JJEES

JJEES (2019) 10 (2): 118-126
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Development of Irrigation Water Quality Index for Wadi Araba Basin, Southern Jordan

Ali El-Naqa[1] and Amani Abu Al Adas[2]

[1] Hashemite University, Department of Water Management Environment, Faculty of Natural Resources and Environment, Zarqa, Jordan
[2] Hashemite University, Department of Earth and Environmental Sciences, Faculty of Natural Resources and Environment, Zarqa, Jordan

Received 17 January 2019; Accepted 4 April, 2019

Abstract

This paper attempts to evaluate the quality of irrigation water regards to potential soil, crop problems and irrigation types for specific use. For this purpose, the Water Quality Index for irrigation (IWQI) was introduced which is a technique that can be used to classify irrigation waters with respect to three suitability classes and three degrees of restriction on use. The objective of this index is to transform complicated water quality data into information that can be utilized by the public. The IWQI was used to identify the irrigation water along Wadi Araba area in southern Jordan. Irrigation water quality was assessed based on salinity hazard, sodium hazard (soluble sodium percentage and sodium adsorption ratio, bicarbonate hazards (residual sodium carbonate), magnesium hazard, permeability index, Kelly's ratio, chloride hazard and boron hazard. The spatial distribution of water quality index (WQI) map has been prepared using ArcGIS 10.2 in which 59.5% of groundwater used for drinking purposes was classified as poor water category, where 75.7% of the water has a medium suitability based on irrigation water quality index. Moreover, the Wilcox's diagram was used for classifying the irrigation water based on the salinity and sodium hazard, where 67.6% of the groundwater have permissible to doubtful irrigation water quality due to the presence of high salinity and low sodium hazard (Class C3S1).

Keywords: Keywords: IWQI, FAO, Hazard maps, Suitability, Alluvial Aquifer, Groundwater.

1. Introduction

In recent decades groundwater became one of the most important natural resources as a result of increasing water demand, decreasing rainfall amount and surface water supplies. It became very essential to find groundwater that has high quantity and good quality to be used for multi-purposes. It is sometimes necessary to analyze all related parameters as a combination rather than focusing on a single isolated parameter. With this objective in mind, the paper focused on the implementation and validation of water quality index based on FAO's criteria in order to assess the water suitability for irrigation purposes.

A water quality index in a simplified concept is a management technique for linking the water quality data into a single value or single status to provide the composite influence of individual water quality parameters on the overall water quality. This study involved the development of a new index called the 'Irrigation Water Quality Index (IWQI)'. The Water Quality Index has been applied to assess the quality of groundwater in the recent years due to its serves the understanding of water quality issues by integrating complex data and generating a score that describes water quality status (khalid, 2011; Rizwan and Singh, 2010). The water quality index (WQI) was calculated for evaluating influence of natural and anthropogenic activities based on several key parameters of groundwater chemistry (Krishna et al., 2014). World Health Organization (2011) standards for drinking water quality have been used to calculate the WQI. To calculate the WQI, the weight has been assigned for the physico–chemical parameters according to the parameters relative importance in the overall quality of water for drinking water purposes.

The WQI technique was applied to assess the irrigation water quality of based on water quality data in Wadi Araba area. The hydrochemical data representing two periods of sampling (pre- and post-rainfall seasons). This WQI aims to help decision makers in reporting the spatial state of the water quality variations.

The spatial distribution of IWQI index was constructed using the GIS to categorize the irrigation water quality based on the spatial variations of physicochemical quality parameters during pre- and post-rainfall seasons.

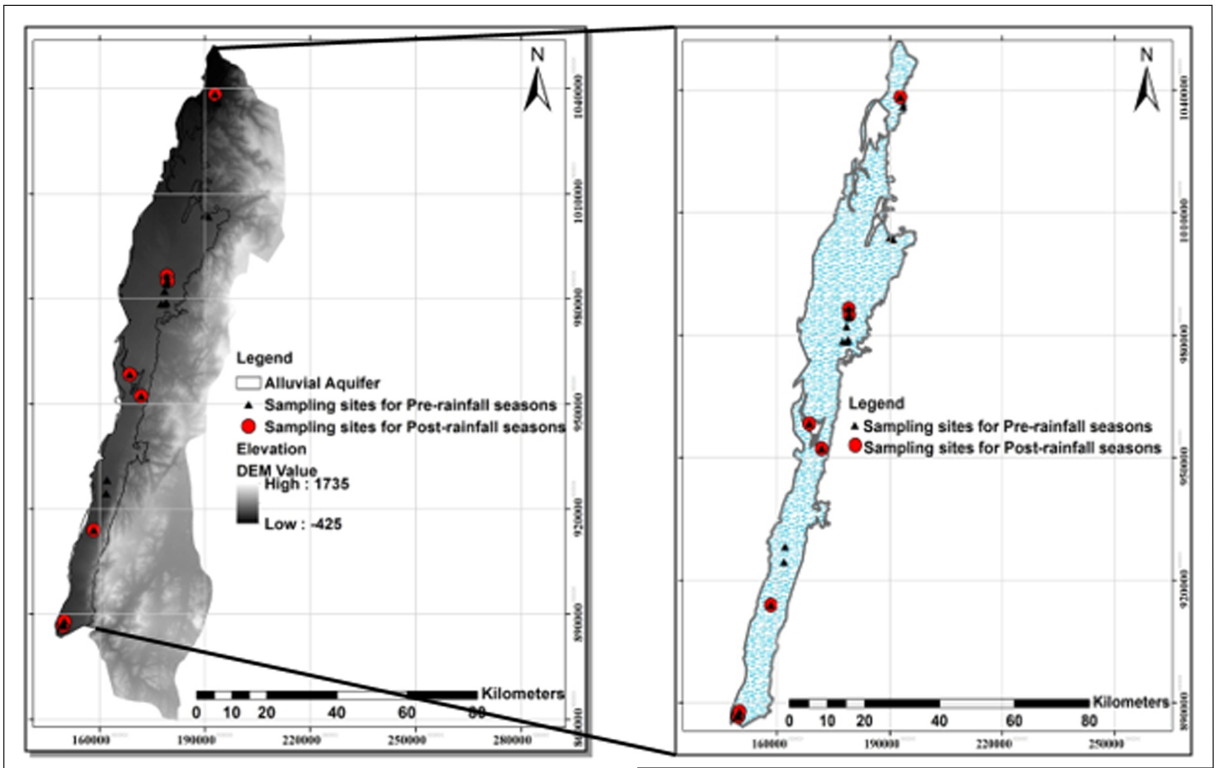
2. Description of study area

The study area includes Wadi Araba Basins (North and South) which is considered part of Jordan Rift Valley, and it occupies approximately 5835 km². The northern Wadi Araba catchment extends for about 100 km from the Dead Sea shore southward, with a width of 25 to 30 km and a total area of 3080 km² while southern Wadi Araba catchment extends around 75 km north of the Gulf of Aqaba, with a maximum E–W width of 30 km and total catchment area measures 2756 km²), the Alluvial deposits which is the main target aquifer in this study represent approximately 1700 km² which is extend along the western side of the tow sub-basins (Figure 1A). The Wadi Araba catchment area includes the eastern escarpment and highlands where the elevation ranges from 1735 m above sea level at Jabal Al Hisha) to 425 m below sea level in the floor of Wadi Araba south Ghor Es-Safi. (Fig. 1-A). The

* Corresponding author e-mail: elnaqa@hu.edu.jo

wadi floor of the Wadi Araba basin is comprised of alluvial sediments which forms the fresh and brackish groundwater in the uppermost parts of the aquifer (Dames and Moore, 1979).

The recharge to alluvium aquifer comes from precipitation falling on the surrounding mountains in the east and infiltrates in the barren rocks and flows laterally into the fluviatile and alluvial deposits of Quaternary age that covers the wadi floor (El-Naqa and Kuisi 2012). The groundwater flow direction map of Wadi Araba aquifer system is from the foot of the eastern escarpment towards the Wadi Araba floor and from the south to the north, towards the Dead Sea as shown in Fig. 1-B.



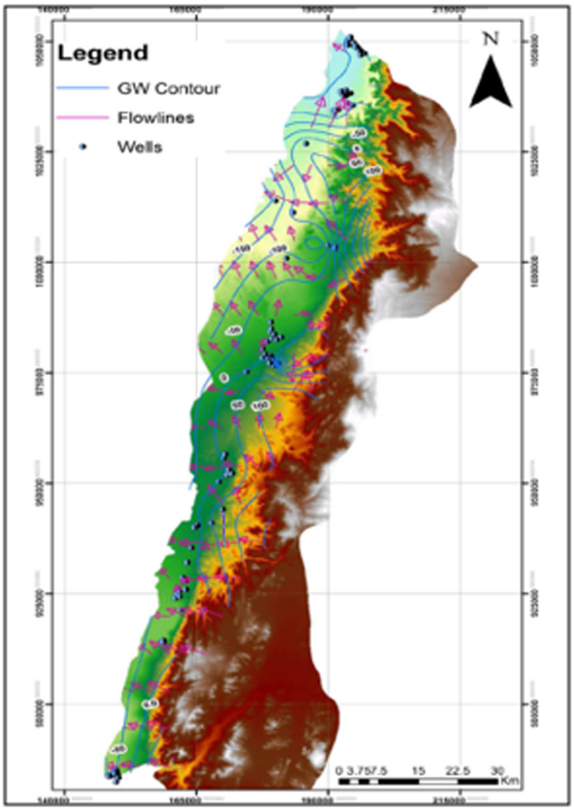


Figure 1. (A): Digital Elevation Model of Wadi Araba Groundwater Basins and focusing on the locations of samples both in two periods.
(B): Groundwater flow direction map of Alluvial Aquifer System (El-Naqa and Al Kuisi, 2012).

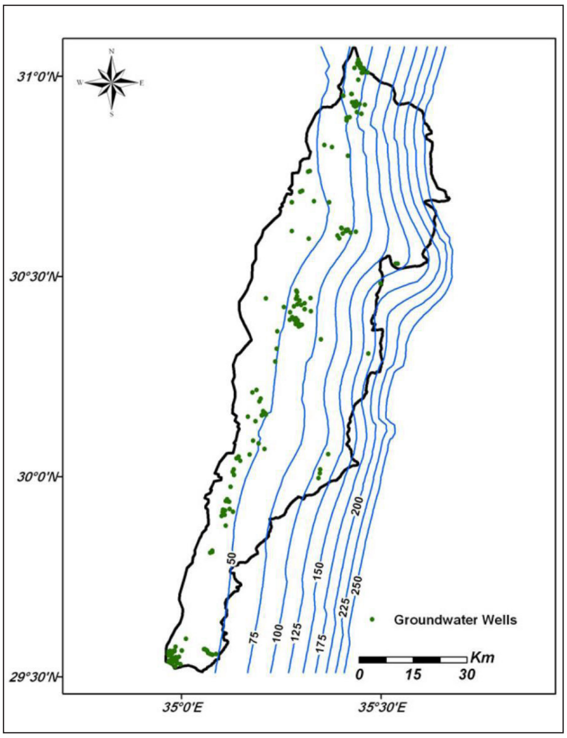


Figure 2. Isohyet map of Wadi Araba Basin (El-Naqa et al. 2009).

The area of Wadi Araba has in general a very arid-hot climate; the rainfall over Wadi Araba basin is orographic and seasonal. The average monthly temperature in the south of Jordan ranges from 20°C to 31°C. The average relative humidity ranges from 41% to 63%. The prevailing winds are from the west. Rainfall generally occurs between September and May with most of the rainfall occurring between December and March (El-Naqa and Al Kuisi, 2012). The mean annual rainfall is very low, ranges between 50 to 100 mm along the floor of Wadi Araba and upward from 300 to 400 mm along the escarpment and highlands (Fig. 2) (El-Naqa et al., 2009).

2. Materials and methods

2.1. Sample collection

Twenty-three (23) water samples were collected during pre-rainfall seasons (August-September 2014) and 14 water samples were collected during post-rainfall seasons (April-May 2014). These water samples were collected from 21 boreholes (4 private wells and 17 governmental wells). The water samples were collected polyethylene bottles of one liter size after washing them twice by samples water in order to avoid the contamination and then stored and transported to the Laboratory of Ministry of Water and Irrigation to analyze the major cations & anions and some trace elements. The sampling plan was to collect site-specific information relating to the agricultural activities near the water sampling sites. The physical parameters including pH, electrical conductivity (EC), and temperature carried out directly in the field using the portable instruments.

Spatial Analyst tool in ArcGIS 10.2 was used to generate the final irrigation water quality index maps which constructed based on the calculated quality value multiplied by the recommended weight of each parameter then constructed by overlying of the thematic maps of above mentioned parameters and reclassified it according to the water quality classes of IWQI. The inverse distance weight (IDW) technique was used in the spatial modeling of the distribution of groundwater quality parameters. This technique is proved to be the ideal interpolation method which covers all samples along the narrow strip of alluvial aquifer. The average cannot be greater than the highest or lesser than the lowest input.

2.2. SAnalytical method

Samples were analyzed in the Laboratory for the major ions chemistry and trace elements. The analytical methods used for the analyses of the different parameters are listed in Table 1. These analytical techniques were performed according to the procedures mentioned in the Standard Methods for Examination of Water and Wastewater (1998).

Table 1. Methods of analysis used to determine Physical and Chemical properties for Alluvial Aquifer along WadiAraba groundwater samples.

Parameter	Unit	Analytical Methods
Electrical Conductivity at 25 C°	μs/cm	Field EC–meter
pH–Value	–	Field pH–meter
Total Dissolved Solid (TDS)	mg/l	By calculation Eq.(5)
Total Harness (TH)	mg/l	By calculation Eq.(6)
Sodium, Potassium, Calcium, Magnesium	mg/l	ICP–MS
Chloride	mg/l	Titration with 0.01 $AgNO_3$ using Potassium Chromate(K_2CrO_4) indicator
Sulfate	mg/l	Ultra violet visible spectrophotometer wave length 492 nm
Nitrate	mg/l	Ultra violet visible spectrophotometer– wave length 206 nm
Phosphate	mg/l	Ultra violet visible spectrophotometer– wave length 690 nm
Bicarbonate	mg/l	Titration with 0.02N H_2SO_4 using DiphenyI carbazone indicator.
Ammonium	mg/l	Ultra violet visible spectrophotometer– wave length 425 nm
As, Zn, Se, Ni, Fe, Mn, Cu, Cd, Cr, B	mg/l	ICP–MS

The analytical precision for ions was determined by the ionic balances calculated as 100× (cations−anions)/(cations and anions), which is generally within ±5% (Srinivasamoorthy et al. 2010). The descriptive statistics of chemical analyses and trace elements of groundwater samples collected from pre- and post-rainfall seasons are presented in Table 2.

2.3. Mapping Irrigation Water Quality Index (IWQI)

Water quality index (WQI) is an important parameter for identifying the water quality and its sustainability for drinking purposes (Subba, 2006) and Magesh et al., 2013). WQI is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall water quality (Mitra, 1998).

It is commonly accepted that the problems originating from irrigation water quality vary in type and severity as a function of numerous factors including the type of the soil and the crop, the climate of the area as well as the farmer who utilizes the water. Nevertheless, there is now a common understanding that these problems can be categorized into the following major groups: (a) salinity hazard, (b) infiltration and permeability problems, (c) toxicity hazards; and, (d) miscellaneous problems (Ayers and Westcot, 1985). The toxicity hazards can further be grouped into problems associated with specific ions as well as hazards related to the presence of trace elements and heavy metals. The criteria classification of irrigation water quality is presented in Table 3 and Table 4.

Table 2. Basic statistics of field parameters and analytical data for groundwater samples both in two periods.

Parameter	Unit	Descriptive statistics pre-rainfall seasons				Descriptive statistics post-rainfall seasons			
		Minimum	Maximum	Mean	Std. Deviation	Minimum	Maximum	Mean	Std. Deviation
pH	- -	6.48	7.99	7.52	0.38	6.84	7.94	7.52	0.31
EC	µS/cm	882.00	4800.00	1851.30	1000.09	772.00	5860.00	1909.79	1217.55
TDS	mg/l	519.50	2828.80	1101.08	589.72	439.40	3554.20	1105.70	764.20
Ca^{2+}	mg/l	21.64	261.92	118.04	59.18	71.14	428.25	135.02	91.25
Mg^{2+}	mg/l	14.11	163.55	57.77	32.16	4.01	206.80	53.54	54.22
Na^{+}	mg/l	50.83	538.20	190.62	122.51	37.26	556.60	186.97	124.06
K^{+}	mg/l	3.13	15.25	7.01	3.05	1.96	16.81	6.02	3.37
Cl^{-}	mg/l	85.20	1322.73	408.04	293.71	94.08	1873.70	438.45	438.24
HCO_3^{-}	mg/l	18.30	251.32	155.19	62.84	75.64	281.82	173.18	66.70
SO_4^{2-}	mg/l	21.12	488.16	238.37	119.51	33.12	422.88	193.20	121.98
NO_3^{-}	mg/l	0.22	19.31	7.47	4.24	0.23	46.54	11.93	12.16
SAR	__	1.18	7.06	3.54	1.59	0.92	5.53	3.39	1.13
Trace Elements									
As	Ppm	0.002	0.01	0.006	0.004	0.002	0.01	0.008	0.004
Se	Ppm	0.01	0.01	0.010	3.55E-18	0.01	0.01	0.010	1.80E-18
Cu	Ppm	0.01	0.12	0.030	0.035	0.01	0.12	0.033	0.034
Cr	Ppm	0.01	0.07	0.013	0.013	0.01	0.07	0.014	0.016
Ni	Ppm	0.01	0.02	0.015	0.005	0.02	0.01	0.012	0.004
Mn	Ppm	0.01	0.096	0.022	0.021	0.01	0.096	0.034	0.024
Fe	Ppm	0.03	0.22	0.085	0.058	0.02	0.22	0.068	0.054
Zn	Ppm	0.008	0.25	0.062	0.068	0.01	0.25	0.102	0.087
B	Ppm	0.23	0.55	0.409	0.097	0.23	0.54	0.023	0.085
Cd	Ppm	0.003	0.02	0.005	0.005	0.003	0.02	0.005	0.005

Table 3. Food and Agriculture Organization (FAO) guidelines for interpretation of water quality for irrigation (Ayers and Westcot, 1985).

Potential irrigation problems	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
(1) Salinity (affects crop water availability)				
EC	µS/cm	< 700	700 – 3000	> 3000
TDS	mg/l	< 450	450 – 2000	> 2000
(2) Permeability (effects infiltration rate of water into soil)	and EC= (µS/cm)			
SAR = 0 – 3		> 700	700 – 200	< 200
SAR = 3 – 6		> 1200	1200 – 300	< 300
SAR = 6 – 12		> 1900	1900 – 500	< 500
SAR = 12 – 20		> 2900	2900 – 1300	< 1300
SAR = 20 – 40		> 5000	5000 – 2900	< 2900
(3) Specific ion toxicity (effects sensitive crops)				
Sodium (Na)				
Surface irrigation	SAR	< 3	3 – 9	> 9
Sprinkler irrigation	meq/l	< 3	> 3	–
Chloride (Cl^{-})				
Surface irrigation	mg/l	< 140	140 – 350	> 350
Sprinkler irrigation	meq/l	< 3	> 3	–
Boron (B)	mg/l	< 0.7	0.7 – 3.0	> 3.0
(4) Trace elements toxicity (Table 7)	ppm	–	–	–
(5) Miscellaneous effects (effects susceptible crops)				
Nitrate–nitrogen (NO_3 – N)	mg/l	< 5	5 – 30	> 30
Bicarbonate (HCO_3^{-}) effects only on sensitive plants and sprinkler irrigation	mg/l	< 90	90 – 500	> 500
pH	–		Normal range 6.5 – 8.4	

Table 4. Recommended maximum concentrations of trace elements in irrigation water (Ayers and Westcot, 1985).

Element	Recommended Maximum Concentration (mg/l)	Remarks
Zn (Zinc)	2.00	Toxic to many plants at widely varying concentrations; reduced toxicity at pH>6.0 and in fine textured organic soils.
As (Arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Cd (Cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Cr (Chromium)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu (Copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
Fe (Iron)	5.00	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Mn (Manganese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Ni (Nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Se (Selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.

In the proposed technique, each one of these parameters is given a weighing coefficient from 1 to 5 such that the most and the least important intensity groups in irrigation water quality are given the highest (5) and lowest (1) points. As the salinity hazard is considered to be the most intensity important factor in irrigation water quality assessment, it is given the highest significance. On the other hand, the miscellaneous effects to sensitive crops are generally considered as the least important factor influencing the irrigation water quality. Between these two extremes, the infiltration and permeability hazard, specific ion toxicity and trace element toxicity are rated in decreasing order of significance for irrigation water quality. The technique assigns rating factors for each parameter as shown in Tables 5, 6, and 7. In the present study, Irrigation Water Quality Index (IWQI) is developed based on the method given by Ayers and Westcot (1985) and Simsek and Orhan (2007) with regards the guidelines presented by Ayers and Westcot (1985). The proposed IWQ index is then calculated as:

$$\text{IWQ Index} = \sum_{i=1}^{5} Gi \quad \text{(1)}$$

Where i is an incremental index and G represents the contribution of each one of the five hazard categories that are important to assess the quality of an irrigation water resource.

The first category is the salinity hazard that is represented by the EC value of the water and is formulated as:

$$G1 = w1r1 \quad \text{(2)}$$

Where w is the weight value of this hazard group and r is the rating value of the parameter as given in Table 5.

The second category is the infiltration and permeability hazard that is represented by EC–SAR combination and is formulated as:

$$G2 = w2r2 \quad \text{(3)}$$

where w is the weight value of this hazard group and r is the rating value of the parameter as given in Table 6.

The third category is the specific ion toxicity that is represented by SAR, chloride and boron ions in the water and is formulated as a weighted average of the three ions:

$$G3 = \frac{w3}{3}\sum_{j=1}^{3} rj \quad \text{(4)}$$

Where j is an incremental index, w is the weight value of this group as given in Table 3 and r is the rating value of each parameter as given in Table 5. The fourth category is the trace element toxicity that is represented by the elements given in Table 4 and is formulated as a weighted average of all the ions available for analysis:

$$G4 = \frac{w4}{N}\sum_{k=1}^{N} rk \quad \text{(5)}$$

Where k is an incremental index, N is the total number of trace element available for the analysis, w is the weight value of this group and r is the rating value of each parameter as given in Table 7.

The fifth and the final category is the miscellaneous effects to sensitive crops that are represented by nitrate–nitrogen, bicarbonate ions and the pH of the water, and is formulated as a weighted average:

$$G5 = \frac{w5}{N}\sum_{m=1}^{3} rm \quad \text{(6)}$$

Where m is an incremental index, w is the weight value of this group and r is the rating value of each parameter as given in Table 5.

Table 5. Classification for IWQ index parameters.

Hazard	Weight	Parameter	Range	Rating	Suitability
Salinity hazard	5	Electrical conductivity (μS/cm)	EC < 700	3	High
			700 ≤ EC ≤ 3000	2	Medium
			EC > 3000	1	Low
Infiltration and permeability hazard	4	Table 6 for details			
Specific ion toxicity	3	Sodium adsorption ratio (–)	SAR < 3.0	3	High
			3.0 ≤ SAR ≤ 9.0	2	Medium
			SAR > 9.0	1	Low
		Boron (mg/l)	B < 0.7	3	High
			0.7 ≤ B ≤ 3.0	2	Medium
			B > 3.0	1	Low
		Chloride (mg/l)	CI < 140	3	High
			140 ≤ CI ≤ 350	2	Medium
			CI > 350	1	Low
Trace element toxicity	2	Table 7 for details			
Miscellaneous effects to sensitive crops	1	Nitrate Nitrogen (mg/l)	NO_3–N < 5.0	3	High
			5.0 ≤ NO_3–N ≤ 30.0	2	Medium
			NO_3–N > 30.0	1	Low
		Bicarbonate (mg/l)	HCO_3 < 90	3	High
			90 ≤ HCO_3 ≤ 500	2	Medium
			HCO_3 > 500	1	Low
		pH	7.0 ≤ pH ≤ 8.0	3	High
			6.5 ≤ pH < 7.0 and 8.0 < pH ≤ 8.5	2	Medium
			pH < 6.5 or pH > 8.5	1	Low

Table 6. Classification for infiltration and permeability hazard.

SAR					Rating	Suitability
3>	6–3	12–6	20–12	20<		
700<	1200 <	1900<	2900<	5000<	3	High
200–700	300–1200	500–1900	1300–2900	2900–5000	2	Medium
200>	300>	500>	1300>	2900>	1	Low

Table 7. Classification for trace element toxicity.

Factor	Range	Rating	Suitability
Arsenic (mg/l)	As < 0.1	3	High
	0.1 ≤ As ≤ 2.0	2	Medium
	As > 2.0	1	Low
Cadmium (mg/l)	Cd < 0.01	3	High
	0.01 ≤ Cd ≤ 0.05	2	Medium
	Cd > 0.05	1	Low
Chromium (mg/l)	Cr < 0.1	3	High
	0.1 ≤ Cr ≤ 1.0	2	Medium
	Cr > 1.0	1	Low
Copper (mg/l)	Cu < 0.2	3	High
	0.2 ≤ Cu ≤ 5.0	2	Medium
	Cu > 5.0	1	Low
Iron (mg/l)	Fe < 5.0	3	High
	5.0 ≤ Fe ≤ 20.0	2	Medium
	Fe > 20.0	1	Low
Manganese (mg/l)	Mn < 0.2	3	High
	0.2 ≤ Mn ≤ 10.0	2	Medium
	Mn > 10.0	1	Low
Nickel (mg/l)	Ni < 0.2	3	High
	0.2 ≤ Ni ≤ 2.0	2	Medium
	Ni > 2.0	1	Low
Selenium (mg/l)	Se < 0.01	3	High
	0.01 ≤ Se ≤ 0.02	2	Medium
	Se > 0.02	1	Low
Zinc (mg/l)	Zn < 2	3	High
	2 ≤ Zn ≤ 10	2	Medium
	Zn > 10.0	1	Low

3. Results and discussion

The assessment of chemical characteristics of the groundwater samples that were analyzed compared with Word Health Organization (WHO) and Jordanian water quality standards. Groundwater quality for drinking purposes was evaluated by calculation the Water Quality Index (WQI) for each sample that indicates the influence of individual water quality parameters on the overall water quality. The Water Quality Index (WQI) was calculated for evaluating influence of natural and anthropogenic activities based on several key parameters of groundwater chemistry. The weight has been assigned for the physico-chemical parameters according to the parameters relative importance in the overall quality of water for drinking water purposes. The IWQI has advantages by reflecting the suitability of water for specific use. The proposed index method utilizes five limitation groups that have been mentioned by Ayers and Westcot (1985) with few modification in their classification categories for irrigation water quality assessment. These limitation groups are: (a) salinity limitation, (b) infiltration and permeability limitation, (c) specific ion toxicity, (d) trace element toxicity; and, (e) miscellaneous impacts on sensitive crops. These parameters are given a weighing coefficient from 1 to 5 such that the most and the least important groups in irrigation water quality are given the highest (5) and lowest (1) points. As the salinity hazard is considered to be the most intensity important factor in irrigation water quality assessment, it is given the highest priority.

After the total value of the index is computed, a suitability analysis is determined based on the three different categories given in Table 8. The values given in Table (8) is obtained by assigning different rating factors (i.e., 1, 2 and 3) to each parameter without changing its weighing coefficient, thus yielding two different index values (i.e., 30 and 39). The suitability map can be constructed based on the computed index value which is evaluated according to three categories given in Table 8. When the IWQI value is greater than 37, the quality of irrigation water is high and no problems with irrigation water quality. However when the IWQI ranges between 22 and 37, the quality of irrigation water is of moderate suitability for irrigation purposes. Finally if the IWQ index is less than 22, the quality of irrigation water is considered poor and not suitable for irrigation.

Table 8. Irrigation water quality (IWQ) index.

IWQ index	Suitability of water for irrigation
< 22	Low
22 – 37	Medium
> 37	High

The irrigation water quality index (IWQI) maps was prepared using ArcGIS to represent the suitability of irrigation water quality in Wadi Araba area. The IWQI classify the quality of irrigation water into two categories as moderate and high suitability water for irrigation. Accordingly, 75.7 % of the irrigation water has a medium suitability for irrigation in both periods pre and after wet season, whereas only 24.3 % has exhibit high suitability for irrigation for both investigating periods (Fig.3). The northern regions of Wadi Araba basin appear to have high water suitability for irrigation purposes as in wadi Feifa, Umruq, Wadi Musa, Feedan, and some wells in Um Methla and Risha areas. It can be noticed that the suitability of irrigation water quality can be deteriorated towards the southern part of the study area.

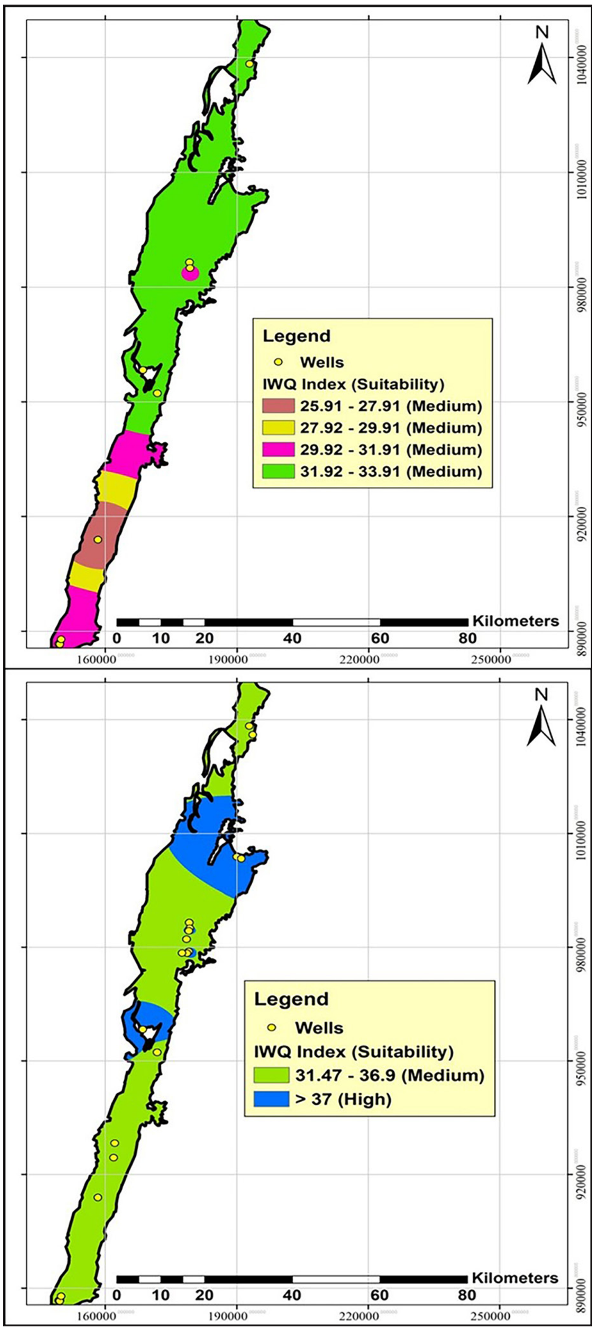


Figure 3. Spatial distribution of IWQI values in the study area during two periods and their suitability: pre-rainfall period and post-rainfall periods, respectively.

The suitability map obtained from the computed index value is evaluated according to three categories given in Table 9. When the computed index value is bigger than 37, the corresponding area is considered to have minimum problems with respect to irrigation quality. When the computed index value is between 22 and 37, the corresponding waters demonstrates moderate suitability for irrigation purposes. Within this range, values higher than 30 are considered to represent waters that could be easily used on resistant crops. However, the IWQ index values of less than 22 are considered to be poor quality irrigation waters and are not suitable for irrigating agricultural fields; this range of index value does not represent all samples.

Table 9. The contribution of each one of the five hazard categories that are important to assess the quality of an irrigation in the pre and post-rainfall periods.

Pre-rainfall period									
Station ID	Station Name	Sampling Date	G_1	G_2	G_3	G_4	G_5	IWQI	Suitability
DA1008	WADI MUSA No.7	10–Aug	5	12	6	5.2	2.67	30.87	Medium
DA1010	FEIFA No.2	06-Sep	10	8	6	5.2	2.67	31.87	Medium
DA1010	FEIFA No.2	10–Aug	10	12	9	5.2	2.67	38.87	High
DA1020	UMRUQ No.2	10–Aug	10	12	6	5.2	2.67	35.87	Medium
DA1027	WADI MUSA No.10	10–Aug	10	12	8	5.2	2.67	37.87	High
DA1029	WADI MUSA No.12	10–Aug	10	12	8	5.2	2.67	37.87	High
DA1102	WADI MUSA No.1	10–Aug	5	12	6	5.2	2.67	30.87	Medium
DE1001	FEEDAN No.1	14–Sep	10	12	9	5.2	3	39.2	High
DE1003	FEEDAN No.6	14–Sep	10	12	9	5.2	2.67	38.87	High
DF1003	UM MITHLA No.1B	10–Aug	5	12	6	5.2	2.67	30.87	Medium
DF1005	UM MITHLA No.5	10–Aug	10	12	8	5.2	2.67	37.87	High
DA3039	UM MITHLA No.8	10–Aug	10	12	8	5.2	3	38.2	High
EA1005	RAHMA No.6	10–Aug	10	12	6	5.2	3	36.2	Medium
EA1013	RAHMA No.7	10–Aug	10	12	6	5.2	2.67	35.87	Medium
EA3013	QATAR No.2	10–Aug	10	8	7	5.2	3	33.2	Medium
EA3018	Q'A ASSAIDIYIN No.2A	10–Aug	10	12	6	5.2	2.67	35.87	Medium
DA3046	WADI ARABA No.3 (WA3)/ RISHA	10–Aug	10	12	8	5.2	2.67	37.87	High
EA3033	PILOT PROJECT OBSERVATION WELL No.1	06–Sep	10	12	6	5.2	2.67	35.87	Medium
EA3034	PILOT PROJECT OBSERVATION WELL No.2	06–Sep	10	12	6	5.2	2.67	35.87	Medium
EA3034	PILOT PROJECT OBSERVATION WELL No.2	14–Sep	10	8	7	5.2	2	32.2	Medium
EA3035	PILOT PROJECT OBSERVATION WELL No.3	06–Sep	10	12	6	5.2	2.67	35.87	Medium
EA3035	PILOT PROJECT OBSERVATION WELL No.3	14–Sep	10	12	7	5.2	2.67	36.87	High
EA3036	PILOT PROJECT OBSERVATION WELL No.4	06–Sep	10	12	6	5.2	2.67	35.87	Medium
Post-rainfall period									
Station ID	Station Name	Sampling Date	G_1	G_2	G_3	G_4	G_5	IWQI	Suitability
DA1010	FEIFA No.2	02–Apr	10	12	9	0.5	2.33	33.85	Medium
DF1002	UM MITHLA No.1A	13–Apr	10	12	8	0.5	2.67	33.19	Medium
DF1005	UM MITHLA No.5	13–Apr	10	12	6	0.5	2.67	31.19	Medium
DF1005	UM MITHLA No.5	14–May	10	12	8	0.5	2.67	33.19	Medium
DF1005	UM MITHLA No.5	28–May	10	12	6	0.5	2.67	31.19	Medium
EA3013	QATAR No.2	13–Apr	5	12	6	0.5	2.33	25.85	Medium
EA3018	Q'A ASSAIDIYIN No. 2A	13–Apr	10	12	7	0.5	2.67	32.19	Medium
DA3046	WADI ARABA No.3 (WA3)/ RISHA	13–Apr	10	12	8	0.5	2.67	33.19	Medium
EA3033	PILOT PROJECT OBSERVATION WELL No.1	28–May	10	12	6	0.5	2.67	31.19	Medium
EA3033	PILOT PROJECT OBSERVATION WELL No.1	13–Apr	10	12	6	0.5	2.67	31.19	Medium
EA3033	PILOT PROJECT OBSERVATION WELL No.1	02–Apr	10	12	6	0.5	2.33	30.85	Medium
EA3034	PILOT PROJECT OBSERVATION WELL No.2	14–May	10	8	7	0.5	2.67	28.19	Medium
EA3035	PILOT PROJECT OBSERVATION WELL No.3	14–May	10	12	7	0.5	3	32.52	Medium
EA3036	PILOT PROJECT OBSERVATION WELL No.4	14–May	10	12	7	0.5	2.67	32.19	Medium

4. Conclusions

The IWQ index is a numerical index which can be used for the assessment of the suitability of water quality for irrigation. The irrigation water quality index map was constructed using ArcGIS to identify the suitability of irrigation water in the investigated area.

The suitability map obtained from the computed index value which is evaluated according to specific categories. Accordingly, the IWQI maps showed that 75.7% of the water quality in pre and post rainfall seasons has medium suitability and 24.3% has high suitability for irrigation use. The IWQI values in pre-rainfall seasons quite decrease of IWQI values in post-rainfall seasons as a result of water dilution or aquifer recharge from rainfall and decreasing the water discharge from wells. As the aquifer was being recharged, the concentration of the major ions decreased which led to reduction in the IWQI values.

The water quality for irrigation showed signs of water deterioration towards the southern part of the investigated area. While in the northern part, the water quality for irrigation is highly suitable during the pre-rainfall period as in Feifa, Umruq, Wadi Musa and Feedan areas. Accordingly, the water quality from in Wadi Araba is currently suitable for use in irrigation. It is believed that the proposed IWQI can be used as a tool in future agricultural management plans that serve decision-makers and farmers in Wadi Araba area.

Acknowledgments

The Ministry of Water and Irrigation (MWI) is acknowledged for their support in carrying out the chemical and physical analyses that achieved at their laboratories.

References

American Public Health Association (APHA), (1998). A standard methods for examination of water and wastewater, 20th edition, Washington, NW.

Ayers, R.S., and Westcot, D.W. (1985). Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29, Food and Agriculture Organization, Rome.

Dames and Moore. (1979). Preliminary Evaluation of the Hydrology of Wadi Araba and Southern Ghor, Water Resources Study. Amman–Jordan.

El-Naqa, A., and Al Kuisi, M. (2012). Groundwater resources assessment for irrigable agricultural lands in the Wadi Araba area, southern Jordan. Journal of Arab J Geosci, doi: 10.1007/s12517-012-0579-5.

El-Naqa, A., Hammouri, N., Ibrahim, K., and El-Taj, M. (2009). Integrated Approach for Groundwater Exploration in Wadi Araba Using Remote Sensing and GIS. Jordan Journal of Civil Engineering, Volume 3, No.3.

Khalid, H.L. (2011). Evaluation of Groundwater Quality for Drinking Purpose for Tikrit and Samarra Cities using Water Quality Index. European journal of scientific research 58(4): 472–481.

Krishna, K., S., Logeshkumaran, A., Magesh, N., Prince, S., Godson, N. (2014). Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. Appl. Water Sci., DOI 10.1007/s13201-014-0196-4.

Magesh, N., Krishna, K., Subbiah, K., Chandra, S. (2013). Groundwater quality assessment using WQI and GIS techniques, Dindigul district, Tamil Nadu, India. Arabian Journal of Geosciences, 6(11): 4179–4189.

Mitra, B.K. (1998). Spatial and temporal variation of ground water quality in sand dune area of Aomori Prefecture in Japan. ASABE.

Rizwan, R., and Gurdeep, S. (2010). Assessment of Ground Water Quality Status by Using Water Quality Index Method in Orissa, India. World Applied Sciences Journal, 9(12): 1392-1397.

Simsek, C. and Orhan, O. (2007). IWQ Index: A GIS-Integrated Technique to Assess Irrigation Water Quality. Environ. Monit., 128: 277–300.

Srinivasamoorthy, K., Vijayaraghavan, K., Vasanthavigar, M., Sarma, V.S., Rajivgandhi, R., Chidambaram, S., Anandhan, P., Manivannan, R. (2010). Assessment of groundwater vulnerability in Mettur region, Tamilnadu, India using drastic and GIS techniques. Arab J. Geosci., doi:10.1007/s12517-010-0138-x.

Subba, R.N. (2006). Seasonal variation of groundwater quality in a part of Gunturdistrict, Andhra Pradesh, India. Environmental Geology, 49: 413–429.