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Suitability Assessment of Groundwater for Irrigation and Drinking Purpose in the Northern Region of Jordan

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ABSTRACT

Groundwater is an important source of fresh water for agricultural and drinking purposes in Jordan and contributes about 50% of the total water supply. Importance of groundwater for irrigation has been increasing day by day by bringing more area under cultivation. Contamination of such water source is a big problem creating health hazards. In the study, groundwater samples were collected from fifty wells in the northern region of Jordan. These samples have been assessed on the basis of various qualitative parameters. The considered water quality parameters are; pH, electrical conductivity, total dissolved salts, calcium and magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulphate, fluoride, sodium adsorption ratio, residual sodium carbonate and soluble sodium percentage. Regarding cation and anion constitutes, groundwater is suitable for irrigation and drinking purposes except of few wells. Electrical conductivity, pH, calcium, magnesium, sodium bicarbonate, chloride, sulfate, nitrate and phosphate concentrations are below the usual limit for irrigation water. In addition, the calculated values indicate a good to permissible use of ground water for irrigation.

Key words: Groundwater, contamination, irrigation, water quality, Jordan

INTRODUCTION

In Jordan, water scarcity has been exacerbated in recent years by rapidly increase in the demand. The available water from the existing renewable sources are projected to fall to less than 91 m^3 per capita per year (m^3/c.y) by the year of 2025, which is very low in comparison with the international water poverty line of 1000 (m^3/c.y) (Al-Smadi *et al*., 2010). Water resources consist of groundwater, surface water and treated waste water. Most of the available amount from these resources is used mainly in agriculture (~65%), domestic purposes (~30%) and only 5% is used in industrial sector (Al-Zboon and Al-Ananzeh, 2008). The groundwater contributes about 50% of the total supplied water. Most of the groundwater basins are already exploited beyond their estimated safe yield where the total withdrawal is about 500 million cubic meter (MCM) per year, while the safe yield is less than 270 MCM which indicates an over exploitation by 225 MCM (WAJ, 2008). Water shortage has forced Jordan to take in consideration all available water resources to bridge the gap between demand and the available resources. Some of these sources are: water reuse, saline and brackish water.

In aquifers expose to human activity, the quality of water can be directly affected by the infiltration of pollutants in the recharge area of aquifers (Daghrah, 2009; Daghrah and

Al-Sa'ed, 2009). In addition to natural sources, groundwater quality could be affected by urbanization, agricultural waste, land cover, intensive applications of fertilizers, pesticides, utilization of wastewater for irrigation, leakage from wastewater lagoons, landfill disposal sites, septic tanks and industrial discharge (Close, 1989; Ali *et al.*, 1998; Al-Kharabsheh, 1999; Thomas, 2000; Tomer and Burkart, 2003; Laghari *et al.*, 2004; Muhibbullah *et al.*, 2005; Munoz-Carpena *et al.*, 2005; Scanlon *et al.*, 2005; El-Naqa *et al.*, 2007; El- Saeid *et al.*, 2011). Domestic wastewater is considered as a major source of pollution. Urban runoff, fertilizers from agricultural return flows and solid waste disposal appear to be secondary sources (Hammouri and El-Naqa, 2008). The groundwater in different country was contaminated probably due to lack of proper waste management (Nkolika and Onianwa, 2011). The contamination of ground water creates hazards to public health, aquatic plant and animals. According to the previous investigation, groundwater at some locations if used for irrigation, may cause either soil salinity or sodicity problems due to high salt concentration and high sodium contents relative to other elements (Al-Naeem, 2011). Specific water may be suitable for irrigation but may not be suitable for drinking and industrial uses due to presence of some other ions at toxic level (Freeze and Cherry, 1979; Tanninen *et al.*, 2005). In the agriculture, it is believed that the polluted irrigation water has effects on soils, crops and the management of water (Shainberg and Oster, 1978).

Groundwater quality will restrict the type of the crop because the water and nutrients requirements for each crop are different. It may be become harmful to some crops and suitable for others. Using of unsuitable water in irrigation will cause reduction in the crop's yield and deteriorate the soil physical properties (Shahalam *et al.*, 1998). Moreover, Clogging of drip emitters is occurred due to high Ca and Mg contents, besides the high bacterial counts and nutrients that promote algal growth (Shatnawi and Fayyad, 1996).

In arid and semi arid area, like Jordan, groundwater is considered the major source of useable water, so that water quality and quality control are the main keys parameters in management of this source in a healthy and sustainable manner. The data of quality indicators is necessary to assess their suitability for irrigation, drinking and industrial purposes. This study aims to: assess the level of ionic toxicity of ground water, classify waters on the basis its quality and evaluate its suitability and acceptability for irrigation and drinking uses. The suitability of groundwater can be determined by comparing its quality with the standards and guidelines of World Health Organization (WHO) and Food and Agriculture Organization (FAO).

MATERIALS AND METHODS

Study area: Study area is located at latitude of 32°12' to 32°37'(N) and longitude of 35°38' to 38° 20' (E) and its elevation ranges from -120 m below sea level to 1000 m above mean sea level. The climate is characterized by rainy cooled in winter and dry hot in summer. Summer day temperatures generally above 30°C while in the winter, temperatures could decease below 0°C. Average rainfall ranged from less than 200 mm in A-Rwshid area to about 500 mm year^{-1} in Irbid area. The location of the wells are presented in Fig. 1. The average annual evaporation is more than 2000 mm in all the study area (JMD, 2006). The western part of the study area (Irbid governorate), is classified as a medium to high density residential area (635 person km^{-2}), where many cities and hundreds of towns and villages are located, while the eastern part has low population density (9.9 person km^{-2}) (DOS, 2006). Rainfed cropland and irrigated agriculture are dominate in the western and eastern part, respectively. The study area covers many groundwater

Fig. 1: The location of the wells

basins. Most of the studied wells are located in Yarmouk basin which is considered as the main source of ground water in Jordan. The principal sources of groundwater in this basin are classified as shallow and upper cretaceous aquifers (Taany *et al.*, 2007). The principal resources occur in the upper B2 formation (Campanian), a limestone overlain by confining marls of the B3 formation (Maastrichtian) (Baijjali *et al.*, 1997). Groundwater levels vary from zero at the Mukheiba area, where aquifers are under water table conditions, to 250 m below the ground surface near Irbid, where the aquifers are confined (Taany *et al.*, 2007). The groundwater flow is directed towards the Jordan Valley area in the west [invent]. The recharge to the aquifer takes place in the highlands of Irbid and Ajlun and further to the northeast beyond Jordan's territories (INWENT, 2005). Five wells are located in Zerka River Basin. the shallow complex in this basin consisting of B2/A7 or A7 along or B2/A7 together with wadi fills and basalts, the deep aquifer is called locally as A4. Groundwater originating in the studied wells flows in a westerly direction (INWENT, 2005). Only one well is located in Hammad basin, where the groundwater in these areas is found in a shallow aquifer consisting of upper cretaceous and tertiary rocks and recent sediments of wadi fills, basalts and alluvial deposits. The general groundwater flow direction is oriented towards the local base level of Sirhan Depression (INWENT, 2005).

Samples collection and preparation: For chemical analysis purpose, water samples were taken from fifty wells using polyethylene bottles, which were previously soaked in 10% nitric acid and thoroughly rinsed with deionized distilled water. Samples used for determination of metals, physical properties, SO_4^{2-} and NO_3^- were collected in plastic bottles. Samples for $SO_4^{2-}$and NO_3^- were refrigerated and analyzed within 24 h. All plastic and glass wares were pre-washed with detergent water solution, rinsed with tap water and soaked for 48 h in 50% HNO_3 then rinsed thoroughly with distilled deionized water. They were then air-dried in a dust free environment. All containers were sterilized in an autoclave at 121°C for 15 min (Chiroma *et al.*, 2007). The plastic bottles were not capped to avoid distortion. The samples for heavy metals analysis were filtered immediately using 0.45 µm filter paper. The filtrates were acidified to pH = 2 with nitric acid in order to keep the metals in solution (Soltan, 1999).

Measurements and analysis: The physiochemical parameters play a significant role in classifying and assessing water quality (Tank and Chandel, 2010). The considered physicochemical parameters to determine water quality are: pH, Electrical Conductivity (EC), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), carbonate (CO_3) or bicarbonate (HCO_3), sulfate (SO_4) and nitrate (NO_3). The results of chemical analyses were used for mathematical calculations of Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), percentage of Na, Kelley's Ratio (KR) and Magnesium hazard MH). Water quality parameters analyzed in accordance to the standard methods (APHA/AWWA/WEF, 1998). All reagents are of analytical grade, purchased from Aldrich chemical company, England. The pH and conductivity were measured using pH meter (Orion Research, Model SA 520, USA) and conductivity meter (JENWAY, Model 4010, UK), respectively. Carbonate and bicarbonate (titrimetrically), SO_4^{2-}, B, NO_3^- (chromotropic acid method) were determined after filtration of the water samples using recommended procedures (APHA/AWWA/WEF, 1998). Ca, Mg, Cl and Total Hardness (TH) were determined by complex volumetric titration (APHA/AWWA/WEF, 1998). Na and K were measured using Flame Atomic Emission Spectroscopy (FAES). Total Dissolved Solids (TDS) was separated by filtering the water through 0.45 μm filter paper and determined according to the standard procedures (APHA/AWWA/WEF, 1998). Iron was determined by flame atomic absorption spectrophotometer (completely automated Model 5000, Perkin Elmer), air acetylene flame at their respective wavelengths and direct concentration using hollow cathodes lamps. Working standard solutions were prepared by diluting the stock solution using deionized water. The precision of measurements was checked taking three replicates from the sample and including a blank in each batch.

Mathematical calculations: Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were calculated on the basis of Eq. 1 and 2 (Richards, 1954; Todd, 1980; Karanth, 1987; Ragunath, 1987). Permeability index (PI) is calculated using a method suggested by Domenico and Schwartz (1990) as illustrated in Eq. 3:

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

where, the concentrations are reported in meq per L:

$$RSC = (CO_3^{-2} + HCO_3^{-1}) - (Ca^{+2} + Mg^{+2}) \quad (2)$$

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{+2} + Mg^{+2} + Na^+} \times 100 \quad (3)$$

The sodium percentage (Na %) was calculated on the basis of equations 4 (Kacmaz and Nakoman, 2010):

$$\%Na = \frac{(Na^+ + K^+) \times 100}{Ca^{+2} + Mg^{+2} + Na^+ + K^+} \quad (4)$$

Kelley's Ratio was calculated on the basis of Eq. 5 (Kelley, 1951):

$$KR = \frac{Na^{+}}{Ca^{+2} + Mg^{+2}} \quad (5)$$

Magnesium Hazard (MH) was calculated on the basis of Eq. 6 (Szabolcs and Darab, 1964):

$$MH = \frac{Mg^{+2}}{Ca^{+2} + Mg^{+2}} \times 100 \quad (6)$$

Data analysis: Analysis of variance and person correlation parameter were performed on data using SAS program for significant variations and inter-element relationships. Results were presented as the mean of standard error (Steel and Torrie, 1980). Correlation analyses were done between the different combinations of water quality indicators.

RESULTS AND DISCUSSION

Suitability of water for irrigation purpose: Irrigation water should be tested periodically to determine its quality. It may contain essential nutrients at high enough concentrations to justify a reduction in the levels applied in the fertilization program. Water may also contain harmful elements or biological organisms which require corrective procedures. Important irrigation water quality parameters include a number of specific properties of water relevant in relation to the yield and quality of crops, maintenance of soil productivity and protection of the environment. These parameters mainly consist of certain physical and chemical characteristics of water that are used in the evaluation of agricultural water quality. Parameters such as EC, pH, Sodium Adsorption Ratio (SAR), Sodium Percentage (SP) and Residual Sodium Carbonate (RSC) were used to assess the suitability of water for irrigation purposes (Ayers and Westcot, 1994; Soltan, 1999; Islam *et al.*, 2003; Ahmad *et al.*, 2004; Sarkar and Hassan, 2006; Mitra *et al.*, 2007; Raihan and Alam, 2008; Al-Harbi *et al.*, 2009; Ebrahimizadeh *et al.*, 2009; Hakim *et al.*, 2009; Balachandar *et al.*, 2010).

pH indicator: The pH values of groundwater range from 7 to 8.22 with an average value of 7.49 indicated very slight alkaline tendency (Table 1). The lowest value is observed in the Well number 33 (NAY2) and the highest in the well number 6 (ZAM). All groundwater samples have pH value within the irrigation water guidelines (Ayers and Westcot, 1994). High pH values in some wells, could be attributed to the presence of considerable amount of sodium, calcium, magnesium, carbonate and bicarbonate ions (Rao *et al.*, 1982).

The salinity indicator: Electrical conductivity as an indicator of TDS is a useful tool to evaluate the purity of water and a good measure of salinity hazard to crops. Electrical conductivity values of groundwater samples range between 545-7100 $\mu S\ cm^{-1}$ (Table 2). The result indicates that almost all the water samples are within the irrigation permissible limits for irrigation (Ragunath, 1987) except of the Well number 29 (KUF) with EC value of 2200 $\mu S\ cm^{-1}$ and number 7 (SAF well) with EC value of 7100. KUF well locates in a residential area which poses high environmental pressure on ground and surface water quality and soil. High conductivity of water in SAF well is caused by the high level of Ca, Mg, Na and NO3 (617, 433, 460, 207 mg L^{-1}, respectively). High concentration of NO3 is an indicator of surface contamination source, where utilization of fertilizers is the main cause of nitrogen in this area.

Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Saleh *et al.*, 1999).

Table 1: Physical and chemical analyses of samples (meq L^{-1})

Parameter	Max.	Min.	Average	Standard deviation
pH	8.22	7	7.492	0.306
EC	7100	545	961.687	935.301
TDS*	4615	349	618.595	614.992
K^+	0.82	0.025	0.104	0.135
Na^+	20	0.6	2.691	3.420
Ca^{2+}	30.79	1.49	4.756	4.043
Mg^{2+}	35.62	0.076	3.493	4.929
TH α	3320.5	143.3	412.468	441.312
SO_4^{2-}	17.16	0.15	1.294	2.446
NO_3^- *	233	0	24.606	44.719
HCO_3^-	7.42	1.11	5.406	1.466
Cl^-	65.91	0.56	4.318	10.010
B	0.5	0	0.123	0.151
SAR	4.89	0.37	1.257	0.987
%Na	54.79	10.12	23.547	10.994
RSC	3.78	-65.3	-2.870	9.586
KR	1.15	0.11	0.325	0.226
MH	65.9	2.65	39.972	11.354
PI	92.39	24.36	49.733	10.246

*Measured in mg L^{-1}, TH: Total hardness

Table 2: Groundwater quality for irrigation water based on electrical conductivity

	Wells		
Water class	No. (Total = 47)	Percentage	EC ($\mu S\ cm^{-1}$)
Excellent	Nil	0	< 250
Good	14	31	250-750
permissible	31	65	750-2000
Doubtful	1	2	2000-3000
Unsuitable	1	2	>3000

The estimated amounts of TDS ranged from 349-4615 mg L^{-1}. The standard for dissolved solid is up to 500 mg L^{-1} and the maximum permissible quantity is 2000 mg L^{-1} (Ayers and Westcot, 1994). A water containing TDS less than 1000 mg L^{-1} can be considered to be 'fresh water' for irrigation use and will not affect the osmotic pressure of soil solution (Hakim *et al.*, 2009). The TDS values of all the water samples are under permissible limit of 2000 mg L^{-1} except of SAF Well (4615 mg L^{-1}).

Ions constituents indicator: Physical and chemical parameters including statistical measures, such as minimum, maximum, average and standard deviation, are reported in Table 1. The abundance of the major ions in groundwater is in the following order: $Ca^{2+}>Mg^{2+}>Na^+>K^+ = HCO_3^->Cl^->SO_4^{2-}$. Calcium, magnesium and sodium are dominant cations which vary between 1.5 and 30.79 meq L^{-1}, 0.076 to 35.62 meq L^{-1} and 0.61 to 20.01 meq L^{-1}, respectively. Potassium concentration is generally low where minimum and maximum values are 0.0265 and 0.82 meq L^{-1}. The concentration of major cations such as Ca^{+2}, Mg^{+2}, Na^+ and K^+ in groundwater were far below the recommended maximum concentration of these parameters (20, 5, 40, 2 meq L^{-1}, respectively).

SAF Well has a higher concentration of Ca^{+2} and Mg^{+2} (30.79 35.93 meq L^{-1}). Calcium and magnesium cause by far the greatest portion of the hardness occurring in natural waters. Hardness of the water is objectionable from the viewpoint of water use. The values of total hardness of 68% samples are above the permissible range. The values of $HCO3^{-}$ in the water samples varied from 1.11 to 7.42 meq L^{-1} (Table 1). Irrigation water containing $CO3^{-2}$ higher than 0.1 meq L^{-1} and HCO_3-more than 10 meq L^{-1} are not generally recommended. All the samples are far below than the permissible limit. Therefore, all water samples in the study area can be used for long-term irrigation use (Ayers and Westcot, 1994). It is observed that around 8% of the samples have chlorides level higher than the permissible limit for irrigation of 10 meq L^{-1}. The highest concentration of chlorides was recorded in SAF Well (65.92 meq L^{-1}) and the lowest at JUF Well (0.564 meq L^{-1}). Mridha *et al.* (1996) reported that most of the tree crops under sprinkler irrigation are sensitive to chloride having values more than 4.00 meq L^{-1}. This indicated that 84% of the water samples will not cause chloride toxicity problem in the area for tree crops under sprinkler irrigation. Chloride occurs naturally in sedimentary bedrock layers particularly shales, so that a higher concentration is expected in theses formations. Concentrations of sulfate vary between 0.15 and 17.156 meq L^{-1} which are beneath the usual limits according to irrigation water standards. Considering the soluble iron, the water samples will not be problematic at all for irrigation because of the far below concentration of iron concentration than the recommended maximum limit of 5 mg L^{-1} (Ayers and Westcot, 1994).

SAR indicator: The suitability of the well water samples was evaluated by determining the Sodium Adsorption Ratio (SAR) value and they were categorized under different irrigation classes on the basis of salinity and alkalinity hazards. The sodium adsorption ratio parameter evaluates the sodium hazard in relation to calcium and magnesium concentrations. The sodium adsorption ratio is used to predict the potential for sodium to accumulate in the soil, which would result from continued use of sodic water. Sodium Adsorption Ratio (SAR) was computed by using values of water soluble cation (Table 1). The SAR values varied from 0.37 to 4.89 with an average of 1.25. The data revealed that all of the water samples fall in the low sodium class (S1) (Table 3). This implies that no alkali hazard is anticipated to the crops. If the SAR value is greater than 6 to 9, the irrigation water will cause permeability problems on shrinking and swelling types of clayey soils (Saleh *et al.*, 1999). The sodium percentage (% Na) ranges between 10.12 and 54.79% in the tested samples (Table 4). Concerning Na% parameter, the groundwater in the study area is classified as an excellent to permissible for irrigation. When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions. This exchange process of Na^{+} in water for Ca^{2+} and Mg^{2+} in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Collins and Jenkins, 1996; Saleh *et al.*, 1999).

Table 3: Alkalinity hazard classes of groundwater

	Wells			
Water class	No. (Total = 47)	Percentage	SAR	Alkalinity hazard
Excellent	47	100	<10	S1
Good	0	0	18-Oct	S2
Doubtful	0	0	18-26	S3
Unsuitable	0	0	? 26	S4

Table 4: Quality of irrigation water based on Na%

	Wells		
Water class	No. (Total = 47)	Percentage	Sodium (%)
Excellent	19	40.40	<20
Good	24	51.10	20-40
Permissible	4	8.50	40-60
Doubtful	Nil	0	60-80
Unsuitable	Nil	0	>80

Table 5: Groundwater quality for drinking water based on RSC

	Wells		
Water class	No. (Total = 47)	Percentage	RSC guidelines (meq L^{-1})
Good	46	97.80	<1.25
Doubtful	0	0	1.25-2.5
Unsuitable	1	2.12	>2.5

Wilcox (1955) uses sodium percentage (%Na) and EC values for classifying irrigation water quality. The salts, besides affecting the growth of the plants directly, also affect soil structure, permeability and aeration, which indirectly affect plant growth (Singh *et al*., 2008). The Wilcox diagram relating sodium percentage and total concentration shows that most of the groundwater samples fall in the field of excellent to good permissible quality. Only two samples fall in the fields of doubtful to unsuitable for irrigation (SAF and KUF Well, respectively).

RSC indicator: In addition to the SAR and % Na, the excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the suitability of groundwater for irrigation. This is denoted as Residual Sodium Carbonate (RSC). The RSC values varied from -65.3 to 3.78 meq L^{-1} (Table 1). Most samples (72%) showed negative values which indicated that dissolved calcium and magnesium contents were higher than carbonate and bicarbonate contents. Table 5 indicates that 97.8% of the samples have a good water quality where RSC values are less than 1.25 meq L^{-1} and only one well (WAD 1) has a higher value of RSC (3,78).

PI indicator: The Permeability Index (PI) value is used to evaluate the sodium hazards of irrigation water and consequently is used as indicator whether or not the groundwater is suitable for irrigation. From the environmental point of view, a high permeability index, in association with subsurface structural features would facilitate widespread contamination of groundwater. Accordingly, waters can be classified as Class I, Class II and Class III orders. Class I and Class II waters are categorized as good for irrigation with 75% or more of maximum permeability. Class III waters are unsuitable with 25% of maximum permeability.

The PI ranges from 24.36-92.39%, with average value is about 49.734% which locates under class-1 and class-2 of Doneen's chart (Domenico and Schwartz, 1990).

KR indicator: The level of Na^{+} measured against Ca^{+2} and Mg^{+2} is known as Kelley's ratio, based on which irrigation water can be rated (Kelley, 1940 ; Paliwal, 1967). Kelley's Groundwater having

Kelley's ratio more than one is generally considered as unfit for irrigation. Kelley's ratio for the tested samples ranged from 0.11 and 1.15 and only two wells water (ZAM and KUF) have Kelley's ratio value more than 1 which indicating the suitability of 96% of the samples for irrigation purpose.

MH indicator: Magnesium present in water would adversely affect the soil quality rendering it unfit for cultivation (Venugopal *et al*., 2009). Magnesium ion concentration plays an important role in productivity of soil, so that it is used to determine whether the water is suitable for irrigation or not. If magnesium hazard was less than 50, then the water was safe and suitable for irrigation (Szabolcs and Darab, 1964). The values of MH range from 65.9 and 2.65 with an average value 39.97. it is found that 84.5% of the samples have the magnesium hazard values less than 50 and can be classified as suitable for irrigation use (Table 1). On the other hand, ZAM, JAB_2, UMJ, HOD, SAF, ZNA_6, JAB_1, JAB_6 and JAB_5 wells have a magnesium hazard more than 50 and the water from these sources was found to be unsuitable for irrigation. High concentration of magnesium can be attributed to dolomite, a chief mineral of sandstone and siltstone (Haritash *et al*., 2008).

Boron (B) indicator: High boron concentrations in soil water may be deleterious for certain crops. Boron is necessary in small quantities for growth of plants, but a slight excess of boron in the irrigation water or in the soil solution can cause toxicity to a variety of crops. Boron is taken up by the crop and is accumulated ((Ayers and Westcot, 1994).

Boron concentration in the tested samples ranges from 0 to 0.5 mg L^{-1} with an average value of 0.1 mg L^{-1}. The proposed limits of boron concentration in irrigation water and the total number of groundwater samples representing the boron classes are presented in Table 6 (McCarthy and Ellery, 1994). All of the groundwater samples analyzed are within the permissible limits for semi-sensitive crops. The most sensitive crops can tolerate no more than 0.5-1.0 ppm (Todd, 1980).

Correlation of physicochemical parameters of groundwater: In order to find out the relationship amongst physicochemical parameters of the water samples, correlation coefficients were worked out and a large number of significant correlations were obtained. It is a simply measure used to exhibit how well one variable predicts the other (Kurumbein and Graybill, 1965). The inter relationships among 14 variables were determined in terms of correlation coefficient (Table 7). It was observed that EC and TDS show good positive correlation with Mg^{2+}, Na^+, K^+, Cl^-, SO_4^2 and NO_3^- and negative correlation with HCO_3^-. The high positively correlated values were found between TDS and EC (0.99) Mg^{2+} and EC (0.98), Mg^{2+} and TDS (0.98), Cl- and EC (0.989), Cl^-

Table 6: Permissible limits of boron in irrigation water for several types of crops

	Semi-sensitive crops			Semi-tolerant crops			Tolerant crops		
Boron class	Range (mg^{-1})	No. of wells	Wells%	Range (mg^{-1})	No. of wells	Wells %	Range (mg^{-1})	No. of wells	Wells%
Excellent	< 0.3300	36	88	< 0.67	41	100	< 1	41	100
Good	0.33-0.67	5	12	0.67-1.33	Nil	0	1-2	Nil	0
Permissible	0.67-100	Nil	0	1.33-2	Nil	0	2-3	Nil	0
Doubtful	1-1.2500	Nil	0	2-2.5	Nil	0	3-3.75	Nil	0
Unsuitable	> 1.2500	Nil	0	> 2.5	Nil	0	> 3.75	Nil	0

Table 7: correlation coefficient between quality parameters

	EC	pH	TDS	SAR	RSC	RSC	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-
EC	1												
pH	0.08^{ns}	1											
TDS	0.99**	0.08^{ns}	1										
SAR	0.55**	0.041**	0.54**	1									
RSC	-0.89**	-0.12^{ns}	-0.89**	-0.74**	1	1							
Ca^{2+}	0.028^{ns}	-0.15^{ns}	0.28^{ns}	0.61**	-0.64**	-0.64**							
Mg^{2+}	0.98**	0.10^{ns}	0.98**	0.44**	-0.83**	-0.83**	1						
Na^{+}	0.60**	-0.06^{ns}	0.60**	0.65**	-0.78**	-0.78**	0.48**	1					
K^{+}	0.51**	-0.04^{ns}	0.50**	0.74**	-0.78**	-0.78**	0.34**	0.88**	1				
HCO_3^-	-0.42**	-0.76**	-0.42**	-0.57**	0.46**	0.46**	-0.45**	-0.10^{ns}	-0.18^{ns}	1			
Cl^-	0.99**	0.16^{ns}	0.99**	0.56**	-0.88**	-0.88**	0.99**	0.56**	0.47**	-0.51**	1		
SO_4^{2-}	0.96**	0.09^{ns}	0.97**	0.47**	-0.79**	-0.79**	0.97**	0.44**	0.36*	-0.42**	0.96**	1	
NO_3^-	0.75**	-0.03^{ns}	0.75**	0.64**	-0.90**	-0.90**	0.65**	0.88**	0.88**	-0.93*	0.72**	0.59**	1

**Significant at p = 0.01, ns: Not significant

and TDS (0.99), Cl- and Mg^{2+} (0.99), NO_3 and Na^+ (0.88). Similar correlations were obtained (Al-Harbi *et al.*, 2006; Patil and Patil, 2010). Sunitha *et al.* (2005) identified that the EC finds higher level correlation significance with many of the water quality parameters, like TDS, chlorides, total alkalinity, sulphates, total hardness and magnesium. Raman and Geetha (2005) found that the water quality of ground water can be predicted with sufficient accuracy just by the measurement of EC alone. This provides a means for easier and faster monitoring of water quality in a location.

Hydrochemical facies: The geochemical evolution of groundwater can be understood by plotting the concentrations of major cations and anions in the Piper tri-linear diagram (Piper, 1944). The plot shows that most of the groundwater samples fall in the field of mixed Ca-HCO_3 type of water (Fig. 2). Some samples are also representing Ca-Cl and Na-Cl types. From the plot, alkaline earths (Ca^{2+} and Na^+) significantly exceed the alkalis of (Mg^{2+} and K^+) while acids of (Cl and HCO_3) exceed the acids of (SO_4^{2-} and CO_3^-).

Drinking water quality

Water quality: The analytical results of physical and chemical parameters of groundwater were compared with the standard guideline values as recommended by the World Health Organization (WHO, 1994) for drinking and public health purposes.

Total dissolved solids: To ascertain the suitability of groundwater for any purposes, it is essential to classify the groundwater depending upon their hydrochemical properties based on their TDS values (Catroll, 1962; Freeze and Cherry, 1979). Table 8 shows that the ground water samples of 45 wells are classified as a fresh water while two well (SAF and KUF) are considered as a brackish water according to the WHO guidelines.

Total hardness: The classification of groundwater (Table 9) based on Total Hardness (TH) shows that a majority of the groundwater samples fall between hard and very hard water category (Sawyer and McCarty, 1967). The hardness values range from 143.3 to 3320.5 mg L^{-1} with an average value of 412.47 mg L^{-1}. The maximum allowable limit of TH for drinking water is 500 mg L^{-1} and the most desirable limit is 100 mg L^{-1} as recommended by WHO guidelines. Four wells out of 48 exceed the maximum allowable limits (Table 1).

Table 8: Groundwater quality for drinking water based on TDS values

Nature of water	Representing wells	No. of wells	TDS (mg L^{-1})
Fresh water	All wells except	45	<1000
Brackish water	SAF and KUF	2	1000-10000
Saline water	Nil	Nil	10000-100000
Brine water	Nil	Nil	>100000

Table 9: Groundwater quality for drinking water based on hardness

	Wells		
Water class	No. (Total = 47)	Percentage	Total hardness as $CaCO_3^-$ (mg L^{-1})
Soft	0	0	<75
Moderately hard	1	0	75-150
Hard	16	33.40	150-300
Very hard	31	64.60	>300

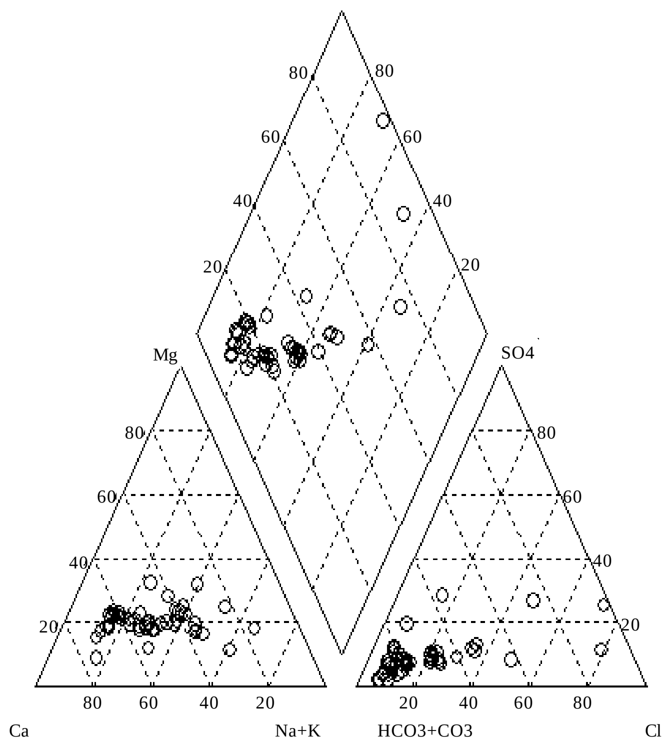

Fig. 2: Piper plots of the groundwater chemistry

Nitrate: The nitrate concentration in groundwater samples range from 0 to 233 mg L^{-1} with an average value of 24.6 mg L^{-1}. The concentration of nitrogen in groundwater is derived from the biosphere (Saleh *et al.*, 1999). Nitrogen is originally fixed from the atmosphere and then mineralized by soil bacteria into ammonium. Anthroponogenic sources of nitrogen include soil nitrogen, fertilizers, sewage, septic tanks, animal waste, green manure and plant residues. Under aerobic conditions nitrogen is finally converted into nitrate by nitrifying bacteria (Tindall *et al.*, 1995). Five wells (KUF, SAF, MAH_5, UMJ_1, NAY_3) exceed the desirable limit of 45 mg L^{-1} as per WHO norms (Table 1). The high concentration of nitrate in drinking water is toxic and causes blue baby syndrome (methaemoglobinaemia) in children and gastric carcinomas (Comly, 1945; Gilly *et al.*, 1984). As most of the study area is intensively irrigated, the fertilizers used for agriculture may be the source for the elevated concentration of nitrate in a few locations (Chandna *et al.*, 2010).

Sulphate and magnesium: Sulphate is unstable if it exceeds the maximum allowable limit of 8.3 meq L^{-1} and causes a laxative effect on human system with the excess magnesium in groundwater (Subramani *et al.*, 2005). Only SAF well exceeds the prescribed value. Also, the same well exceeds the maximum allowable limit of magnesium (12.3 meq L^{-1}). This may result in gastrointestinal irritation to the human system. Significant positive correlation (0.97**) is also noticed between magnesium and sulphate concentration (Table 7).

Fluoride: Fluoride is one of the main trace elements in groundwater, which generally occurs as a natural constituent. Bedrock containing fluoride minerals is generally responsible for high concentration of this ion in groundwater (Handa, 1975; Wenzel and Blum, 1992; Bardsen *et al.*, 1996). The concentration of fluoride in groundwater of the basin varies between 0 and 1.8 mg L^{-1} with an average value of 0.62 mg L^{-1} (Table 1). All tested samples have F concentration within the allowable limit.

Bacteria indicator: Total coliform, fecal coliform and *E. coli* are all indicators of drinking water quality. Total coliform bacteria values in the tested samples ranged from 0-110 MPN. Total coliform bacteria commonly found in the environment such as soil and vegetation are generally harmless. If only total coliform bacteria are detected in drinking water, the source is probably environmental (USEPA, 2010). Fecal coliform and *E. coli* should be tested to decide if the source of bacteria is the natural environment or contaminated sources. The presence of F.C. in a drinking water sample often indicates recent fecal contamination while *E. coli* usually are found in great quantities in the intestines of people and warm-blooded animals (USEPA, 2010). There is undetectable limit of fecal coliform and *E. coli* in all the tested samples, which indicates a normal source of total coliform in the tested samples.

CONCLUSION

Interpretation of hydrochemical analysis reveals that the groundwater in northern region of Jordan is fresh to brackish and alkaline in nature. The sequence of the abundance of the major ions is in the following order: $Ca^{2+}>Mg^{2+}>Na^{+}>K^{+} = HCO_3^{-}>Cl^{-}>SO_4^{2-}$. Alkali ($Ca^{2+}$, Na^{+}) slightly exceed alkalis (Mg^{2+} and K^{+}) and acids (Cl) and (HCO_3) exceed acids of (SO_4) and (CO_3). This leads to a mixed Ca-HCO_3 Ca-Cl type and Na-Cl of groundwater. Magnesium, Sodium, Potassium, chloride, sulphate and nitrate ions show positive correlation with EC and TDS, however, bicarbonate shows a negative correlation. TH is generally high in the groundwater thereby, causing the groundwater to be unsuitable for drinking. Groundwater in 4.2% of the study area exceeded the recommended limits of TDS as per drinking water standard. In respect of all evaluating criteria, groundwater of that area could safely be used for long-term irrigation and drinking purposes.

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