Evaluation of Groundwater Quality Suitability for Drinking Purpose Using Water Quality Index Approach in Yarmouk Basin, Jordan

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Groundwater quality is an issue of national concern in Jordan since it is the main water source for drinking, agriculture and industrial purposes. In this context, an attempt has been made to determine the suitability of groundwater in the Yarmouk Basin in Jordan for drinking purposes using the weighted arithmetic water quality index approach with the respect to the Jordanian standards for drinking water. Groundwater quality records from 15 sampling stations spread across Yarmouk Basin during 2008-2015 are used. Seven physical and chemical parameters are selected to calculate the water quality index. These parameters are pH, total dissolved solids, total hardness, sulfates (SO_4^{-2}), chlorides (Cl^-), nitrates (NO_3^-), and sodium (Na^+). The relationship between the selected groundwater quality parameters is evaluated using the correlation coefficient. A strong relationship is found between several parameters such as Cl^- with Na^+, total dissolved solids with Na^+, Cl^-, TH and SO_4^{-2} and total hardness with SO_4^{-2}. A moderate relationship is found between SO_4^{-2} with Na^+, TH with Cl^- and Na^+, SO_4^{-2} with Cl^-, Cl^- with NO_3^- and NO_3^- with Na^+. Also, the mean concentration values of the physical and chemical parameters are almost below the maximum allowable level based on Jordanian standards for drinking except for two sampling locations. According to water quality index scale classification, the groundwater quality of the studied locations is in the excellent to poor water range with computed mean water quality index values range from 26.3 to 107.93. Out of 15 studied locations, ten locations are classified in the 'Excellent water' class, four locations as a "Good water" class, one as a "Poor water" class. None of the studied locations are classified in the "Very poor water" class and "Water unsuitable for drinking purpose" class. Temporal variations and spatial distribution of groundwater quality in Yarmouk Basin based on WQI are also evaluated. The WQI spatial distribution map clearly showed the best locations for drinking water in the Yarmouk Basin. Water quality indices are used to provide theoretical support to water managers and policymakers for proper actions on groundwater quality management.

Keywords: Water quality index, groundwater quality, drinking water, spatial distribution, hydrochemistry, Yarmouk basin

Introduction

Groundwater is still of great environmental concern given that it provides water for drinking, agricultural and industrial uses especially in arid and semi-arid regions as in Jordan. However, groundwater quality is affected by a wide range of natural processes and anthropogenic pollution that degrade its quality and impair their aforementioned uses. Accordingly, it is very important to properly monitor and assess the groundwater quality for sustainable water resources management and safeguarding the public health. Various approaches have been proposed to assess surface water and groundwater quality such as water quality indices (WQIs) and multivariate statistical method (cluster analysis, factor analysis). WQIs are being widely used in water quality assessment studies and have played an increasingly important role in water resource management (Debels *et al*., 2005; Sutadian *et al*., 2016). Water quality index indicates the overall quality of water for any intended use by a dimensionless single value and common rating scale (i.e. excellent, good, poor, very poor, and unsuitable) that provides the overall water quality condition.

This approach overcomes the traditional water quality assessment approach which compares the individual parameter with guideline permissible limit values without providing a whole picture of water quality. The WQI was firstly proposed by Horton in 1965 (Horton, 1965) and then modified by Brown and co-workers in 1970 (Brown *et al*., 1970). Since then, many different methods for calculating the WQIs have been proposed by several authors (Abbasi and Abbasi, 2012; Ashok Lumb *et al*., 2011; Sutadian *et al*., 2016).

These indices are different in how their sub-indices are formulated and in the aggregation process of these sub-indices to compute the final index value (Ponsadailakshmi *et al*., 2018; Sutadian *et al*., 2016). Examples these indices include the National Sanitation Foundation Water Quality Index (NSFWQI) (Brown *et al*., 1970), the British Columbia Water Quality Index (BCWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), the Florida Stream Water Quality Index (FWQI), the Oregon Water Quality Index (OWQI), the Overall Index of Pollution (OIP) (Sargaonkar and Deshpande, 2003) and Universal Water Quality Index (UWQI) (Boyacioglu, 2007). Among these indices, the NSFWQI is the most commonly used index for water quality evaluation worldwide (Misaghi *et al*., 2017). Recent references such as (Abbasi and Abbasi, 2012; Asadollahfardi, 2015; A. Lumb *et al*., 2012; Ashok Lumb *et al*., 2011; Sutadian *et al*., 2016) summarize the development and application of these indices around the world. In Jordan, the groundwater provides 60% of the total supply in 2015 (602 million cubic meters (MCM) out of 1008 MCM) distributed as

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332.5 MCM for drinking and domestic uses, 237.6 MCM for Agricultural, 31 MCM for industry (MWI, 2015). The renewable groundwater resources in Jordan are concentrated mainly in four basins (El-Naqa and Al-Shayeb, 2009).

Yarmouk basin (hereafter denoted YB) in the north of Jordan is one of these basins. No previous studies on evaluation of groundwater quality in YB for drinking purposes by using water quality indices methodologies were carried out to the best of my knowledge. The focus in previous studies was on hydrochemistry, hydrogeology, and quality of groundwater (Abboud, 2018; Abu-Jaber and Kharabsheh, 2008; Howari *et al*., 2005; Obeidat *et al*., 2013; Salameh, 2004; Ta'any *et al*., 2007).

Accordingly, the focus of the present study is to develop a WQI for groundwater in YB that provides theoretical support to water managers and policymakers for proper actions on groundwater quality management. In view of this, the specific objectives of this effort are: (1) to evaluate the suitability of groundwater in YB in Jordan for drinking purposes based on WQI approach, (2) to assess the physicochemical properties of groundwater in YB (3) to determine the temporal variations of groundwater quality in YB based on WQI and (4) to determine the spatial distribution of groundwater quality in YB depending on WQI and to create WQI map using GIS.

1 Materials and Methods

1.1 Yarmouk Basin (YB) groundwater resources

The YB located in the northern part of Jordan between 210 to 280 east and 190 to 240 north (according to Palestine grid) is selected as the study area. The basin area is about 7242 km^2 of which 1424 km^2 are located in Jordan and the remaining areas are in Syria. **Figure 1**. Groundwater resources in YB are classified as renewable resources. The safe yield of YB was provided by the ministry of water and irrigation as 40 (MCM/yr) (MWI/NWMP, 2004).

The actual abstraction of groundwater resources was around 54 MCM in 2015 (MWI, 2015). In this study, groundwater quality records from 15 sampling stations spread across YB during the period from 2008 to 2015 for most stations, collected from (Abboud, 2018), were used in this study.

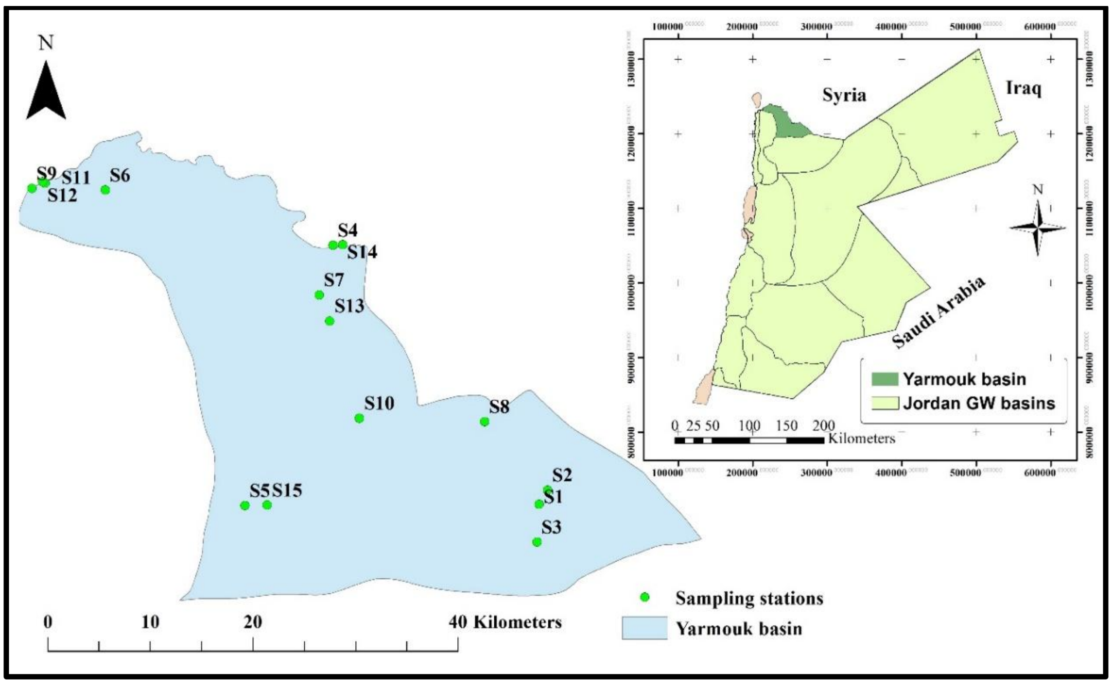

Fig. 1 Yarmouk Basin and the location of sampling stations.

Samples collection, preservation, and all the parameters analysis were performed as per the standard methods for water and wastewater (APHA, 2005) by the Ministry of Water and Irrigation and the University of Al Al-Bayt laboratories (Abboud, 2018). The locations of these stations across the basin are shown in Fig. 1, and the details of these stations are given in **Table 1**.

Table 1 Details of groundwater sampling stations.

Station ID	Station Code	Station Name	Palestine Coordinates	
			Latitude	Longitude
S1	AD1046	Abd El Razzaq Tbaishat	1203700	264160
S2	AD1050	Khleif Serhan	1205085	264995
S3	AD1105	Muhyi Eddeen Taweela	1200015	263975
S4	AD1173	Mahmoud Al Nahlawi	1228950	244070
S5	AD1219	Nuaymeh Mun 1 (PP344)	1203575	235475
S6	AD1239	Saham Exp WSE	1234340	221870
S7	AD1251	Ahmad F. El Fandi	1224115	242723
S8	AD1262	Swailmeh Exp	1211765	258860
S9	AD1276	Mukheiba (JRV1)	1234500	214700
S10	AD1280	Hasan Industrial City	1212100	246640
S11	AD1284	Mukheiba 1	1235000	216000
S12	AD1290	Mukheiba 6	1235150	215750
S13	AD1295	Mahasi 6 (Deep)	1221580	243750
S14	AD3008	Turra No. 1	1229000	245000
S15	AD3011	Nuaymeh 3	1203630	237640

1.2 Calculation of the WQI

In this study, the WQI for groundwater is calculated by the weighted arithmetic mean method (Brown *et al*., 1970). The WQI is used here to evaluate the overall quality of groundwater for drinking purposes at selected locations in YB with respect to Jordanian standards for drinking water (*JS 286/2015*) (*JS, 2015*), hereafter referred to as the *JS286*. Seven parameters were selected to include in the calculation of WQI. These parameters are pH, total dissolved solids (TDS), total hardness (TH), sulfates (SO_4^{-2}), chlorides (Cl^-), nitrates (NO_3^-), and sodium (Na^+). The methodology for calculating the WQI can be summarized in the following four steps:

Step 1: Unit weight assignment and relative weight calculation for each parameter. Each of the seven parameters has assigned a weight (w_i) in range from one to five based on its health effects when presents in drinking water Table 2. Then, the relative weight for each parameter (Wi) is calculated by the following formula:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

where W_i is the relative weight, w_i is the unit weight of each parameter and n is the number of selected parameters (n = 7 in this study).

Step 2: Calculation of the rating scale for each parameter. The rating scale (Q_i) for each parameter is calculated according to the following equation:

$$Q_i = \left(\frac{C_i - I_i}{S_i - I_i}\right) \times 100 \quad (2)$$

where Q_i is the rating scale, C_i is the concentration corresponding to i^{th} parameter in mg/L at a given sampling location, I_i is the ideal value of i^{th} parameter in pure water (i.e., The ideal value for pH = 7, and equal to zero for all other parameters), and S_i is the drinking water standard for i^{th} parameter in mg/L according to the JS286.

Step 3: Developing sub-indices. The water quality sub-index value (SI_i) is determined for each parameter by:

$$SI_i = W_i \times Q_i \quad (3)$$

Where SI_i is the sub-index value for i^{th} parameter.

Table 2 The unit weight and relative weight of each parameter used for WQI computation with Jordanian standards for drinking water quality.

Parameters	**Unit weight**	**Relative weight**	**JS 286/2015 Standard***
pH	4	0.138	6.5 - 8.5
Total dissolved solid (TDS), mg/L	4	0.138	1000 - 1300
Total hardness (TH) as $CaCO_3$, mg/L	3	0.103	500 - 600
Sulphates (SO_4^{-2}), mg/L	5	0.172	200 - 500
Chlorides (Cl^-), mg/L	5	0.172	200 - 500
Nitrates (NO_3^-), mg/L	5	0.172	50-70
Sodium (Na^+), mg/L	3	0.103	200 - 300

* For each parameter, lower value indicates maximum allowable limit and higher value indicates maximum allowable limit in case there is no water resource with a better quality, and with the approval of the Ministry of Health.

Step 4: sub-indices Aggregation. In this study, additive aggregation is applied to obtain the WQI as per the following equation:

$$WQI = \sum_{i=1}^{n} SI_i \quad (4)$$

The groundwater quality types are determined according to the computed WQI values. These types are classified into five categories (Sahu and Sikdar, 2008) as shown in **Table 3**.

Table 3 The WQI range and water quality classification for drinking purposes.

WQI range	**Type of water**
<50	Excellent water
50–100	Good water
100.1–200	Poor water
200.1–300	Very poor water
>300	Water unsuitable for drinking

2 Results and Discussion

2.1 General characteristics of Yarmouk basin groundwater quality

The summary statistics (mean, standard deviations and range) of the selected groundwater quality parameters in all studied locations are present in Table 4. The pH values ranged from 6.63 in S2 to 8.49 also in S2 which indicates the slightly acidic to alkaline nature of groundwater in all studied locations. As per the JS286, all values fall within the permissible limits (6.5 to 8.5). This variation in pH values is mainly due to variation in bicarbonate concentration in the water aquifers.

According to JS286, total dissolved solids (TDS) up to 1000 mg/L is the maximum allowable limit and up to 1300 mg/L is the maximum allowable limit in case there is no water resource with a better quality, and with the approval of the Ministry of Health in Jordan. The TDS value varies in the range 345.6 mg/L in S5 to 1548.8 mg/L in S7. The mean TDS values in all studied locations are below the allowable limit of 1000 mg/L except the sample locations S7 and S9 where the mean TDS concentrations are 1198.44 and 1065.01 mg/L, respectively.

The palatability of drinking water can be classified according to TDS as excellent (<300 mg/L), good (30–600 mg/L), fair (600–900 mg/L), poor (900–1200 mg/L) and unacceptable (>1200 mg/L) (WHO, 1996). According to this classification, most of the studied locations (10 out of 15) fall under the good water class. While the small number of studied locations can be classified as fair and poor water (3 and 2 locations, respectively). Total hardness (TH) of groundwater results mainly from the presence of calcium and magnesium. TH as $CaCO_3$ of groundwater samples in the studied locations ranges from 136.77 mg/L in S2 to 631.67 mg/L in S9. Out of 15 groundwater sampling locations, the mean TH value in one location namely S9 is exceeded the permissible limit of 500 mg/L as $CaCO_3$ as per the JS286 where the mean TH is 512.88 mg/L as $CaCO_3$. The groundwater can be classified according to TH as soft (TH 75), moderately hard (75<TH<150), hard (150<TH<300) and very hard (TH>300) (Sawyer *et al*., 2003). Therefore, the groundwater of the majority of the studied locations is hard to very hard water. Out of 15 sampling locations, seven locations belong to hard water and eight locations belong to very hard water.

The sulfate (SO_4^{-2}) concentration in the studied locations ranges between 5.76 mg/L in S5 and 545.28 mg/L in S9. The mean SO_4^{-2} values in all studied locations are below the allowable limit of 200 mg/L as per the JS286 except the sample location S9 where the mean $SO_4^{-}2$ concentration is 278.8 mg/L. In the studied locations, the chloride (Cl^-) value is between 16.33 mg/L in S6 and 461.5 mg/L in S7. The maximum allowable limit of Cl^- for drinking water is specified as 200 mg/L and 500 in case there is no water resource with a better quality, and with the approval of the Ministry of Health in Jordan as per JS286. All of the Cl^- values are falling within the allowable limit except two sampling locations S7 and S9 where the mean Cl^- concentrations are 347.78 and 226.89 mg/L, respectively.

The nitrate (NO_3^-) concentration varies from 0.08 mg/L in S11 to 148.71 mg/L in S7. Base on mean NO_3^- concentrations, only in S7 sampling location the mean NO_3^- concentration is exceeded the maximum allowable limits of 50 mg/L and 70 mg/L that represent the maximum allowable limit in case there is no water resource with a better quality, and with the approval of the Ministry of Health in Jordan as per the JS286. For sodium (Na^+), the JS286 is specified 200 mg/L as the maximum allowable limit for drinking water and 300 mg/L in case there is no water resource with a better quality. The Na^+ concentration varies from 17.71 mg/L in S5 to 296.01 mg/L in S7. Out of 15 sampling locations and according to mean Na^+ values, only in S7 sampling location, the mean Na^+ concentration is exceeded the maximum allowable limits as per the JS286.

The correlation coefficient (**r**) is calculated between various parameters to understand the relationships and variations between them. The values of correlation coefficients are presented in **Table 5**. The terms strongly, moderately and weakly correlations refer to r>0.7, 0.5<r<0.7, and r<0.5, respectively. Strong positive correlation is found among TDS with Na^+, Cl^-, TH, and SO_4^{-2}. This indicates that these four parameters are the main contributors to TDS value in YB. The strongest positive correlation is observed between Cl^- and Na^+ (r = 0.94) indicating that these two ions are derived from the same origin by chemical dissolution and leaching of chloride minerals (such as halite). Strong positive correlation is also observed between TH and SO_4^{-2} (r = 0.76) indicating that the groundwater hardness in YB is related to SO_4^{-2} in addition to its main attributed calcium and magnesium.

The high moderately correlation between SO_4^{-2} and Na^+ (r=0.63) demonstrates that fraction of these two ions are derived from the weathering of sodium sulfate minerals, which may exist in the YB aquifers (Abboud, 2018). In other hand, moderate correlation is observed between several water parameters such as TH with Cl^- and Na^+(r=0.52 and 0.55, respectively), SO_4^{-2} with Cl^- (r=0.56), Cl^- with NO_3^- (r=0.54) and NO_3^- with Na^+ (r=0.55). In general, this positive correlation between groundwater quality parameters contributes to water chemistry within the YB. Also, these positive correlations controlled by mineral dissolution, mineral solubility, ion exchange, evaporation, anthropogenic activities, and water flow path conditions (Amalraj and Pius, 2018; Rao *et al.,* 2012).

2.2 Assessment of the groundwater quality using WQI

During the study period, the WQI values and the corresponding water quality type in the studied locations are presented in **Table 6**. The computed mean WQI values range from 26.3 to 107.93. Consequently, the groundwater quality of the studied locations is in the excellent to poor water range. Results from Table 6 indicated that, out of 15 studied locations, ten locations are classified in the ‘Excellent water’ class, four locations as“Good water” class, one as a “Poor water” class. None of the studied locations are classified in the “Very poor water” class and “Water unsuitable for drinking purpose” class.

Table 5 Correlation matrix between groundwater quality parameters of YB.

	pH	TDS	TH	SO_4^{-2}	Cl^-	NO_3^-	Na^+
pH	1.00						
TDS	-0.24	1.00					
TH	-0.49	0.80	1.00				
SO_4^{-2}	-0.19	0.76	0.76	1.00			
Cl^-	-0.02	0.89	0.52	0.56	1.00		
NO_3^-	0.00	0.46	0.16	0.02	0.54	1.00	
Na^+	-0.04	0.92	0.55	0.63	0.94	0.55	1.00

Table 6 Results of water quality index for drinking purposes of the studied groundwater locations.

Station ID	WQI Mean ± SD	Water Type
S1	38.45 ± 4.49	Excellent water
S2	42.78 ± 4.26	Excellent water
S3	65.51 ± 7.05	Good water
S4	54.58 ± 5.21	Good water
S5	32.07 ± 9.57	Excellent water
S6	26.13 ± 3.08	Excellent water
S7	107.93 ± 13.68	Poor water
S8	35.11 ± 2.57	Excellent water
S9	80.37 ± 9.95	Good water
S10	51.34 ± 3.93	Good water
S11	28.52 ± 2.47	Excellent water
S12	28.43 ± 2.43	Excellent water
S13	34.93 ± 2.91	Excellent water
S14	39.09 ± 2.73	Excellent water
S15	39.66 ± 7.46	Excellent water

Table 4 Summary statistics (Mean ± standard deviations and range in regular brackets) of the selected groundwater quality parameters at each sampling location.

Station ID	Parameters						
	pH	TDS	TH	SO_4^{-2}	Cl^-	NO_3^-	Na^+
S1	7.79 ± 0.27	512.62 ± 22.21	250.47 ± 10.81	54.34 ± 6.94	117.84 ± 19.77	3.73 ± 3.84	65.42 ± 4.73
	(6.73 - 8.23)	(444.80 - 579.84)	(223.95 - 270.01)	(41.28 - 72.96)	(85.20 - 202.35)	(0.55 - 16.87)	(58.19 - 82.57)
S2	7.99 ± 0.27	491.38 ± 15.38	176.22 ± 12.72	57.56 ± 10.76	109.73 ± 7.13	12.85 ± 8.24	84.79 ± 3.28
	(6.63 - 8.49)	(448.0 - 513.92)	(136.77 - 218.44)	(43.60 - 109.92)	(81.30 - 118.22)	(1.37 - 61.36)	(75.90 - 93.38)
S3	7.68 ± 0.24	770.79 ± 67.08	359.44 ± 27.41	128.73 ± 41.06	164.75 ± 27.2	29.87 ± 6.11	108.03 ± 19.27
	(6.81 - 8.18)	(590.08 - 931.84)	(320.64 - 431.86)	(37.92 - 262.08)	(71.0 - 213.0)	(21.60 - 59.46)	(26.91 - 140.76)
S4	7.51 ± 0.18	619.04 ± 46.24	301.71 ± 22.07	54.38 ± 8.04	163.21 ± 21.99	35.12 ± 5.09	81.48 ± 4.21
	(7.27 - 7.67)	(576.0 - 663.68)	(277.55 - 329.63)	(46.08 - 65.28)	(135.61 - 187.44)	(28.20 - 39.51)	(75.44 - 84.87)
S5	7.51 ± 0.28	408.58 ± 111.54	282.98 ± 66.52	35.78 ± 65.66	40.26 ± 17.14	23.06 ± 8.92	27.05 ± 17.88
	(6.80 - 7.84)	(345.60 - 814.72)	(243.48 - 528.55)	(5.76 - 276.48)	(30.18 - 101.18)	(5.71 - 41.16)	(17.71 - 80.27)
S6	7.65 ± 0.22	456.60 ± 63.12	283.17 ± 26.57	27.15 ± 9.46	43.11 ± 11.25	1.20 ± 1.56	29.72 ± 3.61
	(7.40 - 8.09)	(416.0 - 621.44)	(233.46 - 331.66)	(13.44 - 47.52)	(16.33 - 54.32)	(0.22 - 5.25)	(23.92 - 37.49)
S7	7.56 ± 0.28	1198.44 ± 155.3	400.72 ± 52.52	93.48 ± 16.34	347.78 ± 65.79	82.16 ± 28.28	223.29 ± 34.96
	(7.19 - 8.17)	(976.0 - 1548.80)	(322.64 - 504.50)	(56.64 - 118.56)	(184.60 - 461.50)	(43.10 - 148.71)	(169.97 - 296.01)
S8	7.50 ± 0.25	546.18 ± 19.67	282.95 ± 10.37	34.46 ± 6.29	107.71 ± 6.95	4.07 ± 1.92	66.70 ± 4.61
	(7.30 - 7.93)	(522.24 - 576.64)	(272.03 - 298.15)	(25.44 - 43.20)	(97.63 - 113.60)	(1.0 - 5.75)	(60.49 - 73.37)
S9	7.37 ± 0.27	1065.01 ± 86.8	512.88 ± 53.19	278.80 ± 66.48	226.89 ± 13.62	1.06 ± 1.73	148.96 ± 20.25
	(6.93 - 7.77)	(940.16 - 1414.40)	(351.20 - 631.76)	(213.60 - 545.28)	(189.57 - 258.80)	(0.08 - 9.03)	(127.42 - 232.30)
S10	7.28 ± 0.33	821.06 ± 41.28	455.75 ± 27.76	116.49 ± 26.62	125.06 ± 13.51	6.38 ± 4.31	96.53 ± 6.42
	(6.67 - 7.80)	(739.20 - 909.44)	(374.75 - 513.52)	(64.80 - 185.28)	(111.47 - 180.70)	(0.66 - 13.10)	(84.41 - 113.62)
S11	7.18 ± 0.22	535.33 ± 7.81	351.65 ± 19.55	53.45 ± 7.28	59.06 ± 2.27	1.15 ± 1.51	40.21 ± 1.28
	(6.98 - 7.67)	(521.60 - 550.40)	(298.59 - 369.74)	(44.16 - 64.32)	(56.09 - 63.19)	(0.08 - 4.60)	(38.64 - 42.78)
S12	7.36 ± 0.24	499.15 ± 20.2	304.53 ± 22.29	38.97 ± 16.44	63.32 ± 5.21	2.36 ± 1.66	45.07 ± 4.05
	(6.91 - 8.0)	(458.24 - 531.20)	(257.01 - 359.22)	(8.64 - 68.64)	(46.15 - 70.65)	(0.17 - 4.87)	(28.06 - 48.53)
S13	7.70 ± 0.31	509.66 ± 13.4	272.53 ± 11.76	39.57 ± 8.34	105.49 ± 5.44	1.07 ± 0.76	56.96 ± 1.52
	(6.78 - 8.21)	(464.0 - 538.24)	(249.50 - 295.08)	(24.96 - 61.92)	(95.50 - 116.44)	(0.21 - 3.40)	(54.05 - 60.49)
S14	7.85 ± 0.14	531.18 ± 20.56	263.03 ± 12.82	47.43 ± 23.27	119.21 ± 6.52	2.52 ± 1.52	62.37 ± 6.49
	(7.48 - 8.11)	(485.12 - 609.28)	(228.96 - 284.57)	(19.68 - 161.76)	(95.50 - 138.10)	(0.10 - 8.33)	(37.03 - 82.11)
S15	7.51 ± 0.33	462.53 ± 62.82	301.49 ± 33.49	18.14 ± 9.13	53.50 ± 23.8	43.15 ± 14.9	26.01 ± 11.22
	(6.84 - 7.97)	(426.24 - 630.40)	(270.05 - 374.85)	(10.56 - 40.32)	(33.37 - 119.28)	(16.10 - 70.11)	(18.40 - 57.50)

The poor water has been observed in sampling location S7 (i.e. Ahmad El-Fandi's well). This may be due to relatively high measured concentration values of TDS, Cl^-, NO_3^- and Na^+ parameters in water samples in comparison to their maximum allowable limit values as prescribed in the JS286. The high measured concentration values are reflecting the presence of anthropogenic pollution sources within the surrounding area such as percolation from septic tanks and agricultural practices.

Figure 2 is used to show the temporal variations of groundwater quality by considering the change of the WQI values with time. As the temporal change of the WQI values reflect groundwater quality variations. Figure 2 illustrates temporal variations of S5, S7, and S9 sampling locations at the YB as an example. The temporal trend of WQI in S5, S7, and S9 sampling locations represents the major trends found in all studied locations. Each of the remaining studied locations follows one of these observed trends to some extent. It is apparent that the WQI at the S7 is historically changed from good water to poor water in recent years with WQI ranges from 87 to 130. While the trend shows the S9 has been historically good water except one sampling point in 2014 with WQI ranges from 66 to 116. Also, the trend shows the S5 has been historically excellent water except one sampling point in 2010 with WQI ranges from 21 to 64.

Figure 3 depicts the spatial distribution of the water quality types in YB. It is shown that a majority of the area is covered by excellent water. The area occupied by good water is almost observed in the central and southeastern parts of the basin. In about a small area around the sampling location S7, the water is poor water.

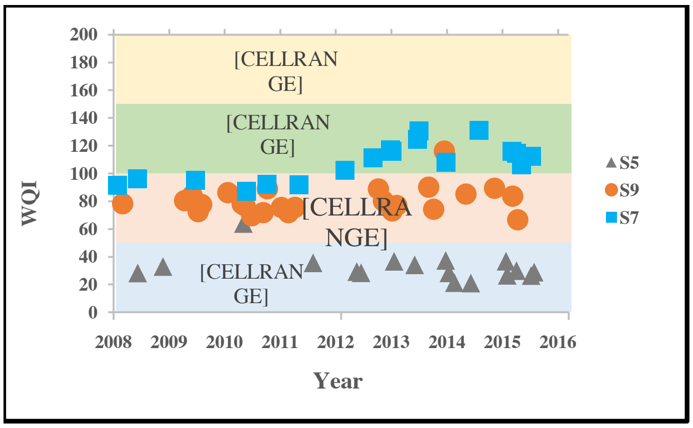

Fig. 2 Temporal variations of water quality types in YB for sampling locations S5, S7 and S9.

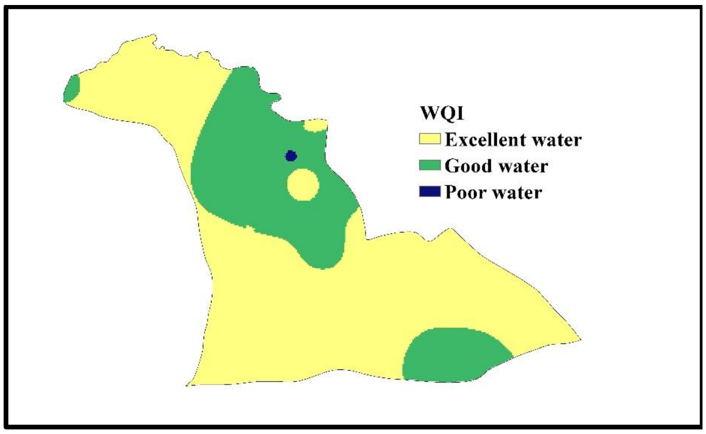

Fig. 3 Spatial variations of mean WQI values in the Yarmouk Basin.

Conclusions

This study presents the using of WQI in evaluating the groundwater quality in YB in Jordan for drinking purposes. Based on the result, the following specific conclusions can be drawn:

- Groundwater in the YB is slightly acidic to alkaline and hard to very hard in nature. The mean concentration values of the physical and chemical parameters are almost below the maximum allowable level based on JS286 in all stations except the sampling stations S7 (TDS, Cl^-, NO_3^-, and Na^+ are above the maximum allowable level) and S9 (TDS, TH, SO_4^{-2}, and Na^+ are above the maximum allowable level).
- The relationship between the selected groundwater quality parameters is evaluated using the correlation coefficient. A strong relationship is found between several parameters such as Cl^- with Na^+, TDS with Na^+, Cl^-, TH and SO_4^{-2} and TH with SO_4^{-2}. A moderate relationship is found between SO_4^{-2} with Na^+, TH with Cl^- and Na^+, SO_4^{-2} with Cl^-, Cl^- with NO_3^- and NO_3^- with Na^+.
- The computed mean WQI values range from 26.3 to 107.93. Therefore, out of 15 studied locations, ten locations are classified in the 'Excellent water' class, four locations as a "Good water" class, one as a "Poor water" class. None of the studied locations are classified in the "Very poor water" class and "Water unsuitable for drinking purpose" class.
- Using the geographic information system (GIS) environment, the WQI spatial distribution map evidently showed that a majority of the area is covered by excellent water, whereas the area occupied by good water is almost

observed in the central and southeastern parts of the basin. On the other hand, the poor water zone is observed in a small region around the sampling location S7. This is mainly due to the presence of anthropogenic pollution sources within the surrounding area of S7 which leads to high measured concentration values of TDS, Cl−, NO3− and Na+ parameters in water samples in comparison to their maximum allowable limit values as prescribed in the JS286.

- Not all temporal variations of WQI are significant. For most of the studied locations, the historically WQI class is either excellent water as in S5 or good water as in S9. While for some locations the WQI class is historically changed from good water to poor water as in S7.
- Over-abstraction associated with a low recharging rate, as in the case of YB, will eventually lead to depletion of groundwater and impaired its quality (i.e.an increase in the salinity levels). So, it is recommended that future work focuses on this issue in the context of the WQI approach.

Nomenclature

C_i	=Concentration corresponding to i^{th} parameter	[g/L]
Cl^-	=Chlorides ion concentration	[mg/L]
GIS	=GeographicIinformation System	[-]
I_i	=Ideal concentration value of i^{th} parameter in pure water	[mg/L]
JS286	=Jordanian standards for drinking water (JS 286/2015)	[-]
km^2	=Square Kilometer	[km^2]
MCM	=Million Cubic Meters	[-]
N	=The number of selected parameters	[-]
Na^+	=Sodium ion concentration	[mg/L]
NO_3^-	=Nitrates ion concentration	[mg/L]
pH	=Hydrogen ion concentration	[-]
Q_i	=Rating scale	[%]
r	=Correlation coefficient	[-]
SD	=Standard deviation	[-]
S_i	=Drinking water standard value for i^{th} parameter according to the JS286	[mg/L]
SI_i	=Water quality sub-index value	[-]
SO_4^{-2}	=Sulphates ions concentration	[mg/L]
TDS	=Total Dissolved Solid	[mg/L]
TH	=Total Hardness	[mg/L]
w_i	=unit weight	[-]
Wi	=Relative weight	[-]
WQI	=Water Quality Index	[-]
YB	= Yarmouk Basin	[-]

References

Abbasi, T., and Abbasi, S., *Water Quality Indices* 1 ts Ed., Elsevier, (2012)

Abboud, I., "Geochemistry and quality of groundwater of the Yarmouk basin aquifer, north Jordan", *Environmental Geochem. and Health*, **40**, 1405–1435 (2018)

Abu-Jaber, N., and Kharabsheh, A., "Groundwater origin and movement in the upper Yarmouk Basin, Northern Jordan", *Environ. Geol.*, **54**, 1355–1365 (2008)

Amalraj, A., and Pius, A., "Assessment of groundwater quality for drinking and agricultural purposes of a few selected areas in Tamil Nadu South India: a GIS-based study", *Sus. Water Resou. Manag.*, **4**, 1–21 (2018)

APHA. *Standard Methods for the Examination of Water and Wastewater* (21st Edition). Washington, DC: American Public Health Association, (2005).

Asadollahfardi, G., *Water Quality Management Assessment and Interpretation*, 1st . Ed., Springer-Verlag Berlin Heidelberg, (2015)

Boyacioglu, H. "Development of a water quality index based on a European classification scheme", *Water SA*, **33**, 101–106 (2007)

Brown, R., McClelland, N., Deininger, R., and Tozer, R., "A Water Quality Index: Do We Dare?", *Water Sewage Works*, **117**, 339–343 (1970)

Debels, P., Figueroa, R., Urrutia, R., Barra, R., and Niell, X. "Evaluation of Water Quality in the Chillán River (Central Chile) Using Physicochemical Parameters and a Modified Water Quality Index", *Environ. Monit. and Assess.*, **110**, 301–322 (2005)

El-Naqa, A., and Al-Shayeb, A., "Groundwater Protection and Management Strategy in Jordan", *Water Res. Manag.*, **23**, 2379–2394 (2009)

Horton, R., "An index number system for rating water quality", *J. of Water Poll. Cont. Feder.*, **37**, 300–306 (1965)

Howari, F., Yousef, A., and Rafie, S., "Hydrochemical Analyses and Evaluation of Groundwater Resources of North Jordan", *Water Res.*, **32**, 555–564 (2005)

JS. *Jordanian Standard 286/2015 on Water/Drinking Water*, Jordan Standards and Metrology Organization, Amman, Jordan (2015).

Lumb, A., Sharma, T., and Bibeault, J., "A Review of Genesis and Evolution of Water Quality Index (WQI) and Some Future Directions". *Water Qual., Expos. and Heal.*, **3**, 11–24 (2011)

Lumb, A., Sharma, T., Bibeault, J., and Klawunn, P., "A Comparative Study of USA and Canadian Water Quality Index Models", *Water Qual., Expos. and Heal.* **3**, 203–216 (2012)

Misaghi, F., Delgosha, F., Razzaghmanesh, M., and Myers, B., "Introducing a water quality index for assessing water for irrigation purposes : A case study of the Ghezel Ozan River", *Sci. of the Total Env.*, **589**, 107–116 (2017)

MWI/NWMP. *National Water Master Plan (NWMP).* Ministry of Water and Irrigation (MWI), Amman, Jordan (2004).

MWI. *Jordan Water Sector Facts & Figures 2015*, *Ministry of Water and Irrigation*. Ministry of Water and Irrigation (MWI), Amman, Jordan (2015).

Obeidat, M., Awawdeh, M., Abu Al-Rub, F., "Multivariate statistical analysis and environmental isotopes of Amman/Wadi Sir (B2/A7) groundwater, Yarmouk River Basin, Jordan", *Hydr. Proc.*, **27**, 2449–2461 (2013)

Ponsadailakshmi, S., Sankari, S., Prasanna, S., and Madhurambal, G. "Evaluation of water quality suitability for drinking using drinking water quality index in Nagapattinam district , Tamil Nadu in Southern India", *Groundwater for Sus. Dev.*, ***6***, 43–49 (2018)

Rao, N., Rao, P., Reddy, G., Nagamani, M., Vidyasagar, G., and Satyanarayana, N., "Chemical characteristics of groundwater and assessment of groundwater quality in Varaha River Basin, Visakhapatnam District, Andhra Pradesh, India". *Env. Mon. and Ass.*, **184**, 5189–5214 (2012)

Sahu, P., and Sikdar, P., "Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India", *Env. Geology*, **55**, 823–835 (2008)

Salameh, E., "Using environmental isotopes in the study of the recharge-discharge mechanisms of the Yarmouk catchment area in Jordan", *Hyd. J.l*, **12**, 451–463 (2004)

Sargaonkar, A., and Deshpande, V., "Development of an Overall Index of Pollution for Surface Water Based on a General Classification Scheme in Indian Context", *Env. Mon. and Ass.*, **89**, 43–67 (2003)

Sawyer, C., McCarty, P., and Parkin, G., *Chem. for Env. Eng. and Sci.* (5th Ed). Boston, McGraw-Hill Education, (2003).

Sutadian, A., Muttil, N., Yilmaz, A., and Perera, B., "Development of river water quality indices — a review", *Env. Mon. and Ass.*, **188**, 1-33 (2016)

Ta'any, R., Batayneh, A., and Jaradat, R., "Evaluation of groundwater quality in the Yarmouk Basin, North Jordan", *J. of Env. Hyd.*, **15,** 267-287 (2007)

WHO. *Guidelines for drinking water quality, Volume 2, Health Criteria and Other Supporting Information* (2nd edn, Vol. 1). Geneva, Switzerland: World Health Organization (WHO), (1996).