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Demarcation of Groundwater Quality Using Drinking Water Quality Index (DWQI), Nitrate Pollution Index (NPI), and Irrigation Indices: A Case Study from Jerash Region

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Abstract

Groundwater storage represents the ultimate source of drinking water in dry regions. Over-pumping, climate change, and diverse types of pollutants have all contributed to the deterioration of this precious resource. In order to protect human health and efficiently manage resources, it is crucial to conduct groundwater quality assessments for agricultural and domestic uses, especially drinking. In this study, two indices, the DWQI and NPI, are utilized to assess the fitness of the groundwater quality for drinking and to assess the magnitude of contamination by nitrate in Jerash region. Moreover, the fitness of the groundwater for irrigational purposes was assessed using the most commonly used indices, such as Kelly's index (KI), magnesium hazard index (MHI), sodium adsorption ratio (SAR), electrical conductivity (EC), and the sodium percentage (%Na). Hierarchical cluster analysis (HCA) and conventional hydrochemical methods were applied to evaluate the groundwater chemistry. Results showed that the groundwater in the studied area is basically of a Ca-Mg-HCO_3 facies, hardvery hard water. Although 38% of the samples (dry season) and 35% of the samples (rainy season) possess NO_3^- concentration above the maximum permissible limit (50 mg/L), the vast majority of the samples (96%) showed good to excellent water quality based on DWQI, authenticating suitability for drinking. On the other hand, the results of the NPI indicated that about 30% of the samples in both seasons present significant tovery significant levels of nitrate pollution with nitrate concentration surpassing 50 mg/L. In general, the NPI might be a better expression of water quality than the DWQI, which at low values, obscures or extremely masks important parameters such as nitrate, despite exceeding WHO guidelines. Thus, the DWQI should be used with high precaution, especially at low levels of the used hydrochemical parameters. Based on irrigational water quality indices, the groundwater in the studied area authenticates appropriateness for irrigation.

Keywords: *NPI, DWQI, Jordan, Nitrate Pollution, Groundwater*

1. Introduction

Water is the "elixir of life" and the foundation of sustainable socioeconomic advancement (Cosgrove and Loucks 2015). In fact, the majority of freshwater is frozen, and the remainder is primarily stored in groundwater. Only 0.3% of freshwater is available for humans, animals, and plants' requirements (Hotloś, 2008). Groundwater represents the major supply of water for all purposes in dry regions due to limited surface water supplies (Gutiérrez et al., 2018). However, human interventions have degraded groundwater quality to levels that exacerbate water scarcity, especially in water-stressed countries (Elbeltagi et al., 2022). Therefore, protection and sustainable management of groundwater is essential (Liu et al., 2019). Evaluating natural factors/processes as well as human interventions governing groundwater quality is a cornerstone in any sustainable management program of groundwater (Wang et al., 2020). Assessment of groundwater pollution could aid in the identification of potentially harmful sources of pollutants and areas at risk of groundwater pollution for proper water resources management (Ibrahim, 2019). Nitrate (NO_3^-) is a big problem in many aquifers around the world, and it poses a big threat to groundwater resources, especially in areas where water is utilized for drinking and irrigation (Troudi et al., 2020; Soleimani et al., 2022). Hence, protecting water sources from NO_3^- contamination is vital, especially in water-stressed countries (Zhang et al., 2018; Yang et al., 2020). Numerous researches have shown that overexploitation and the usage of nitrogen fertilizers contaminate groundwater and cause human health problems (Qiu et al., 2023). High nitrate exposure can result in several health problems such as "blue baby syndrome" (primarily in infants less than 6 months), an increased risk of cancer, miscarriages, heart disease, and thyroid enlargement (Gangolli et al., 1994). Additionally, the quality of irrigational water affects soil conditions, and consequently, the growth of crops (Ayers and Westcot 1985). Typically, nitrate contamination is detected in groundwater due to its high solubility (Richa et al., 2022). Many studies have used different models and tools to assess groundwater fitness for irrigation and domestic purposes and its potential

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risk to human health (Adimalla and Wu 2019; Li et al., 2019; Adimalla et al., 2020). The drinking water quality index (DWQI) is a widely used tool to assess water quality and has recently been extensively used to demarcate water quality for domestic purposes (Xiao et al., 2021). The first water quality index was developed by Horton (1965), to convert the hydrochemical parameters into a single number describing the overall water quality. Horton's index classifies the overall water quality into the following categories: excellent, good, poor, very poor, and unsuitable, based on the hydrochemical parameters, and the WHO guidelines of drinking water quality (Rahman et al., 2022). The nitrate pollution index (NPI) was initially developed by Obeidat et al., (2012) to evaluate groundwater contamination by nitrate. The index is a single parameter index that incorporates the measured nitrate concentration in groundwater, and the threshold value of human origin (20 mg/L). It categorizes water quality into the following classification: clean (unpolluted), light pollution, moderate pollution, significant pollution, and very significant pollution (Obeidat et al., 2012). The index has been widely and successfully used to assess groundwater contamination by nitrate (Xiao et al., 2021; El Mountassir et al., 2022). Various criteria are utilized to assess the quality of irrigation water: electrical conductivity (EC), sodium adsorption ratio (SAR), sodium percentage (Na%), Kelley's index (KI), and magnesium hazard (MH) (Subramani et al., 2005). By analyzing similarities/differences between sampling sites, multivariate statistical techniques have been widely utilized to characterize water quality (de Andrade et al., 2008; Obeidat et al., 2013). It provides a dependable technique for water resources management and rapid responses to water pollution (Bodrud-Doza et al., 2016). Among these techniques, cluster and principal component analyses are the most prevalent ones.

Jordan is a country in the arid Middle East region with an area of about 89,210 km^2. Most of the country is an expanse of desert, where water resources are limited and scarce (Al-Kharabsheh, 2020). The current Jordanian share of freshwater is estimated at 90 m^3/per capita/year, making it rank as the second most water-stressed country (Odeh, 2019). Jordan gets about 67% of its water from groundwater extraction, with 27% of that coming from nonrenewable groundwater (Salameh et al., 2014). The crisis is worsening over time because of the high population growth, associated with sudden refugee influxes, agricultural expansion, increasing drought events, climate change, and inefficient water use, placing extraordinary demands on water resources (Al-Kharabsheh, 2020). Within the Jordanian context, several studies have utilized the DWQI to assess the appropriateness of water quality for drinking and irrigation purposes (Ibrahim 2018; Obeidat and Awawdeh 2021; Hyarat et al., 2022). Several studies have shown that the studied area is vulnerable to contamination, particularly nitrate (Hammouri and El-Naqa, 2008). Accordingly, this study was initiated to map the groundwater quality in the studied area. Groundwater contamination by nitrate is a common problem and has gained great concern worldwide. This is attributed to its detrimental effects on human health and the environment. Additionally, the DWQI has been extensively used to assess water quality fitness for drinking purposes because it helps understand water quality aspects by integrating complex data and producing a score that describes water quality status. Therefore, the present study was initiated with the following specific goals: (1) assessment of the groundwater quality for drinking using DWQI, (2) assessment of the groundwater contamination using the NPI, (3) assessment of the groundwater quality for irrigation, and (4) shedding light on the efficacy of the DWQI, especially at high levels of nitrate, and low levels of other hydrochemical parameters. The above-mentioned goals lie within the milestones of the Sixth Sustainable Development Goal of the United Nations.

2. Studied Area

The studied area is located in the northwestern highlands of the Amman-Zarqa basin (Figure 1a). It encompasses an area of approximately 188.3 km^2, and is located between the coordinates at 3568545 m - 3582908 m N and 750269 m - 777068m E (UTM system). It is just a few kilometers west of Jerash city, which is home to some of the best-preserved Roman ruins in the world. Jerash city is located 48 kilometers north of Amman, the capital of Jordan. The climate of the area under study is both arid and Mediterranean. Winter temperatures are a few degrees Celsius below zero, while summer temperatures average around 40 degrees Celsius (Al-Fugara et al., 2022). Average monthly temperature ranges from 7.9 ºC in January to 25.7 ºC in August. Minimum average temperature ranges from 3.6 ºC to 19.3 ºC, and maximum average temperature ranges from 12.7 ºC in January to 33.1 ºC in August. The area experiences a wide range of precipitation, which varies from 319 mm to 560 mm (Figure 1b). As shown in Figure 1c, the agricultural land occupies about (33.4%) of the study area, followed by urban (29.5%), bare (28%), and forestlands (9%).

Geologically, the sedimentary rocks of the Upper Cretaceous Ajloun (A) and Belqa (B) groups dominate the studied area. These rocks overlie the sandstones of Kurnub group of the Lower Cretaceous (Figure 2a). The lithological and geological characteristics were thoroughly discussed in several studies (Bender 1974; Al Mahamid 2005; Hammouri and El-Naqa 2008; Al Kuisi et al., 2014; Al-Fugara et al., 2022). The main lithological characteristics of the rock formations in the studied area are presented in Table 1. In the studied area, there are three aquifer complexes: The Kurnub sandstone aquifer, the Lower Ajloun aquifer (Na'ur and Hummar aquifers), and the Amman/Wadi As-Seir aquifer (Figure 2b). Kurnub aquifer is a potentially good aquifer in Jordan; however, in the studied area, it shows poor water quality and produces an uneconomical groundwater supply (Hammouri and El-Naqa 2007). Na'ur aquifer (A1/2) overlies the Kurnub, and it has a specific capacity in the range of 0.01-12 m^3/hr. Transmissivity is in the range of 0.3-100 m^2/d corresponding to a hydraulic conductivity of 0.0083 to 2.7 m/d (Salameh and Bannayan 1993). Hummar aquifer has a transmissivity of 32 to 300 m^2/d, corresponding to a hydraulic conductivity of $8.1 * 10^{-7}$ to $7.6 * 10^{-4}$ m/d (Rimawi, 1985). The groundwater level contour maps of Na'ur and Hummar aquifers are presented in Figure 3. Groundwater flow in both aquifers is directed towards the southwest and southeast of the study area.

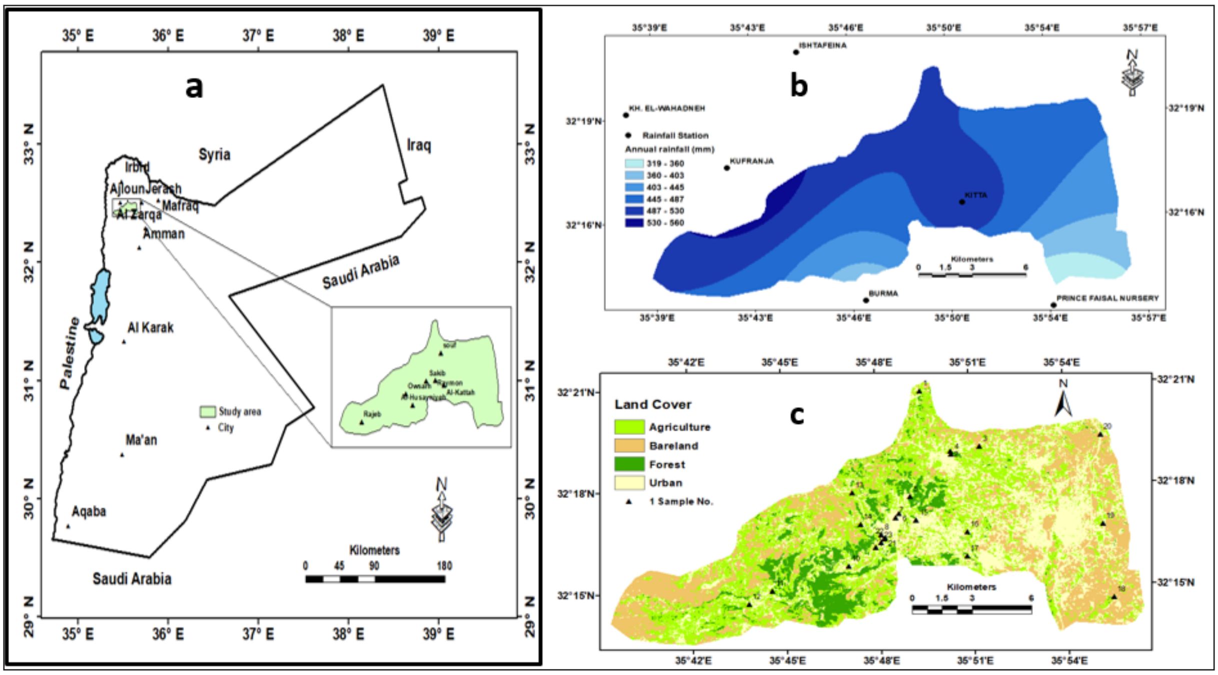

Figure 1. Location map of the studied area a), a rainfall map b), land use/land cover with sampled localities c).

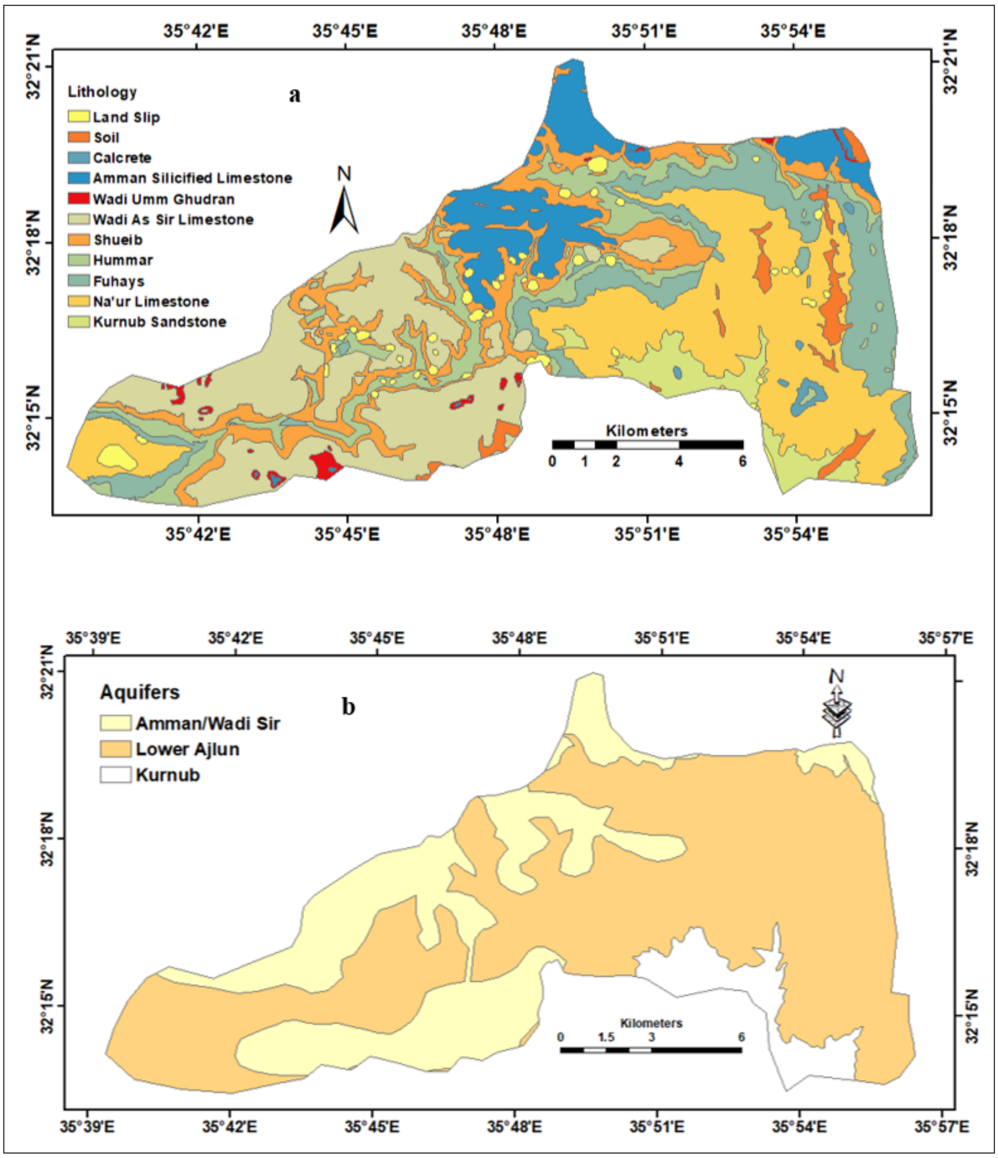

Figure 2. Geological map of the study area a), and hydrogeological units b).

Table 1. Geological and Hydrogeological Classification of the Rock Units in the Studied Area.

Age	Group	Formation name	Symbol	Lithology	Thickness (m)	Aquifer potentiality
Maestrichtain	Belqa	Muwaqqar	B3	Chalk, marl, chalky limestone	60-70	Poor
Campanian		Amman	B2	Chert and limestone with phosphate	80-120	Poor
Santonian		Ghudran	B1	Chalk, marl, marly limestone	15-20	Poor
Turonian	Ajloun	Wadi As Sir	A7	Hard limestone, dolomitic limestone, with some chert	90-110	Excellent
Cenomanian		Shueib	A5/6	Light gray limestone, inter-bedded with marl and marly limestone	75-100	Poor
Cenomanian		Hummar	A4	Hard, high density limestone, dolomitic limestone	40-60	Good
Cenomanian		Fuheis	A3	Gray, olive, soft marl, marly limestone	60-80	Poor
Cenomanian		Na'ur	A1/2	Limestone interbedded with marl and marly limestone	150-200	Good
Lower Cretaceous	Kurnub	Kurnub	K	Massive, white, multicolored sandstone	300	Good (poor water quality)

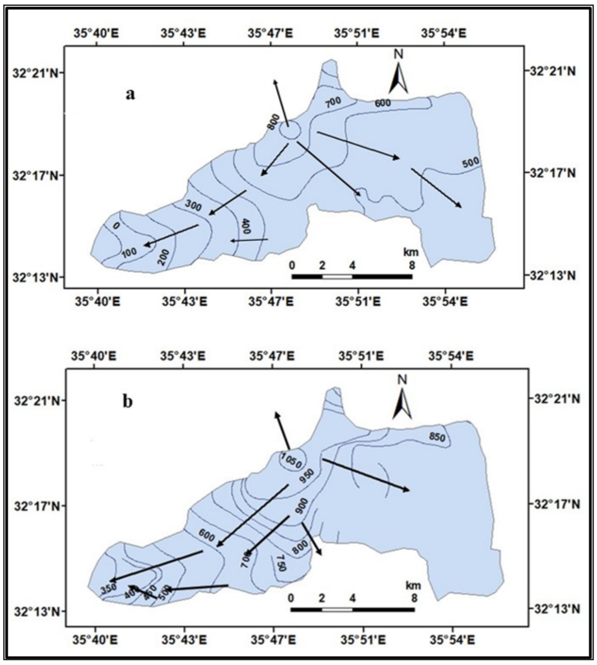

Figure 3. Groundwater level contour map and groundwater flow direction of a) Na'ur aquifer, and b) Hummar aquifer.

3. Material and Method

3.1. Sampling and Fieldwork

Forty-four groundwater representative samples were gathered from 25 wells and springs distributed in the studied area (Figure 1c). All samples belong to the Lower Ajloun aquifer (Na'ur and Hummar aquifers). Two sampling campaigns were conducted: The first one, which represents the rainy season in Jordan, was conducted in March 2021, and the second campaign, which represents the dry season, was conducted in September 2021. The first campaign included samples no. (1-23), which represent one well (sample no. 19) and twenty-two springs. The second campaign included samples no. (1-9, 11-14, 16-21, 24, and 25), which represent one well (sample no. 25) and twenty springs. The pH value, temperature, dissolved oxygen (DO), total dissolved solids (TDS), and electrical conductivity (EC) were all measured in using portable meters by Thermo Scientific (Elite PCTS pH/Conductivity/TDS/Salinity Pocket Testers) and Lovibond (SensoDirect 150 (Set 3) pH/Oxi/Temp). The accuracy of the devices is as follows: Electrical conductivity (±1% full scale), pH (±0.02), TDS (±1% full scale), and dissolved oxygen (0.4 mg/L). The samples were taken at the mouths of springs. Prior to sampling, the sampled wells were purged by removing a minimum of three well volumes or until T, EC, temperature, and pH became constant. The goal is to assure that the taken water samples accurately demonstrate the subsurface environment's features and circumstances. The samples were filtered using a 0.45 µm acetate cellulose membrane and, then, moved to a pre-washed low-density polyethylene (LDPE) bottle gathered in 1000 mL and 60 mL with proper storage and preservation techniques for the laboratory examination. The procedures given by American Public Health Association (APHA) (Apha, 1998) were utilized during fieldwork and laboratory work analyses. The coordinates of the sampled places were determined using GPS (GARMIN, GPS map 60CSx).

3.2. Laboratory Chemical Analyses

Thermo Scientific Ion Chromatograph (Dionix ICS-1600) was used to determine the concentrations of Cl^-, Na^+, K^+, Ca^{2+}, and Mg^{2+}. The concentrations of SO_4^{2-} and NO_3^- were determined using a spectrophotometer (Lovibond 712005 SpectroDirect Spectrophotometer). Bicarbonate (HCO_3^-) concentration was determined by the titration method.

Determination of the total hardness (TH) was carried out using the formula given by Todd (1980):

$$\text{TH (as mg/l } CaCO_3) = 2.497\ (Ca^{2+}) + 4.11\ (Mg^{2+}) \qquad (1)$$

The analytical uncertainty is less than 4%, where samples were analyzed in triplicate. The ionic charge balance was utilized to evaluate the analysis's correctness, where it was reproducible within ±10% error limits (Appelo, 2005). According to Freeze and Cherry (1979), it can be calculated as follows:

$$\text{Error (\%)} = \frac{\sum cations - \sum anions}{\sum cations + \sum anions} * 100 \qquad (2)$$

The concentrations are expressed in meq/L.

The results were compared against the established Jordanian Standards (JS, 2015) and WHO (2011) guidelines for drinking water quality.

3.4. Statistical Analysis

Using univariate and multivariate statistical methods, large data sets are streamlined and arranged to provide substantial insight into the relationships between variables (Dixon and Massey Jr 1951). ANOVA test was utilized to determine whether dry and rainy water chemistry differed significantly. The P-value 0.05 was utilized as the statistical significance threshold. Hierarchical cluster analysis (HCA) was applied to the experimental groundwater data from Jarash studied area. The goal is to deduce the primary natural and anthropogenic processes/factors influencing groundwater quality. Ten parameters, including the major cations and anions, EC, and TDS are the input data for the analysis. Hierarchical clustering is the most prevalent technique, which gives conjectural similarity relationships between a single sample and the complete data set and is often represented as a dendrogram (McKenna Jr, 2003). To reduce the impact of the difference in the data dimensions, the data were normalized by z-scale transformation (Liu et al., 2003). The statistical analyses and tests were performed using SPSS 13 (version 21, SPSS Inc., Chicago, Illinois, United States) and MS Excel.

3.5. Drinking Water Quality Index (DWQI)

To evaluate groundwater quality for drinking purposes, eight parameters (TDS, Mg^{2+}, Ca^{2+}, Na^{+}, Cl^{-}, SO_4^{2-}, K^{+}, and NO_3^{-}) were utilized. Four steps were followed to calculate the DWQI (Swamee and Tyagi 2007):

1- Determination of the selected parameters' levels in the samples.

2- Assigning a weight (AWi) to the parameters. The weight was estimated based on the parameter's degree of significance for drinking (Table 2). The weight falls in the range of 1 to 5. NO_3^{-}, SO_4^{2-}, Cl^{-}, and TDS have been assigned the highest weight (5) because of their importance in assessing water quality (Srinivasamoorthy, et al., 2008). Na^{+} was assigned a weight of 4, and Ca^{2+}, Mg^{2} and K^{+} were assigned a weight of 3 (Obeidat and Awawdeh, 2021). The following formula was utilized to estimate the relative weight (RWi) of each parameter (Njuguna et al., 2020):

$$RW_i = \frac{AWi}{\sum_{i=0}^{n} AW_i} \tag{3}$$

, where

RW_i: the relative weight, AW_i: the parameter's assigned weight, n: the number of parameters

3- Calculating the parameter's quality rating (qi) using the following formula:

$$q_i = \frac{C_i}{S_i} \times 100 \tag{4}$$

, where

q_i: the quality rating, C_i: the parameter's measured concentration (mg/L), S_i: WHO (2011) drinking water guideline (mg/L) for each parameter.

4- Calculating the water quality index using the following formula (Rabeiy, 2018):

$$DWQI = \sum_{i=0}^{n} W_i \, x q_i \tag{5}$$

The DWQI values obtained are classified as follows (Ismail et al., 2020): excellent, good, poor, very poor, and unsuitable with the DWQI values: <50, 50-100, 100-200, 200-300, and >300, respectively.

Table 2. WHO Guidelines, Assigned Weight (wi) and Calculated Relative Weight (Wi) for each Parameter.

Parameter	WHO (2011)	Assigned weight (AW_i)	Relative weight (RW_i)
TDS (mg/L)	1000	5	0.15
Cl^{-} (mg/L)	250	5	0.15
SO_4^{2-} (mg/L)	250	5	0.15
NO_3^{-} (mg/L)	50	5	0.15
Na^{+} (mg/L)	200	4	0.13
Ca^{2+} (mg/L)	75	3	0.09
Mg^{2+} (mg/L)	100	3	0.09
K^{+} (mg/L)	10	3	0.09
Sum of weights		33	1

3.6. The Nitrate Pollution Index (NPI)

The NPI was initially developed by Obeidat et al., (2012) for the purpose of assessing the level of nitrate pollution in groundwater. It is a single-parameter water quality index and can be calculated using the following formula (Obeidat et al., 2012):

$$NPI = \frac{Cs - HAV}{HAV}, \text{ where} \tag{6}$$

, where

NPI refers to the nitrate pollution index.

Cs refers to the measured nitrate concentration of each sample.

HAV refers to the human-affected value (20 mg/L) (Spalding and Exner 1993).

The level of groundwater nitrate pollution was classified into five groups as shown in Table 3.

Table 3. NPI Classes (Obeidat et al., 2012).

NPI value	Classification
< 0	Clean water
0-1	Light pollution
1-2	Moderate pollution
2-3	Significant pollution
>3	Very significant pollution

3.7. Assessment of Water Quality for Irrigation

Water appropriateness for irrigation can be evaluated based on the presence of undesirable dissolved chemicals. Since a considerable portion (33.4%) of the land-use in the studied area is agricultural, the groundwater quality was assessed for its suitability for irrigation purposes. The main parameters used in this study to assess groundwater for irrigation purposes are EC, sodium adsorption ratio (SAR), sodium percentage (Na%), Kelley's index (KI), and magnesium hazard (MHI) (Table 4). These parameters were calculated based on the following formulae:

$$\text{Na\%} = \frac{(\text{Na}+\text{K})}{(\text{Ca}+\text{Mg}+\text{Na}+\text{k})} * 100$$ (Wilcox, 1955)

$$\text{SAR} = \frac{\text{Na}}{\sqrt{(\text{Ca}+\text{Mg})/2}}$$ (Spandana et al., 2013) (7)

$$\text{KI} = \frac{\text{Na}}{(\text{Ca}+\text{Mg})}$$ (Kelley, 1940)

$$\text{MHI} = \frac{\text{Mg}}{(\text{Mg}+\text{Ca})} * 100$$ (Spandana et al., 2013)

Concentrations are expressed in meq/l.

Table 4. Water Quality Classification Based on the SAR (Spandana, Suresh et al. 2013), Na% (Wilcox 1955), KI (Kelley 1940), MHI (Spandana, Suresh et al. 2013) and EC (Rajankar, Tambekar et al. 2011).

Parameter	Range	Water Class	Sample no.	
			Rainy season	Dry season
Sodium adsorption ratio (SAR)	<10	Excellent (S1)	All samples	All samples
	10-18	Good (S2)	__	
	18-26	Doubtful (S3)	__	
	>26	Unsuitable (S4)	__	
Sodium ratio (Na%)	<20	Excellent	1, 2, 5, 9, 11, 13, 14, 15, 16, 21, 22, 23	2, 3, 5, 6, 11, 14, 16, 17, 24, 25
	20-40	Good	3, 6, 7, 10, 12, 17, 19, 20	1,7, 8, 12, 13, 18, 19, 20, 21
	40-60	Permissible	4, 8, 18	4, 9
	60-80	Doubtful	__	
	>80	Unsuitable	__	
Kelly's index (KI)	<1	Good	All samples	All samples
	>1	Unsuitable	__	
Magnesium hazard index (MHI)	<50	Good	All samples except sample no. 19	All samples except sample no. 20
	>50	Bad	19	20
EC µS/cm	<250	Excellent	__	
	250–750	Good	2, 3, 5, 9, 10, 11, 13, 14, 15, 19, 20, 21, 22, 23	2, 3, 5, 6, 9, 11, 12, 13, 14, 16, 17, 19, 20, 21, 24
	750–2,000	Permissible	1, 4, 6, 7, 8, 12, 16, 18	1, 4, 7, 8, 16, 25
	2,000–3,000	Doubtful	__	
	>3,000	Unsuitable	__	

4. Results and Discussion

4.1 Hydrochemical Characterization

The descriptive statistics of the hydrochemical parameters alongside with WHO (WHO, 2011) guidelines for drinking water quality and the Jordanian standards (JS, 2015) are shown in Table 5, and the detailed analytical results of nitrate, which are the main focus of this study, are presented in Table 6. The pH value ranges from 7.3 to 8.6 with an average of 7.7 in the rainy season, and from 7.2 to 8.3 with an average of 7.5 in the dry season. The groundwater is of slightly alkaline type, with a limit pH value considered safe between 6.5 to 9.0, based on WHO and Jordanian standards (JS, 2015). The DO concentration ranges from 4.6 mg/L (sample no. 7) to 11.6 mg/L (sample no. 4) with an average of 7.5 mg/L in the rainy season and from 5.0 mg/L (sample no. 14) to 9.2 mg/L (sample no. 11) with an average of 6.9 mg/L in the dry season. About 9% and 29% of the samples during the rainy and dry seasons, respectively, showed DO levels of less than 6.5 mg/L, which could indicate a polluted or overgrown watershed system. The TDS content falls in the range of 324 mg/L (sample no. 3) to 1030 mg/L (sample no. 4) in the rainy season, with an average of 539 mg/l, and from 172 mg/L (sample no. 12) to 690 mg/L (sample no. 4), with an average of 351 mg/L in the dry season. According to WHO and JS, all of the water samples in the studied area have TDS levels of less than 1000 mg/L and are considered safe, with the exception of sample no.4 in the northeast of the studied area with a TDS value of 1030 mg/L in the rainy season. The EC value lies in the range of 457 µS/cm (sample no. 2) to 1423 µS/cm (sample no. 4) with an average of 759 µS/cm in the rainy season (Figure 3a), and from 354 µS/cm (sample no. 12) to 1368 µS/cm (sample no. 4) with an average of 705 µS/cm in the dry season (Figure 3b). The high spatial variation in EC value can be attributed to differences in geology, agricultural activity, soil conditions, and leaching of surface contaminants (Daghara et al., 2019). For health purposes, the recommended value of EC is no more than (1,500 µS/cm) (WHO, 2011). All measured values of EC fall within the acceptable limits of the WHO and JS. ANOVA test revealed that there is no significant difference between the EC values of collected groundwater samples in the dry and rainy seasons. This was because the calculated F-value (1.6) was less than the critical F-value (4.1), and the calculated P-value (0.3) was greater than 0.05. This means that there are no seasonal variations in the EC. The TH ranges from 152.4 mg/L (sample no. 3) to 426.4 mg/L (sample no. 4), with an average of 262.2 mg/L, and from 15.8 mg/L (sample no. 6) to 459.9 mg/L (sample no. 4), with an average of 293.4 mg/L in the rainy and dry seasons, respectively. Consequently, the groundwater in the studied area falls in the categories hard or very hard water, with the exception of sample no.6 in the middle part of the studied area in the rainy season, which can be classified as soft water.

Table 5. Descriptive Statistics of Hydrochemical Parameters during the Rainy and Dry Seasons in the Studied Area, Jordanian Standards (JS 2015), and WHO Guidelines (WHO 2011).

Season	Parameter	Min.	Max.	Mean	Standard deviation	Coefficient of variation (CV) (%)	WHO (2011)	Jordanian standard (2015)
Rainy season	pH	7.3	8.6	7.7	0.4	5.2	6.5–8.5	6.5–9.0
	Temp	13.6	21.6	17.9	1.5	8.4	-	-
	TDS (mg/L)	324	1030	539.3	163.8	30.4	500–1000	500-1500
	EC (µS/cm)	457	1423	758.9	228.2	30.1	1000-1500	750-2300
	TH (mg/L $CaCO_3$)	152.4	426.4	57.4	13.0	22.6	500	500
	DO (mg/L)	4.6	11.6	7.5	1.27	16.9	-	-
	Na^+ (mg/L)	10.3	80.5	26.8	18.6	69.4	200	200-400
	K^+ (mg/L)	0.10	26.0	2.6	5.4	200.1	10-12	10-50
	Mg^{2+} (mg/L)	5.9	32.3	14.0	7.7	55	50	50-150
	Ca^{2+} (mg/L)	44.3	156.0	81.9	23.7	28.9	75	75-200
	SO_4^{2-} (mg/L)	13.0	117.7	33.4	22.4	67.1	250	200-500
	Cl^- (mg/L)	14.2	139.1	47.2	36.0	76.3	250	200-500
	HCO_3^- (mg/L)	64.0	128.0	96.9	19.0	19.6	250-500	100-500
	NO_3^- (mg/L)	3.5	230.8	50.9	56.4	100.1	50	70
Dry season	pH	7.2	8.3	7.5	0.3	4.0		
	Temp	17.8	27.5	21.0	2.3	11		
	TDS (mg/L)	172.1	690	351.2	129.8	37		
	EC (µS/cm)	354	1368	704.6	254.9	36.2		
	TH (mg/L $CaCO_3$)	15.8	459.9	293.4	92.0	31.4		
	DO (mg/L)	5	9.2	6.9	1.0	14.5		
	Na^+ (mg/L)	0.6	93.8	31.5	24.9	79		
	K^+ (mg/L)	0.1	32.8	3.4	7.0	200.1		
	Mg^{2+} (mg/L)	1.0	37.4	18.0	9.9	55		
	Ca^{2+} (mg/L)	4.7	164.0	87.8	32.5	37		
	SO_4^{2-} (mg/L)	12.2	127.6	33.5	24.7	73.7		
	Cl^- (mg/L)	13.0	154.4	57.5	46.0	80		
	HCO_3^- (mg/L)	76.0	136.0	107.4	16.6	15.5		
	NO_3^- (mg/L)	2.5	262.6	60.2	70.1	100.2		

4.2 Major Cations and anions

Minerals are usually more easily absorbed in the intestines from water than from food (Rosborg and Kozisek, 2016). Their origin is largely rooted in the bedrock and some anthropogenic activity, and they can all be present in high or low quantities in the groundwater as well as surface water (Rosborg and Kozisek 2016). In the studied area, the order of dominance of major cations is as follows: Ca^{2+} > Mg^{2+} > Na^+ > K^+, whereas that of anions is HCO_3^- > Cl^- > NO_3^- > SO_4^{2-}. The major source of calcium in water comes from limestone weathering (Meybeck, 1987) and agricultural fertilizers (Weyhenmeyer et al., 2019). Calcium concentration lies in the range of 44.3 mg/L (sample no. 19) to 155.9 mg/L (sample no. 4) with an average of 81.8 mg/L in the rainy season and 4.7 mg/L (sample no. 6) to 164 mg/L (sample no. 4) with an average of 87.7 mg/L in the dry season. About 71%, and 57% of the samples in the dry and rainy seasons, respectively, exceeded the maximum calcium levels set by the WHO guidelines. However, according to the Jordanian standards (JS, 2015), all groundwater samples are considered safe in both seasons. Sodium and magnesium in groundwater originate from natural sources such as mineral dissolution (silicate weathering and magnesium-containing rocks) (Lakshmanan et al., 2003). Agricultural operations, sewage, and industrial effluents may be additional sources of sodium and magnesium in the groundwater (Hem, 1985). None of the samples exceeded the maximum magnesium and sodium levels set by the WHO guidelines and JS. In the rainy season, potassium concentration ranges from 0.10 mg/L (sample no. 21) to 26.04 mg/L (sample no. 4), with an average of 2.59 mg/L and ranges from 0.12 mg/L (sample no. 6) to 32.76 mg/L (sample no. 4), with an average of 3.39 mg/L in the dry season. None of the samples exceeded the maximum potassium levels set by the WHO and JS, except sample no.4 during both the rainy and dry seasons. Throughout the rainy season, bicarbonate concentration ranges from 64.0 mg/L (sample no. 6) to 128.0 mg/L (sample no. 16), with an average of 96.9 mg/L, and in the dry season It ranges from 76.0 mg/L (sample no. 3) to 136.0 mg/L (sample no. 9), with an average of 107.4 mg/L. The aquifer's calcite and dolomite weathering would contribute 50% of the bicarbonate ions. This process adds calcium, magnesium, and bicarbonate ions to the groundwater (Jeevanandam et al., 2007). Typically, chloride level in groundwater does not exceed 30 mg/L, but in arid areas, concentrations of 1000 mg/L or higher are typical (Saha et al., 2019). A high chloride concentration is detrimental to metal pipelines, structures, and agricultural crops (Khashogji and El Maghraby 2013). In the rainy season, chloride concentration ranges from 14.2 mg/L (sample no. 14) to 139.1 mg/L (sample no. 4) with an average of 47.23 mg/L, while in the dry season, its concentration ranges from 12.0 mg/L (sample no. 3) to 154.4 mg/L (sample no. 4) with an average of 57.5 mg/L. In the rainy season, sulfate concentration ranges from 13.0 mg/L (sample no. 9) to 117.7 mg/L (sample no. 4), with an average concentration of 33.4 mg/L, and in the dry season, its concentration ranges from 12.2 mg/L (sample no. 3) to 127.6 mg/L (sample no. 4), with an average concentration of 33.5 mg/L. Dry fallout and industrial runoff are among the primary human activities that raise sulfate concentration (Venkatesan et al., 2021). Oxidation of marcasite and pyrite may play a significant role in this link (Rahman et al., 2013). The levels of bicarbonate, chloride, and sulfate in all groundwater samples are below the WHO guidelines and JS. Nitrate ion has a high solubility in water and readily reaches the groundwater. Its concentration ranges from 3.5 mg/L (sample no. 19) to 230.8 mg/L (sample no. 4) with an average of 50.9 mg/L in the rainy season, and from 2.5 mg/L (sample no. 19) to 262.6 mg/L (sample no. 4) with an average of 60.1 mg/L in the dry season. About 81%, and 91% of the samples from both dry and rainy seasons, respectively, showed NO_3^- concentrations exceeding the concentration of natural origin (5-10 mg/L (Panno et al., 2006), indicating human-induced nitrogen pollution. About 38%, and 35% of the samples from both dry and rainy seasons, respectively, showed NO_3^- concentration higher than the WHO guidelines and JS of 50 mg/L. The favorable factor for the high level of nitrate in the studied region is primarily anthropogenic, consisting of agricultural practices, livestock farming, and home sewage (Al-Ajlouni et al., 2019; Al Kuisi et al., 2009). As a result of contamination, eight groundwater wells and springs (sample no. 1, 4, 7, 8, 12, 17, 18, and 25) are not recommended for drinking purposes. ANOVA test revealed no significant difference between the NO_3^- values of the collected groundwater samples in the rainy and dry seasons because the calculated F-value (0.005) was less than the critical F-value (4.1), and the calculated P-value (1.0) was greater than 0.05. This means that there are no seasonal variations in nitrate concentration. Analyzing the groundwater samples, using a Piper diagram (diamond shape), revealed that the predominant water type is Ca–Mg–HCO_3, followed by a Ca–Mg–Cl and a Ca–Mg–SO_4 types during both the rainy and dry seasons (Figures 4a and b). The Ca–Mg–HCO_3 type reflects the weathering of limestone and dolomite that comprise the region's primary rock formations. This type of freshwater indicated that it has been recently introduced and has not been contaminated by human activity (El Yaouti et al., 2009). Ca-Mg-Cl water type originates as a result of invasion of highly saline, polluted water into unpolluted freshwater, followed by ion exchange reactions (Selvam et al., 2016). The majority of samples falls within the Ca-dominant zone of the cation facies, followed by the zone where no cation-anion pair exceeded 50%. Furthermore, the majority of samples was found within the anion zone's no-dominating zone, with only a few samples falling within the HCO_3^- and Cl^- zones.

Table 6. Detailed Analytical Results of Nitrate (the Focus of This Study), EC, DO, and pH.

Samples no	Rainy season					Dry season				
parameter	pH	DO (mg/L)	TDS (mg/L)	EC (µS/cm)	NO_3^- (mg/L)	Ph	DO (mg/L)	TDS (mg/L)	EC (µS/cm)	NO_3^- (mg/L)
1	7.7	6.2	602	851	54.3	7.76	5.4	375	758	39.5
2	7.4	7.1	471	659	24.1	7.64	6.7	309	627	33.5
3	8.0	7.5	324	457	13.8	7.94	6.6	220	449	13.1
4	7.4	11.6	1030	1423	230.8	7.44	7.5	690	1368	262.6
5	7.3	7.7	456	643	10.3	7.36	6.4	316	638	6.8
6	7.4	7.1	590	832	73.4	7.35	8.2	346	698	42.8
7	7.9	4.6	573	804	63.2	7.4	7	382	767	62.6
8	7.4	9.4	787	1114	120.3	7.46	5.9	614	1220	172.2
9	7.3	7.3	489	684	12.1	7.19	8.4	331	679	7.3
10	7.6	7.7	475	667	31.1	–	–	–	–	–
11	8.1	7.8	511	716	20.2	7.93	9.2	289	586	17.8
12	7.6	7.5	762	1080	164.4	7.41	6.3	172.1	354	190.3
13	7.5	6.8	434	609	16.2	7.94	5.7	233	497	17.2
14	7.3	7.8	420	592	14.7	7.22	5	276	555	8.4
15	7.9	8.2	442	618	18.1	–	–	–	–	–
16	7.3	7.5	550	796	43.5	7.27	7.6	314	629	40.1
17	7.3	7.5	623	876	72.5	7.19	7.9	337	674	52.5
18	7.3	7.3	750	1055	97.4	7.22	7.5	510	1015	97.4
19	7.7	8.1	511	723	3.5	7.5	6.5	313	632	2.5
20	8.5	8.4	409	576	46.7	8.25	6.9	285	519	37.2
21	7.8	6.6	418	587	14.8	7.55	7.7	271	547	19.9
22	8.1	7.2	406	572	14.1	–	–	–	–	–
23	8.6	6.2	370	520	12.4	–	–	–	–	–
24	–	–	–	–	–	7.41	6.3	269	542	21.7
25	–	–	–	–	–	7.38	6.9	523	1042	118.5

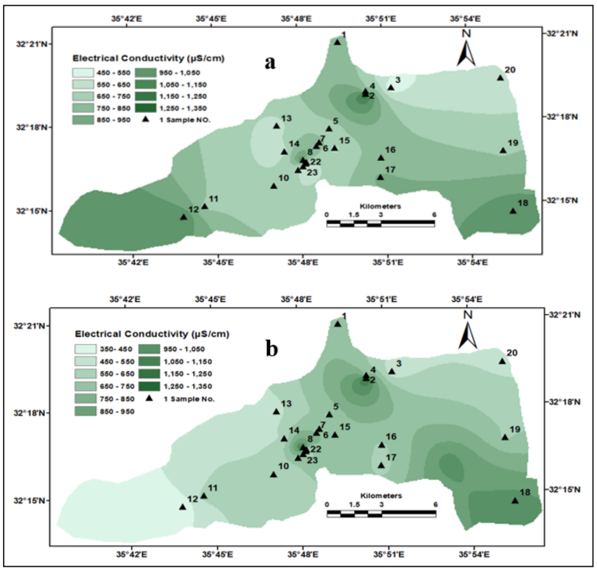

Figure 4. Spatial distribution of EC (µS/cm) in the rainy season a), and in the dry season b).

4.3 Hierarchical Cluster Analysis (HCA)

Hierarchical cluster analysis (HCA) has been recently adopted for the purpose of groundwater quality evaluation (Lee et al., 2001; Kumar et al., 2009). It was applied to obtain common clusters of the sampled locations that have similar characteristics in the studied area. The dendrogram plot, which is useful in tracing HCA, was used, and two main clusters were extracted (Figure 5). The variables used in generating the clusters cover the major cations and anions, EC, and TDS of the groundwater for both the rainy and dry seasons. Table 7 presents the two major clusters with their average composition in the rainy and dry seasons. The distance between clusters 1 and 2 is 25, which shows that the geochemical properties of the water samples in cluster 1 are different from those in cluster 2. In the rainy season, cluster 1 encompasses the samples (no. 1, 2, 3, 5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 17, 19, 20, 21, 22, and 23), whereas Cluster 2 encompasses the samples (no. 4, 8, 12, and 18). Cluster 1 represents 83% of the samples, and the water of this cluster can be classified as Ca–Mg–HCO_3 with the lowest TDS content (477.6 mg/L) and lowest mean concentrations for all major parameters. The water of ten samples of this cluster (samples no. 3, 5, 9, 13, 14, 15, 19, 21, 22, and 23) was found to be affected by human activities and by water-rock interaction processes (dissolution and ion exchange reactions) as it is indicated in the slightly higher nitrate concentration than the natural background concentration (5-10 mg/L). Five samples (no. 2, 10, 11, 16, and 20) were found to be contaminated due to human activities since nitrate concentration exceeds the threshold value of (5-10 mg/L) but still less than WHO guidelines and JS (50 mg/L). The four remaining samples (no. 1, 6, 7, and 17) have NO_3^- concentrations higher than the WHO guidelines and JS, demonstrating the impact of nitrogen pollution resulting from human activities. Due to contamination, these samples are not recommended for drinking. Cluster 2 represents 17% of the samples, showing higher ionic concentrations than cluster 1 does, and its water can be classified as Ca–Na–Cl. The nitrate concentration in this group is much higher than the WHO permissible limit (average NO_3^- concentration of these samples =153.2 mg/L), indicating that the origin of nitrate pollution is mainly due to human activities. The water of this cluster is unfit for drinking. In the dry season, Cluster 1 includes the samples (no. 1, 2, 3, 5, 6, 7, 9, 11, 12, 13, 14, 15, 16, 17, 19, and 21), whereas Cluster 2 includes the samples (no. 4, 8, and 18). Cluster 1 represents 84% of the samples, with the lowest concentration of dissolved ions and the water can be classified as Ca–Mg–HCO_3 indicating the water is affected by water-rock interaction processes with slightly higher nitrate concentration than when it is in the natural background. Cluster 2 represents 16% of the samples, showing higher ionic concentrations than cluster 1 does, with nitrate concentration exceeding the WHO permissible limit (average NO_3^- concentration =177.4 mg/L), indicating that the origin of pollution is from human activities. The water of this group can be classified as Ca–Na–Cl. When plotted using Schoeller diagram (Figure 6a and b), it can be concluded that the two clusters stem from a common origin, but due to water rock interaction and human impacts, the two clusters have been generated. Potential anthropogenic sources of groundwater contamination in the study area include cesspits, sewer overflows, illegal dumping of fluid wastes, olive tree cultivation (Hammouri and El-Naqa 2008). This can be confirmed by the land use/land cover map of the study area (Figure 2c). Accurate and specific identification of these sources requires more advanced techniques such as the stable isotope composition of the dissolved nitrate, which is the focus of another research being currently developed by the authors. In both seasons, the average values of all parameters are higher for cluster 2, and most of the samples belong to cluster 1. Additionally, the values of Cl-, NO3-, Ca2+, K+, and EC are higher in the dry season. No significant changes in the values of SO42-, HCO3-, and Na+. Ca–Mg–HCO3 facies are considered the baseline groundwater in the study area. It is worth mentioning that some of the springs sampled in the wet season were not sampled in the dry season, since they became dry. Moreover, there are two additional points sampled in the dry season.

Table 7. The Average of the Main Hydrochemical Parameters of Cluster 1 and Cluster 2 during the Rainy and Dry Seasons.

parameters	Rainy seasons		Dry seasons	
	cluster 1	cluster 2	cluster 1	cluster 2
Cl^-	33.0	114.7	38.6	142.1
NO_3^-	29.4	153.2	37.0	177.4
SO_4^{2-}	26.2	67.3	25.3	76.2
HCO_3^-	95.4	104.0	107.3	101.3
Na^+	19.6	61.1	29.1	55.0
K^+	1.4	8.3	1.8	13.3
Mg^{2+}	13.0	19.1	18.8	15.3
Ca^{2+}	76.1	109.5	83.9	115.8
EC	672.7	1168.0	600.6	1201.0
TDS	477.6	832.3	298.1	604.7

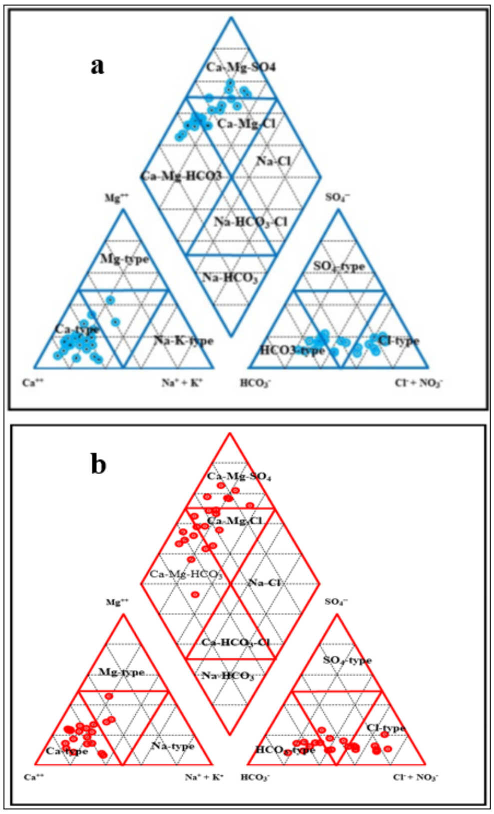

Figure 5. Piper's trilinear diagram showing different facies of the groundwater in the studied area during the rainy season a), and in the dry season b).

4.4 Drinking Water Quality Index (DWQI)

The Drinking Water Quality Index (DWQI) is a rating technique that offers the combined effect of individual water performance indicators of overall water quality based on several chemical parameters (Eslami et al., 2017). The WHO (2011) guidelines for drinking water quality have been used to calculate the DWQI, where water quality was divided into five groups based on the DWQI results (Table 8). The values of the DWQI fall in the range of 19.3 and 148.3 with an average of 43.4 in the rainy season and between 19.5 and 162.4 with an average of 46.0 in the dry season. The highest values of DWQI were found in the northeastern parts of the studied area (sample no. 4) in both the rainy and dry seasons (Figure 7a and b). During the rainy season, the lowest values of DWQI were found in the northeastern, southwestern, southeastern, northwestern, western, and middle parts of the studied area (samples no. 1, 2, 3, 5, 7, 9, 10, 11, 13, 14, 15, 16, 19, and 23), whereas in the dry season, the lowest values of DWQI were found in the northeastern, southwestern, southeastern, northwestern, western, and middle parts of the studied area (samples no. 1, 2, 3, 5, 6, 7, 9, 11, 13, 14, 16, 17, 19, 20, 21, and 24). Accordingly, about 95% of the groundwater samples possess good andexcellent water quality, although more than one third of the samples possesses nitrate levels higher than 50 mg/L. The wide variation in the DWQI reflects the variability of the levels of the used parameters, mainly TDS, Cl^-, and NO_3^-, which in turn reflects the influence of human activities on the water quality.

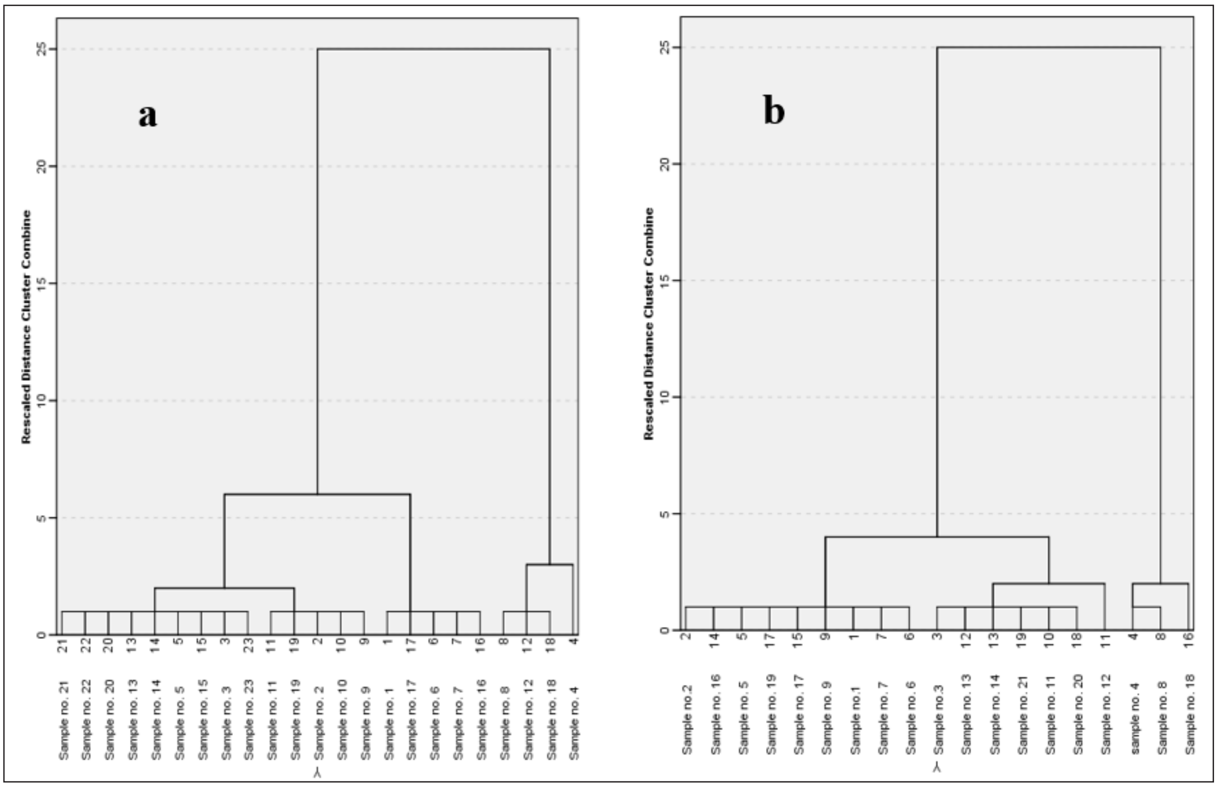

Figure 6. Dendrogram of clusters of the hydrochemical parameters in the rainy season a), and in the dry season b).

Table 8. Water Quality Classification Based on the Water Quality Index (DWQI).

DWQI Range	Type of water	WHO (2011) guidelines	Rainy Samples no.	Dry samples no.
<50	Excellent water	NO_3^- below 50 mg/L, except for samples no. 1 and 7 in rainy season, and samples no. 7, and 17 in the dry season	1,2,3,5,7,9,10,11,13,14,15,16,19,20,21,22,23	1,2,3,5,6,7,9,11,13,14,16,17,19,20,21,24
50–100	Good water	NO_3^-exceeding 50 mg/L	6,8,12,17,18	8,12,18,25
100–200	Poor water	NO_3^-exceeding 50 mg/L	4	4
200–300	Very poor water	NO_3^-exceeding 50 mg/L	__	__
>300	Water unsuitable	NO_3^-exceeding 50 mg/L	__	__

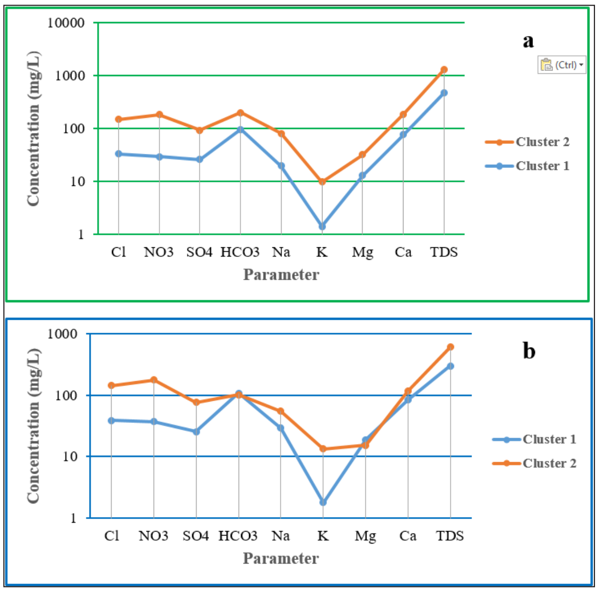

Figure 7. Schoeller's diagram of the two clusters for the rainy a) and dry seasons b).

4.5 Nitrate Pollution Index (NPI)

The nitrate pollution index (NPI) has been utilized as an indicator for nitrate pollution of the groundwater in the studied area. As shown in Table 9, the NPI values fall in the range of -0.82 to 10.5 with an average of 1.5 in the rainy season, and -0.87 to 12.1 with an average of 2.0 in the dry season. In the rainy seasons, 44% of the overall groundwater samples are classified as clean water, 13% light pollution, 13% moderate pollution, 13% significant pollution, and 17% very significant pollution. While 38% of the total groundwater samples in the dry season are considered as clean water, 19% light pollution, 14% moderate pollution, 5% significant pollution, and 24% very significant pollution. In the rainy season, the highest values of the NPI are found in the northeastern, southeastern, southwestern, and middle parts of the studied area (samples no. 4, 8, 12, and 18). The lowest values of the NPI are found in the northeastern, southwestern, northwestern, western, eastern, and middle parts of the studied area (samples no. 3, 5, 9, 13, 14, 15, 19, 21, 22, and 23) (Figure 7c). In the dry season, the highest values of the NPI are found in the northeastern, southeastern, southwestern, and middle parts of the studied area (samples no. 4, 8, 12, 18, and 25). The lowest values of NPI are found in the northeastern, southwestern, northwestern, western, eastern, and middle parts of the studied area (samples no. 3, 5, 9, 11, 13, 14, 19, and 21) (Figure 7d). According to NPI values, light nitrate pollution dominates most of the area. Medium, high, and very significant levels of human-caused nitrate pollution are most common in the central region, which is dominated by agriculture and urbanization. Thus, these regions have significant nitrate concentrations.

Table 9. Water Quality Classification Based on the Nitrate Pollution Index (NPI).

NPI value	NPI class	WHO (2011) guidelines	Rainy Samples no.	Dry samples no.
< 0	Clean (unpolluted)	NO_3^- below 50 mg/L	3,5,9,13,14,15,19,21,22,23	3,5,9,11,13,14,19,21
0–1	Light pollution	NO_3^- below 50 mg/L	2,10,11	1,2,20,24
1–2	Moderate pollution	NO_3^-below 50 mg/L, except for samples no. 1 (rainy season) and no.17 (dry season)	1,16,20	6,16,17
2–3	Significant pollution	NO_3^-exceeding 50 mg/L	6,7,17	7
> 3	Very significant pollution	NO_3^-exceeding 50 mg/L	4,8,12,18	4,8,12,18,25

4.6 Comparison between DWQI and NPI

Except for sample no. 4, which has poor water quality, all samples' DWQI values correspond to good-excellent water quality classes, thus authenticating their appropriateness for drinking. On the other hand, NPI values show a wide range of nitrate pollution levels in groundwater in the studied area. Table 10 presents the matchup of the DWQI and NPI as water quality indicators compared to the WHO guidelines. When compared together, it is found that samples no. 1 (rainy season) and 17 (dry season) fall in the category "excellent water" based on the DWQI, and in the category "moderate pollution" based on the NPI. However, both samples have NO_3^- concentrations above the WHO guidelines of 50 mg/L. Furthermore, samples no. 6, 7, and 17 (rainy season) and no. 7 (dry season) are classified as "good-excellent" by the DWQI and "significant pollution" by the NPI, despite having NO_3^- concentrations above 50 mg/L in all of them. Despite having NO_3^- concentrations above 50 mg/L, samples no. 8, 12, and 18 (rainy season) and no. 8, 12, 18, and 25 (dry season) fall into the category "good water" based on DWQI and the category "very significant pollution" based on NPI. Sample no. 4, representing the rainy and dry seasons, has a NO_3^- concentration greater than 50 mg/L and is classified as "poor water" by DWQI and "very significant pollution” by NPI. According to Obeidat et al., (2012), the NPI categories “significant pollution” and “very significant pollution” have NO_3^- concentrations above 50 mg/L. By grouping measurements of selected parameters such as pH, EC, major cations, and anions, it also provides a concise summary of the overall water quality status (Abbasi and Abbasi 2012). Because it is easy to introduce bias when selecting parameters and calculating individual weighing values, it may not be sufficient to comprehend the DWQI of a large body of water as a whole, although the calculations are straightforward. Certain parameters can influence water quality in a way that can be disregarded during calculation. Hence, the NPI may be a better indicator of water quality than the DWQI, which, at low values, obscures or masks very important parameters such as nitrate despite having levels that exceed WHO guidelines.

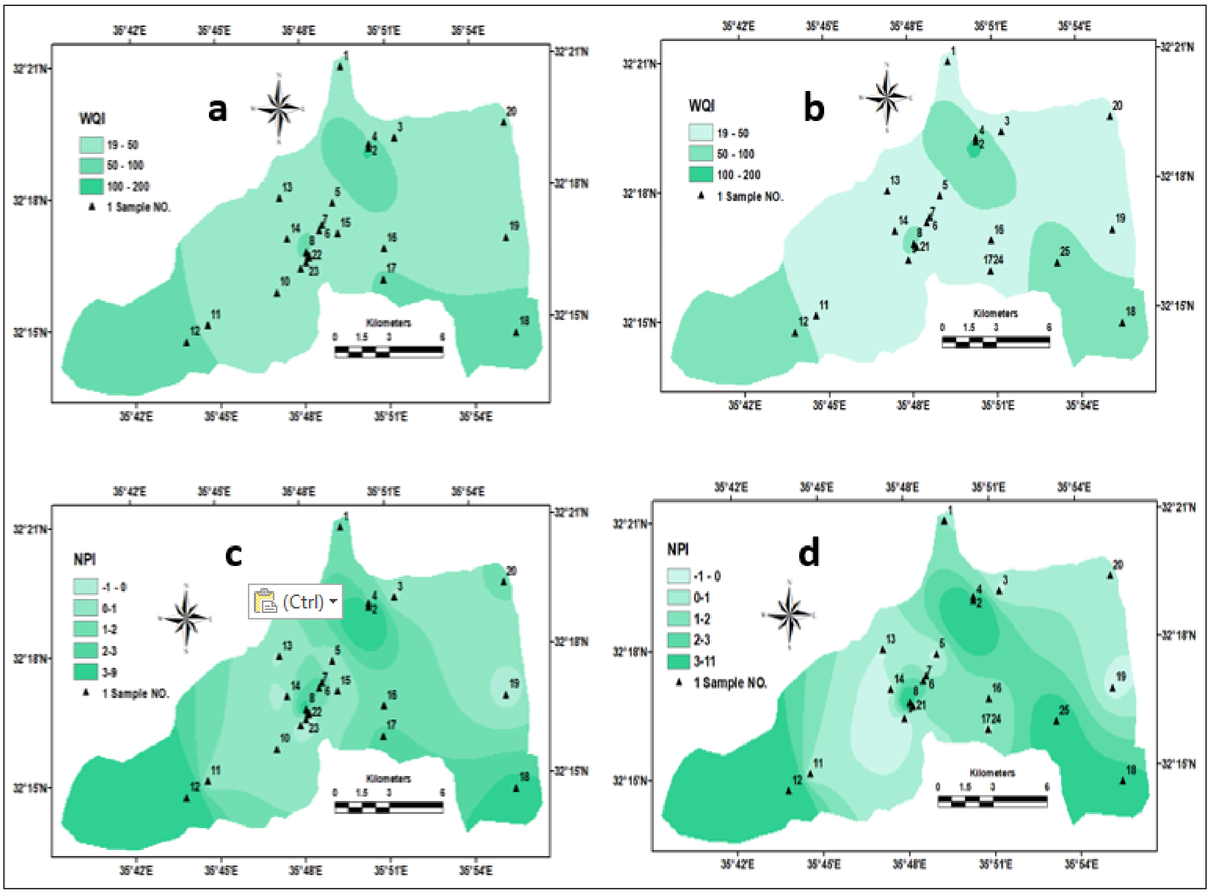

Figure 8. Spatial distribution of DWQI values in the rainy season a), and in the dry season b), and spatial distribution of NPI in the rainy season c), and in the dry season d).

Table 10. Comparison between DWQI and NPI Water Quality Classification.

DWQI Water Type	NPI Water Type	WHO (2011) Guidelines	Rainy Sample no.	Dry Sample no.
Excellent water	Clean (unpolluted)	NO_3^- below 50 mg/L	3,5,9,13,4,15,19,21, 22,23	3,5,9,11,13,14,19,21
Excellent water	Light pollution	NO_3^- below 50 mg/L	2,10,11	1,2,20,24
Excellent water	Moderate pollution	NO_3^- exceeding 50 mg/L except for (samples no. 16 and 20) rainy season, and (samples no. 6 and 16) dry season	1,16,20	6,16,17
Excellent to good water	Significant pollution	NO_3^- exceeding 50 mg/L	6,7,17	7
Good to poor water	Very significant pollution	NO_3^- exceeding 50 mg/L	4,8,12,18	4,8,12,18,25

DWQI has been utilized by several studies to assess water quality for drinking purposes in Jordan. El-Naqa and Al Raei (2021) assessed the DWQI in the Greater Amman, Jordan in the period between 2012-2016. Results indicated that the computed DWQI has values in the range of 29.17-62.32, corresponding excellent to good water quality classes. Additionally, it was found that the water quality in the study area has been deteriorated over time. The highest values of the DWQI were attributed to the high values of TDS, Ca^{2+}, K^+, Cl^-, HCO_3^-, NO_3^-, and SO_4^{2}. A study was carried out by Hyarat et al., (2022) to assess groundwater quality using water quality index in Amman andZarqa areas, Jordan. Based on the index values, 12%, 53%, and 35% of the samples can be described as having excellent, good, fair, and poor quality, respectively. The values of the index were in the range of 31-335 with an average of 95. Evaluation of the groundwater quality suitability for drinking purpose using water quality index in the Yarmouk basin, Jordan, was carried out by Ibrahim (2018). Based on the index scale classification, the groundwater quality of the studied locations falls in the excellent to poor quality, corresponding to the computed index values of 26.3 to 107.93. Ibrahim (2019) investigated the suitability of groundwater in major groundwater basins in Jordan using the water quality index. Groundwater from 16 stations within one year monitoring period (March 2015-Fberuabry 2016) was used. The findings of the study indicated that the computed index values are in the range of 40-4295, corresponding to the quality classes of excellent, good, poor, and very poor water quality. Three locations were classified as excellent water, nine samples as good, one as poor, and two as very poor water. Assessment of groundwater quality in the area surrounding Al-Zataari camp, Jordan, using cluster analysis and water quality index was conducted by Obeidat and Awawdeh (2021). The index calculation indicated that the groundwater quality falls in three classes: excellent covering 46% of the samples, good covering 50% of the samples, and poor involving two samples. The NPI was firstly applied in the Northern part of Jordan by Obeidat and Awawdeh (2021). Since then, the index has been widely utilized to assess groundwater contamination worldwide (El Mountassir et al., 2022; Egbueri et al., 2023; Paneerselvam et al., 2023). In both seasons, three zones of high DWQI and NPI values can be observed: in the northern part, where groundwater levels are high (700-900 masl; see Figure 3), which can be considered as recharge areas; the other two zones are located in eastern and southeast parts of the study area, where groundwater tables become shallower, and these areas might represent discharge areas.

4.7 Water Quality for Irrigation

Water quality for irrigation is determined by the kind and magnitude of the dissolved solids. In the studied area, the EC, the sodium adsorption ratio (SAR), the sodium percentage (Na%), and the magnesium hazard index (MHI) were used to determine the suitability of water for irrigation purposes. SAR is a characteristic that reveals the relative amounts of Na^+, Ca^{2+}, and Mg^{2+} in water samples. SAR takes into account the fact that the negative effects of sodium are mitigated by calcium and magnesium ions. When the SAR value is higher than 12–15, the soil becomes much damaged and plants have trouble getting water. The results of SAR range between 0.4 and 2.4 with an average of 1.0 in the rainy season, and between 0.1 and 1.9 with an average of 0.8 in the dry season. As seen in Table 2, water quality for irrigation purposes was graded into four groups according to the sodium adsorption ratio (SAR) (Anandakumar et al., 2009). The results show that all groundwater samples in our study are less than 10 and are classified as excellent (S1). The sodium concentration in groundwater is crucial for determining its appropriateness for irrigation purposes. This is because sodium ions have a tendency to react with soil formations and the soil will become less permeable (Mohamed et al., 2017). The value of Na% ranges between 8.8% and 45.4% with an average of 21.9% in the rainy season, and between 6.6% and 49.1% with an average of 22.3% in the dry season. As seen in Table 2, water quality for irrigation purposes was graded into five groups (Wilcox, 1955). According to the Na% classification, 51% of the total groundwater samples represent excellent water, 35% good water, and the remaining 19% permissible water during the rainy seasons. While through the dry season, the classification of Na%, 43% of the total groundwater samples represent excellent water, 48% good water, and the remaining 9% permissible water. The lowest value of Na% relative to excellent water was found in samples no.14 and no.11 in the rainy and dry seasons, respectively, which are located in the middle and southwestern parts of the studied area. The highest value of Na% relative to permissible water was found in sample no.4, which is located in the northeastern part of the study region in both seasons. Based on the interpretation, it can be recognized that the majority of the samples exhibit excellent to good characteristics. The ratio of Na^+ to Ca^{2+} and Mg^{2+} is used to calculate Kelley's index (Kelley, 1940). A Kelley's index (KI) greater than one shows an increased level of sodium in the water. Therefore, water with a KI of less than one is suitable for irrigation, whereas those with a ratio greater than one provide alkali dangers and are unsuitable for irrigation (Kelley, 1940). The KI value in the studied area ranges from 0.1 to 0.4 with an average of 0.2 in the rainy season and from 0.1 and 0.5 with an average of 0.2 in the dry season. The Kelley's ratio values show that all the groundwater samples are less than 1, and this indicates suitable water quality for irrigation purposes in both seasons. Ca^{2+} and Mg^{2+} maintain equilibrium in the majority of the water. As the soil gets more alkaline, high quantities of magnesium in the water will negatively impact crop production (Subhash Chandra, 2017). The value of MHI ranges from 8.6 to 54.6 with an average of 22.3 in the rainy season and from 10.7 to 56.8 with an average of 25.5 in the dry season. Water quality was graded into two groups based on the MHI results (Subhash Chandra, 2017). Based on the MHI value, all groundwater samples are suitable for irrigation purposes, which control the majority of the area in the study region. A very small portion (2%) of the higher MHI concentration was recorded as harmful and unsuitable for irrigation purposes, specifically samples no.19 and no.20 in the rainy and dry seasons, respectively, in the eastern and northeastern parts of the studied area. According to Marmontel et al., (2018), electrical conductivity is crucial in determining the appropriateness of water for irrigation purposes. In the studied area, the EC range from 457 to 1423 µS/cm with an average of 759 µS/cm in the rainy season, and from 354 to 1368 µS/cm with an average of 705 µS/cm in the dry season. Water quality is classified into five groups according to the range of EC (Rajankar et al., 2011). The results indicated that water in the studied area is obviously classified as good or permissible for irrigation purposes.

5. Conclusion and Recommendations

The present study aimed to evaluate the quality of groundwater in t Jerash region using the DWQI and NPI as water quality indicators. The DWQI should be used with extreme caution due to the fact that it gives a false impression of water quality by masking pollutants at levels that exceeded the acceptable limit for a drinking water quality. In contrast, the nitrate pollution index (NPI) revealed that approximately 43% of the samples fall into the categories "moderately polluted," "significantly polluted," and "very significantly polluted," with NO_3^- concentrations exceeding the WHO and JS-mandated maximum permissible limit of 50 mg/L. The main sources of nitrate pollution in the studied area are synthetic fertilizers and sewage intrusion. On the other hand, water-rock interaction is the primary natural process affecting groundwater quality, as indicated by the predominant carbonate rock composition of the aquifer material. The quality of all tested groundwater samples was suitable for irrigation with no seasonal variation in the groundwater chemistry. The results shed light on the protection and allocation of usable groundwater supplies, particularly for irrigation and drinking and offer decision-makers an important tool for putting into place effective measures to protect groundwater in the studied area. It is highly recommended to apply best management practices and efficient land use planning including improved agriculture and sanitation techniques. In addition, selecting the most suitable environmental parameters is crucial and will provide the user with a particular form of the algorithm and the potential effects of water body pollution. Furthermore, statistical methods can be utilized to reduce uncertainty in processes like parameter selection.

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