	50
WHO (2003)	7 – 8	1000	100 – 500	75 – 200	30 – 150	200	12	250	250	200	50
G1	7.2	4108	1238	389	76	859	5	1225	1118	287	6.82
G2	7.1	12655	3055	982	154	3192	23	4726	3124	72	16.74
G3	7.4	1258	756	265	19	53	2	107	595	82	2.4
G4	7.5	4019	978	349	48	992	4	1474	976	137	3.72
G5	7.4	3570	1183	362	57	890	8	1403	927	139	6.82
G6	7.7	2740	1348	458	75	275	5	222	1588	105	24.8
G7	7.5	4266	1148	420	54	1016	5	1349	1284	260	9.92
G8	7.5	10920	2988	985	125	2709	13	4552	2295	45	13.5
S9	7.8	2858	942	271	56	690	4	977	791	106	27
S10	7.9	5744	1799	537	119	1279	6	1944	1621	197	4
S11	8.2	3090	1005	297	47	690	4	1034	849	84	8
S12	7.8	706	418	156	12	61	2	62	263	210	2.8
S13	8.3	4044	2219	704	104	361	6	648	1905	68	2.3
S14	8	789	464	142	25	88	1	129	323	129	5
S15	8	999	565	139	51	102	1	228	402	40	3.8
S16	7.9	680	430	140	9	65	3	239	246	80	6.4
V17	7.8	2826	523	181	42	775	6	1225	466	100	5
V18	7.9	2530	463	185	41	663	6	1030	481	125	1.2
V19	8.1	2708	428	170	28	741	6	1101	504	85	1
V20	8	2448	523	208	19	644	6	941	552	107	3

– **Water Uses for Livestock Purposes:** Water quality is evaluated for livestock uses depending on the classification proposed by Altoviski (1962). This classification sets maximum allowed concentration limits for some major cations and anions to each class. Table 7 presents a comparasim between these limits and the range of average concenration values representing wet and dry seasons. All Springs and valley waters range between very good to permissible for livestock as well as water samples of all wells, with the exception of two samples (G2 and G8) which are classified in a lower class, although they can be used for this purpose.

Table 7: Evaluation of water suitability for livestock using Altoviski (1962) classification

Altoviski (1962) Limits	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	TDS	TH
	(mg/l)						
Very Good	800	350	150	900	1000	3000	1500
Good	1500	700	350	2000	2000	5000	3200
Permissible	2000	800	500	3000	3000	7000	4000
Can be used	2500	900	600	4000	4000	10000	4700
Threshhold	4000	1000	700	6000	6000	15000	540000
Wells water	45 – 3198	253 – 990	16 – 151	71 – 4722	589 – 3127	1236 – 12680	712 – 3102
Springs water	48 – 1376	136 – 721	2 – 156	53 – 2024	192 – 1920	594 – 6260	343 – 2219
Valley water	477 – 957	154 – 208	19 – 48	710 – 1509	433 – 552	2024 – 3264	428 – 657

– **Water Uses for Irrigation and Agricultural Purposes:** Irrigation water criteria depend on the types of plants, amount of irrigation and soil and climate (Davis and Deweist, 1966). The suitability of water for irrigation depends on its own quality as well as on other factors; the same quality of water may be considered suitable for a certain type of soil or crop but is not suitable for others (Van Hoorn, *et al*., 1997). In general, The suitability of water for irrigation is determined according to the following three parameters:

- ***Total dissolved solids (TDS):*** Water for irrigation purposes is classified according to its salinity by Rhoades *et al*. (1992) into 6 categories, as shown in Table 8. Based on this classification, all water samples of both seasons are classified as "Moderately Saline", except two groundwater samples (G2 and G8) which are classified as highly saline.

Table 8: Classification of irrigation water according to TDS (Rhoades *et al*., 1992)

Water Class	EC ds/m	TDS (mg/l)	Type of water
Non-Saline	< 0.7	< 500	Drinking and irrigation water
Slightly Saline	0.7 – 2	500 – 1500	Irrigation water
Moderately Saline	2 – 10	1500 – 7000	Primary drainage water and groundwater
Highly Saline	10 – 25	7000 – 15000	Secondary drainage water and groundwater
Very highly Saline	25 – 45	15000 – 35000	Very Saline groundwater
Brine	> 45	> 35000	Sea water

- ***Sodium Percent Na%:*** Sodium content is usually expressed in term of sodium percent; also known as soluble sodium percentage (SSP), and it is an estimation of sodium hazard of irrigation water. It expresses sodium out of the total cations (Na%) which is calculated by the following formula (Todd, 1980):

$$Na\,\% = \frac{(Na + K) \times 100}{Na + K + Mg + Ca}$$

The concentrations are expressed in milliequivalents per liter. Based on Todd (1980), classification of irrigation water is based on the percent sodium and electric conductivity (EC) as shown in Table 9. The Na % is in the range of 15 – 74 with an average of 56 and the EC ranges between 850 µs/cm and 18000 µs/cm, with an average of 5000 µs/cm. Well water sample G3 is of permissible water class, and wells G1, G4, G5, G6, and G7 are doubtful, whereas wells G2 and G8 are unsuitable for irrigation because of their high water EC values. The valley water samples (V17, V18, V19, and V20) and springs water (S9, S11, S13, S16 and S17) are classified as doubtful for irrigation, except for sample S10 (Hassawa spring) which is classified as unsuitable due to its high salinity.

Table 9: Classification of irrigation water based on Na % and EC (Todd, 1980)

Water Class	Na %	Ec µs/cm
Excellent	< 20	< 250
Good	20 – 40	250 – 750
Permissible	40 – 60	750 – 2000
Doubtful	60 – 80	2000 – 3000
Unsuitable	> 80	> 3000

- ***Sodium Adsorption Ratio (SAR):*** The sodium hazard is determined by the absolute and relative concentrations of the cations and can be evaluated through the sodium adsorption ratio (SAR) because of its direct relation with the absorption of sodium by soil (Todd, 1980).

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

where Na^{+}, Ca^{2+}, and Mg^{2+} concentrations are expressed in milliequivalents per liter. Classification of irrigation water based on SAR is shown in Table 10. The SAR for all water samples is in the range of 0.2 – 10 with an average of about 10. Accordingly, most of the wells, springs and valley waters are classified as excellent water class regarding SAR value.

Table 10: Classification of irrigation water based on SAR values (Todd, 1980)

SAR	Water Class
< 10	Excellent
10 – 18	Good
18 – 26	Fair
> 26	Poor

This shows that the only limiting parameter for water to be used for irrigation is its TDS value, however in spite of that, the wells and valley waters can be used to irrigate salt tolerant crops considering the relatively low Na % value and the well drained and high infiltration capacity of the soil, noting that the springs in the Foothill Zone (samples S12, S14, and S15) are of fresh water type and can be classified under good water class for irrigation.

– **Water Uses for Industrial Purpose:** Hem (1991) classified water suitability for certain industrial purposes according to maximum permissible limits of some of its chemical parameters as shown in Table 11.

Based on this classification, all wells water, valley water, and most of the spring water samples are not suitable for any industrial purpose, except the water of the foothill springs (S12, S14, and S15) which can be used for most industrial activities. However their low discharges are not sufficient for big industrial projects, they are therefore considered a source for drinking water.

Table 11: Evaluation of water suitability for different industrial purposes according to (Hem, 1991)

Industry type			Ca ppm	Mg ppm	Cl ppm	HCO_3 ppm	SO_4 ppm	NO_3 ppm	Cu ppm	TH ppm	TDS ppm	pH
Petroleum Products			75	30	300					300	1000	6 – 9
Cement Industry					250		250				600	6.5 – 8.5
Wood Chemical			100	50	500	250	100	5		900	1000	6.5 – 8
Leathers Industry					250		250			Soft		6 – 8
Soft drinking bottling			100		500		500		0.005			
Fruit Icing					250		250	10		250	500	6.5 – 8.5
Synthetic rubber			80	36						350		6.5 – 8.5
Chemical Pulp & Papers		**unbleached**	20	12	200					100		6 – 10
		bleached	20	12	200					100		6 – 10
Water of study area	**dry Season**	**Groundwater**	276 – 985	7 – 155	71 – 4730.5	39 – 351	3	2 – 8.7	-	720 – 3102	1280 – 12680	7.4 – 8.1
		Valley water	154 – 186	47 – 48	1349 – 1509	57 – 157	433 – 452	1 – 1.2	-	585 – 657	3036 – 3264	8.1 – 8.5
		Spring water	140 – 687	16 – 124	71 – 1864	40 – 177	238 – 1889	4 – 15	-	418 – 2219	656 – 5328	7.3 – 8.1
	wet Season	**Groundwater**	252 – 989	17 – 150	142 – 4721	45 – 286	589 – 3120	0 – 24	-	755 – 3055	1236 – 12630	7.1 – 7.7
		Valley water	170 – 208	19 – 36	710 – 1101	85 – 143	480 – 552	2.6 – 5	-	428 – 523	2024 – 2708	7.8 – 8
		Spring water	136 – 721	20 – 114	53 – 2024	40 – 243	192 – 1920	5 – 27	-	343 – 1800	594 – 6062	7.8 – 8.3

– **Water Uses for Building Purposes:** Altoviski (1962) classified water for building purposes depending on major cations and anions as shown in Table 12.

Accordingly, 80% of the sampled water sources are classified as suitable for Building purposes except those of wells G2 and G8 due to their high concentrations of calcium, sodium and sulfates, and well G10 and spring S13 because of high concentration of calcium.

Table 12: Evaluation of water suitability for building purposes (Altoviski, 1962)

Ions (Mg/l)	Permissible Limit	Dry season			Wet season		
		Wells water	Valley water	Spring water	Croundwater	Valley water	Spring water
Na^+	1160	45 – 3197	849 – 957	52 – 1152	60 – 3185	477 – 741	48 – 1376
Ca^{2+}	437	276 – 958	154 – 186	140 – 687	252 – 989	170 – 208	136 – 721
Mg^{2+}	271	7 – 155	47 – 48	16 – 124	17 – 150	19 – 36	20 – 114
Cl^-	2187	71 – 4730	1349 – 1503	71 – 1864	142 – 4721	710 – 1101	53 – 2024
SO_4^{2-}	1460	600 – 3127	433 – 452	238 – 1889	589 – 3120	480 – 552	192 – 1920
HCO_3^-	350	42 – 291	57 – 157	40 – 177	45 – 286	85 – 143	192 – 1920

CONCLUSIONS

The upper unconfined aquifer within the Quaternary sediments (alluvial fans sediments) and the intermittent valleys are the main sources of water in the study area. The quality of groundwater within active alluvial fans and springs of low land is variable, but in general brackish of barely satisfactory category for domestic, livestock, and agricultural uses. Wells that pentrate older alluvium and pre-Ouaternary formations (Mukdadiya and Bia-Hassan formations) in the area show low water quality unsuitable for most purposes because of its high salinity. The springs found in the highlands are of fresh water and therefore represent the main source for drinking purposes in this area. These springs are the interflow of karstic terrain in the high land. They differ from the springs located south of the study area in the low land, whose main source of water is groundwater subsurface flow out of the Quaternary sediments at its intersection with the ground surface along the margins of the active alluvial fan. Phosphate and nitrate concentrations in both surface and groundwater are within natural limits, which reflect low anthropogenic effects. High differences of water quality noted in the area are due to variable hydrogeologic conditions exacerbated by the presence of gypsum and anhydrite in the containing sediments and the high evaporation which is a symptom of the arid zone.

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