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Assessment of groundwater quality in the area surrounding Al-Zaatari Camp, Jordan, using cluster analysis and water quality index (WQI)

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Abstract

Groundwater forms the main freshwater supply in arid and semi-arid areas. However, this precious resource has been subjected to depletion, as a direct result of over-pumping and climate change, and to contamination by different types of pollutants, as a result of growing human activities. Assessment of groundwater quality suitability for domestic uses, particularly for drinking, is essential for human health protection, as well as for effective resource management. The overall objective of this study is an assessment of the groundwater quality in the area surrounding Al-Zaatari camp in Jordan using water quality index (WQI) for drinking, using the major cations and anions that potentially have adverse impacts on human health. Moreover, groundwater quality was assessed using multivariate statistical analysis (k-means cluster analysis), and conventional hydrochemical tools. About 95% of the samples were classified as freshwater, and about 67% were classified as hard to very hard. The groundwater in the study area showed two main hydrochemical facies: mixed Ca-Mg-Cl and Na-Cl. Groundwater chemistry in the study area is influenced by the processes of ion exchange of both types (reverse ion exchange and base ion exchange) and rock weathering as it was deduced from Gibbs diagram. K-means cluster analysis resulted in two main clusters that can be differentiated by the distinct ionic concentration. Water quality index (WQI) calculations revealed three categories of the groundwater: 1) Excellent and involved 46% of the sampled wells, 2) Good, and involved 50% of the sampled wells, and 3) Poor that involved only two sampled wells. Overall, it can be stated that about 96% of the sampled wells under study can be described as good-excellent, authenticating the suitability for drinking.

Keywords: Al-Zaatari camp, groundwater, water quality index, cluster analysis

1. Introduction

Groundwater forms the main source of fresh water supply for the different uses, especially in arid and semi-arid areas. Groundwater is particularly important especially in regions having large population and intense human activities, where it is used for domestic, agricultural and industrial purposes (Wang et al., 2020; Li et al., 2016). However, this priceless natural resource has been undergoing overexploitation in water-scarce communities, which caused depletion and drastic drawdowns, as well as deterioration of water quality making it unfit for domestic uses (Zhang et al., 2019; Wu et al., 2019). The issue is further complicated by the aridity of these areas, represented by a low amount of precipitation, high amount of evapotranspiration, slow and low recharge rates (Ahmed et al., 2019). Conservation of groundwater resources is pivotal in groundwater sustainable management (Liu et al., 2019). Therefore, achieving true sustainability of groundwater resources necessitates an assessment of natural as well as human factors/processes that impact groundwater quality (Wang et al., 2020).

Groundwater quality is strongly influenced by human activities and many natural factors/processes such as the quality of recharge water, rock-water interaction, mixing of groundwater along flow paths, and residence time of the groundwater (Abanyie et al., 2020; Gopinath et al., 2019; Zango et al., 2019; Aghazadeh et al., 2017; Qin et al. 2013; Hem, 1985). Agricultural activities, domestic wastewater leakage, industrial influents, and leachate seepage from landfills can raise pollutants' concentrations in groundwater hundreds times higher than the natural backgrounds (Gibrilla et al., 2020; Lermi and Ertan, 2019; Obeidat et al. (2012), Wakida and Lerner, 2005). Groundwater chemistry is modified by many processes, such as dissolution/precipitation of carbonate and evaporate minerals, and ion exchange (Ahmed et al., 2019; Tiwari et al., 2019; Ayadi et al., 2018; Argamasilla et al., 2017; Han et al., 2015;). Geochemical processes are responsible for the spatiotemporal variation in groundwater chemistry (Kumar et al., 2006).

Multivariate statistical analysis has been extensively used to characterize water quality and to identify sources of contamination (natural and anthropogenic) by analyzing similarities/dissimilarities among the sampled sites (Andrade et al., 2008; Obeidat et al. 2013). It offers a robust method for reliable management of water resources and swift solution of water pollution (Bodrud-Doza et al., 2016). It is a data-reduction technique that can be used to handle and reduce a large number of water quality data (Obeidat et al., 2013). The most common methods are cluster analysis and

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principal component analysis (factor analysis). The principal component analysis is a data dimension reduction method that explains the variability in surface and groundwater data (Rashid et al., 2019). On the other hand, cluster analysis is used to classify the data into different groups based on similarity and dissimilarity among data (Hegeu and Kshetrimayum, 2019).

Water quality index (WQI) is a powerful method that has been commonly used to assess the overall water quality, and to manage water resources (Fang et al., 2020; Gaiwad et al., 2020; Abbasnia et al., 2019; Adimalla and Qian, 2019; Machiwal et al., 2019). WQI integrates a large number of hydrochemical parameters into an easily expressible and understandable format (single score) by selecting and weighting the water quality parameters and applying an aggregation function (Gao et al., 2020; Fang et al., 2020; Zotou et al., 2020; Ponsadailakshmi et al., 2018; Abtahi et al., 2015). WQI has been widely used to assess groundwater suitability for drinking purposes (Heiβ et al., 2020; Udeshani et al., 2020; Varol 2020; Khangembam and Kshetrimayum, 2019; Kawo and Karuppannan, 2018; Wu et al., 2017). It is a very effective method to present water quality data in a simple way to the public as well as policymakers and competent authorities (Keesari et al., 2016)

Jordan is an arid country, that is ranked as the second water-poor country, worldwide. Moreover, about 40% of its water resources are shared by the neighbouring countries. Instability and conflicts in the region have pushed hundreds of thousands of immigrants to flee to the country, putting more burden over the limited water resources. Climatic change is not overriding Jordan; observed effects include decreased precipitation, temperature rise, shifting of the rainy season, and deteriorating water quality (Al-Qaisi, 2010). The overall objective of this study is to assess groundwater quality suitability for drinking purposes using a water quality index method in the area surrounding Al-Zaatari Camp, Jordan. The results of the present study may assist competent authorities by providing baseline information for sustainable management of groundwater in the area under consideration.

2. Study area

2.1 Location and climate

The study area is located within the Amman-Zarqa basin (AZB), east of Mafraq city (Figure 1). The AZB is a transboundary basin of which 3,739 km^2 are in Jordan and 310 km^2 in Syria. It is one of the most important groundwater basins in Jordan and represents a transitional area between the semi-arid highlands in the west to the arid desert in the east. The study area is characterized by arid to semi-arid climatic conditions with a mean annual precipitation in the range of 100 mm in the eastern part to about 300 mm in the south-west (Figure 2). The study area tends to exhibit short and intense rainfall during the rainy season (Al-Rawabdeh et al., 2021). The dominant land use/land cover in the study area (Figure 3) is a sparse vegetative cover, followed by irrigated agriculture, and rangeland (Jawarneh and Biradar, 2017).

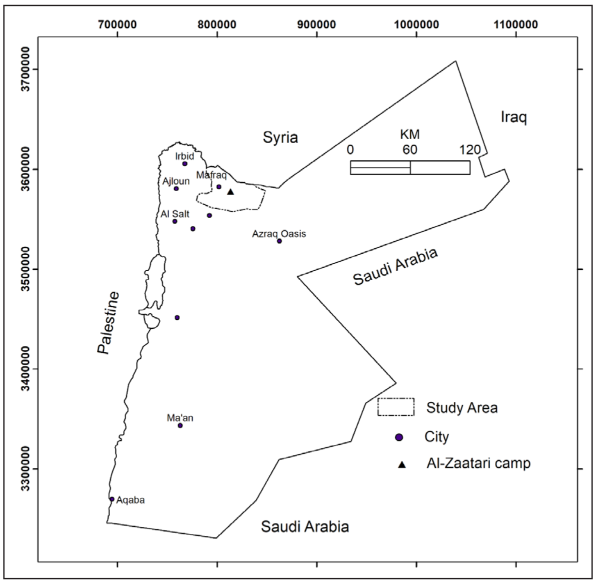

Figure 1. Location map of the study area.

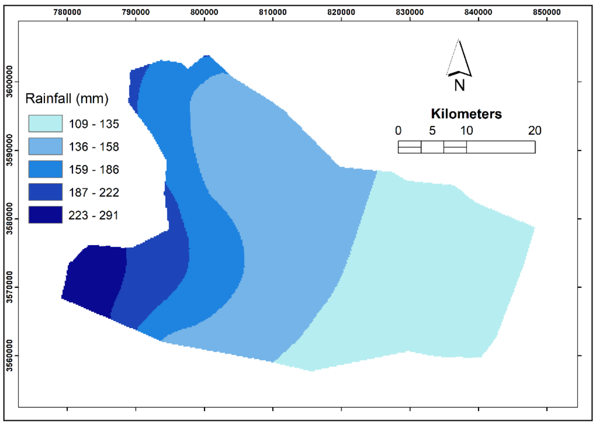

Figure 2. Rainfall map of the study area.

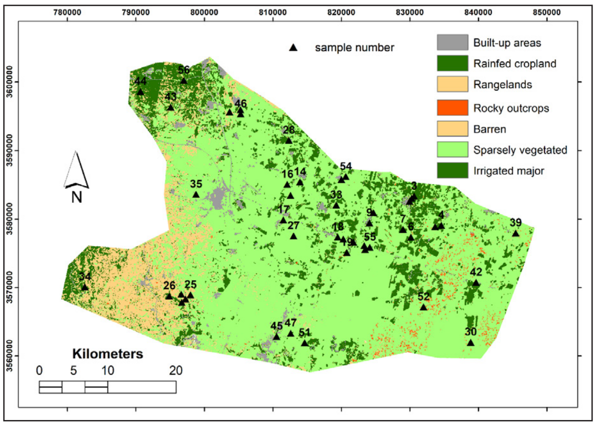

Figure 3. Land use-land cover of the study area with the sampled wells.

2.2 Geological and hydrogeological setting

From a hydrogeological point of view, three aquifer systems (Table 1 and Figure 4) are found in the study area: a composite system of the basalt and Amman Silicified Limestone /Wadi As Sir Limestone formation (B2/A7), the Umm Rijam/Wadi Shallala aquifer (B4/B5), and the Lower Ajlun aquifer which consists of Hummar (A4) and Na'ur

(A1/2) Formations (Al-Zyoud et al. 2015; Al-Rawabdeh et al. 2013). The basalt and the Amman-Wadi As Sir aquifers are hydraulically interconnected and form the main aquifers in the study area. In the eastern parts of the study area, a succession of six lava flows lies unconformably on the sedimentary rocks of the Late Cretaceous Balqa and Ajlun Groups (Bender, 1968). The transmissivity of this system ranges between 2.2 X 10^{-5} and 7x 10^{-3} $m^2\ s^{-1}$ with an average of 3.2x10^{-4} $m^2\ s^{-1}$. The water is transferred laterally or vertically from the basalt aquifer into the Amman-Wadi As Sir aquifer (Obeidat and Alwaneh, 2019).

Based on pumping tests, the uppermost basaltic aquifer, which is formed by highly vesicular lava flows has transmissivity values in the range from 5.0×10^{-5} to 5.4×10^{-1} m2·s^{-1}, and the average is about 8×10^{-2} $m^2\ s^{-1}$, corresponding to a mean hydraulic conductivity of 2.3×10^{-4} m·s–1. The transmissivity of the limestone aquifer (B2/A7) varies between 5.4×10^{-5} and 2.5×10^{-2} $m^2\ s^{-1}$, with an average close to 5×10^{-3} $m^2\ s^{-1}$, corresponding to a mean hydraulic conductivity of 8.1×10^{-5} m^2 s–1 (Al Mahamid, 2005). The Jordan Ministry of Water and Irrigation indicated that the water table of Amman/Wadi Sir aquifer is depleting at a rate of 0.67 to 2 m/yr. On the other hand, the mean annual recharge to the basin is 80 MCM/yr (Al Kuisi et al., 2009; Ta'any et al., 2009).

The Wadi Shallala Formation (B5) of early Middle-early Late Eocene age consists of chalk, chalky limestone and marl with chert intercalations, while the Umm Rijam Chert Limestone Formation (B4) of Paleocene age consists of alternations of limestone, chalk, and chert. The Muwaqqar Chalk Marl

Formation (B3, aquiclude/aquitard) of Maastrichtian age separates the upper aquifer system (B5/B4) from the middle aquifer system (B2/A7). It consists of bituminous marl and marly limestone.

The aquifer (B4) is highly fractured and characterized by cavernous and karstic features. The B5/B4 aquifer has a hydraulic conductivity in the range of 10^{-4} and 10^{-6} m/s with an average 5×10^{-5} m/s (Margane et al., 1999). The aquifers of Lower Ajloun group are composed of limestone, dolomitic limestone, and marl. Naur formation (A1/A2), mainly of marls, limestone and marly limestone, whereas the Hummer (A4) formation consists of hard dense limestone and dolomitic limestone (Awawdeh et al., 2020).

Table 1. Geological and hydrogeological classification of the rock units in the study area

Age	Group	Formation name	Symbol	Lithology	Thickness (m)	Aquifer potentiality
Paleocene	Belqa	Umm Rijam Chert Limestone	B4	Chert and limestone	30-50	Good
Maastrichtian		Muwaqqar Chalk Marl	B3	Chalk, marly chalk, marl	>300	Poor
Campanian		Amman Silicified Limestone	B2	Chert, limestone, with phosphate	30-120	Excellent
Santonian		Wadi Umm Ghudran	B1	Chalk, marl, marly limestone	0-75	Poor
Turonian	Ajloun	Wadi As Sir Limestone	A7	Limestone, dolomite, chert	65-300	Excellent
Turonian		Shueib	A5/6	Limestone, marly limestone	70	Fair-good
Cenomanian		Hummar	A4	Dolomite, dolomitic limestone	60-120	Fair-good
Cenomanian		Fuheis	A3	Marl and marly limestone	80-120	Poor
Cenomanian		Naur	A1/2	Limestone, dolomitic limestone, marly limestone	250-350	Good

2.3 Al-Zaatari Camp for Syrian Refugees

There are five Syrian Refugees camps in Jordan, which were built following the influx of about 1.4 million Syrians, fleeing the war erupted in 2011. Among the 5 refugees camps, only 3 camps are official: Al-Zaatari, Mrajeeb-Al Fhood, and Azraq. Al-Zaatari camp, established in 2012 is the world largest refugees camp in Jordan (Al-Harahsheh et al., 2015). The camp hosts 78,558 Syrian refugees, 20% of the population are under four years, and 40% are females (UNHCR, 2020). The camp close to Jordan's northern border with Syria is located about 10 km east of Mafraq city (Figure 1). Currently, three groundwater wells exist inside the camp which provides about 3000 m^3 a day. In terms of the sources of drinking water, 51% of the households are using trucked water stored in private tanks, 26.7% of households are using purchased bottled water, and 22. 3% are using water from the communal tank (UNICEF, 2017). A wastewater treatment plant with a capacity of 3600 m^3 was established to treat wastewater.

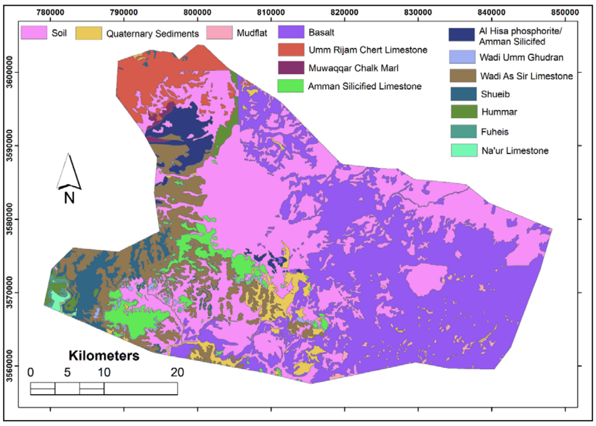

Figure 4. Geological map of the study area.

3. Material and Methods

3.1 Analytical procedure

A total of 450 samples representing 56 groundwater wells were used in this study. These included 26 samples collected by the authors in January 2019, and the rest were retrieved from the open files of the Water Authority of Jordan (Figure 3). It is assumed that after/during the rainy season, pollutants may have been subjected to downward leaching, and thus contaminating the underlying aquifers The samples were collected from the upper aquifer systems and involved 26 wells from the basalt aquifer, and 30 wells from the B2/A7 aquifer. The hydrochemical parameters used in this study represent average values.

The collected samples were field filtered through 0.45 µm Millipore filters into HDPE sample bottles with appropriate storage and preservation methods (refrigeration, freezing, acidification, the addition of chloroform). The methods described by APHA (1998) were followed during fieldwork and laboratory chemical analyses. Electrical conductivity (EC), temperature and pH were measured in situ using portable meters. Before sample collection from the wells, intensive purging was performed, to ensure representativeness and reproducibility of the groundwater sample. Chemical analyses were carried out at the laboratories of Jordan University of Science and Technology and Yarmouk University. Calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), and sulfate (SO_4^{-2}) concentrations were determined by Ion Chromatography (Dionex ICS-1600). Bicarbonate (HCO_3^{-}) and nitrate (NO_3^{-}) were determined by titration method and spectrophotometry, respectively. Total Hardness (TH) was calculated using calcium and magnesium concentrations (Todd, 1980). All samples were analyzed in triplicate with analytical uncertainty of less than 4%. To check the correctness of the analysis, the cations–anions balance was used, where it was within ±5%, which guarantees the reliability of the chemical analysis.

3.2 K-means cluster analysis

K-means analysis is a tool designed to assign cases to a fixed number of groups (clusters) whose characteristics are not yet known but are based on a set of specified variables (Hartigan, 1975). It is useful for the classification of a large number of cases. The computer software IBM SPSS Statistics version 21 was used to carry out the cluster analysis.

3.3 Water quality index calculation

The determination of the WQI includes four major steps (Ismail et al., 2020; Njuguna et al., 2020):

1. Measurement of the selected water quality parameters.
2. Transformation of the measurement of the water quality parameters into a dimensionless number (quality rating).
3. Assignment of weight to each water quality parameter based on its degree of importance for drinking water (Table 2).
4. Aggregation of the quality rating to obtain the final WQI using a suitable aggregation function.
5. The weight was assigned to each parameter according to Adimalla and Qian (2019), Ismail et al. (2020), and Nagaraju et al. (2016).

Quality rating (Qi) was calculated according to the following equation:

$$Qi = 100 * Ci/S \quad (1)$$

whereCi is the measured parameter concentration and S is the WHO (2011) guidelines (Table3).

The final WQI was calculated using the following equation:

$$\mathrm{WQI} = \sum_{i=1}^{n} RWi * Qi \quad (2)$$

Where Wi is the relative weight of the parameter, which was calculated as follows:

$$RWi = AWi / \sum_{i=1}^{n} AWi \quad (3)$$

Where RWi is the relative weight and AWi is the assigned weight.

Groundwater quality in the study area was classified into different groups based on the WQI. The obtained WQI values were categorized into the following categories (Ismail et al., 2020):

- Excellent: <50
- Good: 50-100
- Poor: 100-200
- Very poor: 200-300
- Unsuitable: >300

Table 2. Weights and the relative weight assigned to the hydrochemical parameters in the study area (Ismail et al., 2020).

Parameter	Assigned weight (AWi)	Relative weight (RWi)
TDS	5	0.15
Cl	5	0.15
SO_4	5	0.15
NO_3	5	0.15
Na	4	0.13
Ca	3	0.09
Mg	3	0.09
K	3	0.09
Sum of weights	33	1

4. Results and Discussion

4.1 Major ion chemistry and hydrochemical facies

The descriptive statistics of the hydrochemical parameters are presented in Table 3. The pH value is in the range of 6.68-8.19 with an average of 7.73, indicating that the groundwater is generally neutral. The EC is in the range of 390-2580 µS/cm with an average of 1002 µ/cm (Figure 5a). TDS is in the range of 223-1372 mg/L with an average of 583 mg/L. Based on Davis and Dewiest (1966) classification, about 96.6% of the samples are classified as freshwater. Except for three samples, the TDS content of all samples is below the maximum permissible limit of the drinking water quality guidelines of WHO (2011). The TH as $CaCO_3$ is in the range of 79-607 with an average of 254 mg/L. Based on Sawyer and McCarty (1967) classification, about 32.6% of the samples are classified as moderately hard, 33.7% hard, and 33.7 % very hard water. Three samples have TH above the maximum permissible limit of WHO (2011) drinking water quality guidelines of 500 mg/L.

Table 3. Descriptive statistics of the hydrochemical parameters.

Parameter	Min	Max	Mean	Std. Dev.	Coefficient of variation (C_V, %)	WHO (2011)
Ca (mg/L)	13	150	48	27.2	56.2	75
Mg (mg/L)	8	78	33	16.3	49.5	100
Na (mg/L)	39	288	98	36.1	36.7	200
K	2	14	6	2.6	46.6	10
HCO_3 (mg/L)	19	327	135	63.9	47.4	--
SO_4 (mg/L)	24	405	84	52.5	62.7	250
NO_3 (mg/L)	1	101	17	14.6	85.2	50
Cl (mg/L)	38	651	193	122.8	63.6	250
T (°C)	22	43	31	4.0	12.9	--
pH	7	8	8	0.3	3.9	6.5-8.5
EC (µS/cm)	386	2580	1002	399.2	39.8	--
TH (mg/L)	79	607	254	126.8	50.0	--
TDS (mg/L)	223	1372	583	218.7	37.5	1000
CAI	-0.97	0.93	0.02	--	--	--
WQI	18.5	155.5	50.6	25.1	49.6	--

The Ca and Mg concentrations are in the range of 14-150 mg/L, and 8-78 mg/L, with an average of 48 mg/L, and 33 mg/L, respectively (Figure 5b). All samples have Ca and Mg concentrations which are below the permissible limit of 200 and 100 mg/L, respectively. The main sources of Mg in groundwater include weathering of Mg-containing rocks, and contamination by domestic, animal, and industrial waste (Selvam et al., 2016). Na and K concentrations are in the range of 39-288 mg/L, and 2-14 mg/L, with an average of 98 mg/L, and 6 mg/L, respectively. Only one sample has Na concentration higher than the permissible limit of drinking water quality of 200 mg/L, and all samples have K concentration which is within the permissible limit of WHO (2011) drinking water quality guidelines. The main sources of Na in groundwater include weathering of rock-forming minerals such as Na-plagiocalse, and halite, in addition to contamination by human and animal waste (Selvam et al., 2016). HCO_3 and SO_4 concentrations are in the range of 19-327 mg/L, and 24-405 mg/L, with an average of 135 mg/L and 84 mg/L, respectively. All samples have HCO_3 and SO_4 concentrations which are within the maximum permissible limit of 600 mg/L.Cl and NO_3 concentrations are in the range of 38-651 mg/L, and 1-101 mg/L, with an average of 193 mg/L and 17 mg/L, respectively (Figure 5c & d). Only one sample (sample 24) has Cl concentration above the maximum permissible limit of WHO (2011) drinking water quality guidelines of 600 mg/L.This sample is located in the southwest part of the study area and has a nitrate concentration much higher than the natural background concentration of 5-10 mg/L (Panno et al., 2006), and more than the maximum permissible limit of drinking water quality set by the WHO (2011). Nitrate is the most common human-induced pollutant into groundwater (Babiker et al., 2006). The association of high concentrations of both chloride and nitrate indicates that the source of these ions is anthropogenic, and most likely domestic wastewater. About 28% of the samples have nitrate concentrations above the natural background concentration of 20 mg/L.Three samples have nitrate concentration above the maximum permissible concentration of drinking water quality set by the WHO (2011). According to Nagaraju et al. (2016), the concentration of a chemical component with a single source should have a low coefficient of variation (<10%). Among the major ions, NO_3 has the highest coefficient of variation reaching 85%, followed by Cl (64%), and SO_4 (63%). This may indicate a multi-source of these components, hydrochemical, and mixing processes affecting the spatial distribution of the hydrochemical parameters.

The major ions of the groundwater in the study area showed the following order:

Na>Mg>Ca>K, and Cl>HCO_3>SO_4>NO_3. Groundwater chemistry may reflect the influence of hydrochemical processes occurring in the subsurface (Gaikwad et al., 2020; Jain et al., 2018). The geochemical data of the main cations and anions were plotted using Piper diagram (Piper, 1944), where it revealed two water types (Figure 6): 1) mixed Ca-Mg-Cl type (suggesting interplay of complex geochemical processes in the aquifer), and 2) Na-Cl water type. Seven samples fall in the Ca-Mg-SO_4 field, and only one sample falls in the Ca-Mg-HCO_3 field. The majority of the samples falls in the Na-dominant zone, and no dominant zone in the cations facies. This may reflect the effect of the aquifer mineral make up (basalt), and hydrochemical processes, particularly base ion exchange process where Ca and Mg are sequestered onto the aquifer material and Na is released into the water. Additionally, the majority of samples falls in the Cl-dominant zone, and no dominant zone in the anions facies. The samples fall in both zones 1 and 2 of the diamond plot, revealing that the samples are divided into two main groups: alkaline earth exceeding alkalis, and alkalis exceeding earth alkaline.

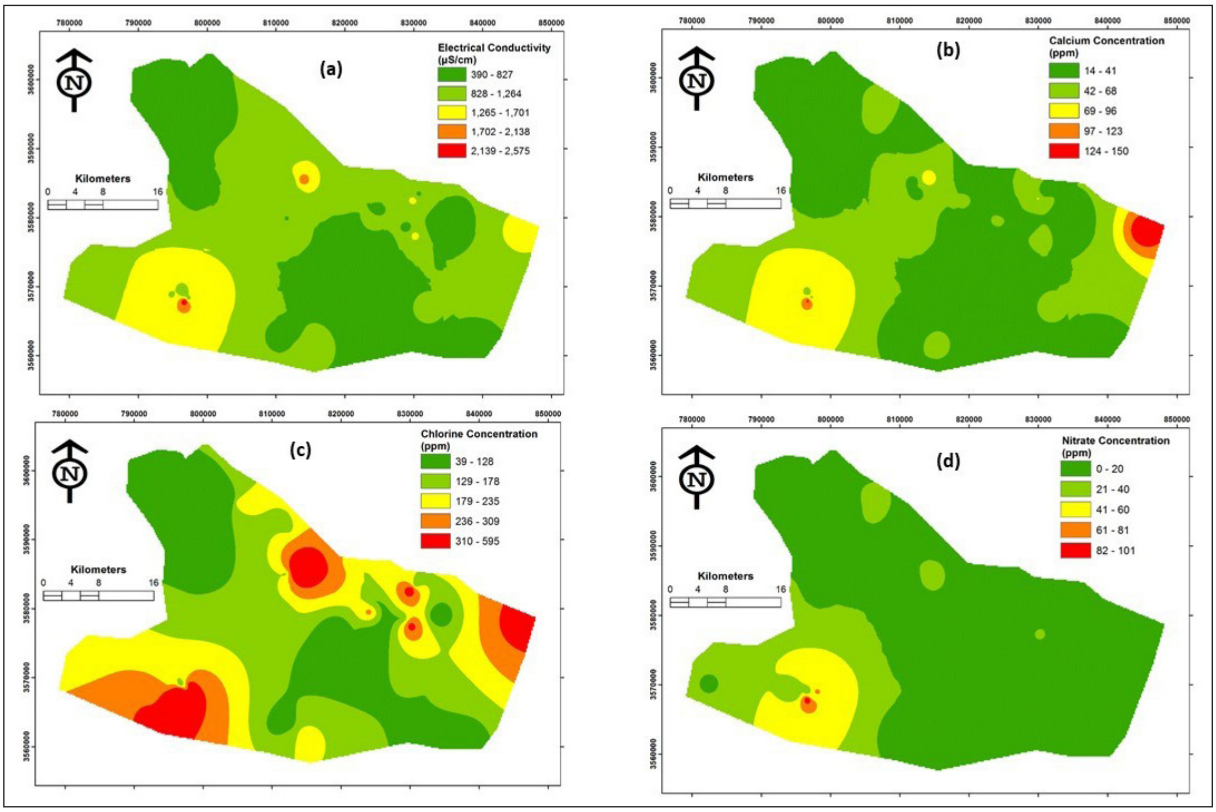

Figure 5. Spatial distribution of (a) EC, Ca (b), Cl (c), and NO_3 (d).

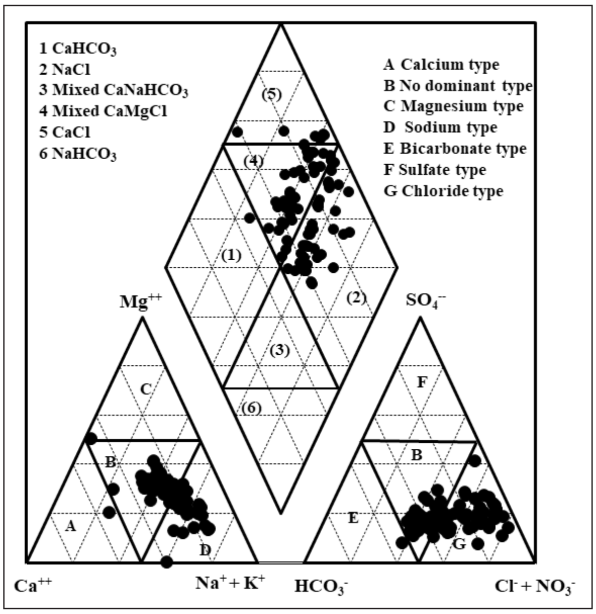

Figure 6. Piper diagram of the groundwater samples.

Gibbs diagram is a useful tool that can be used to investigate the effects of geochemical processes on groundwater chemistry. Evaporation, rock, and precipitation were the main factors identified by Gibbs (1970) that control or modify groundwater chemistry. The groundwater data in the study area was plotted using Gibbs diagram and presented in Figure 7, which revealed that rock weathering is the main process affecting groundwater in the study area. Groundwater-aquifer interaction has significantly impacted the groundwater chemistry. Ion exchange is another geochemical process that controls groundwater chemistry. Ion exchange and adsorption play an important role in regulating solute transport in the soil and aquifers (Appelo and Postma, 2005).

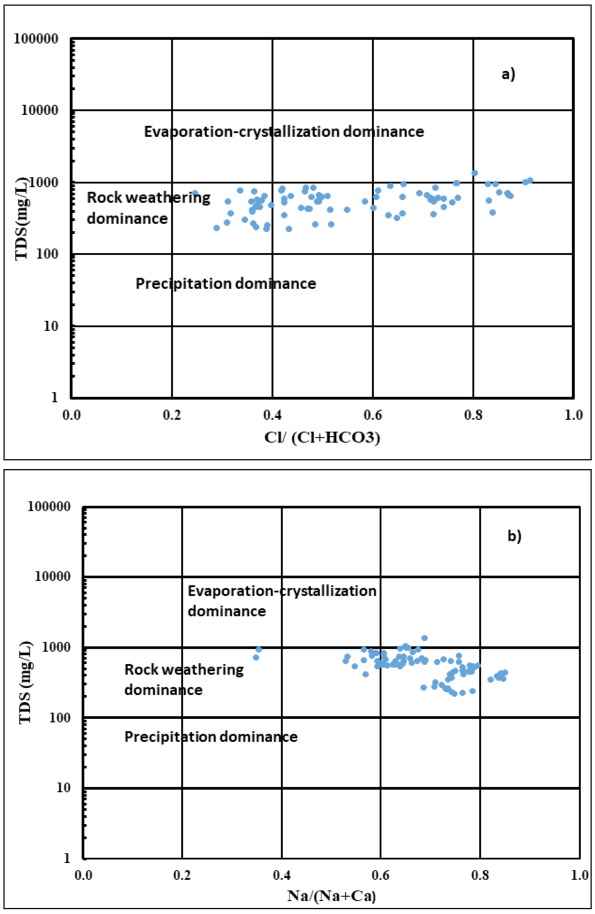

Figure 7. Gibbs diagram of the groundwater samples using anion vs. TDS (a), and cation vs. TDS (b).

Schoeller index (chloro-alkaline indices, CAI) have been used to get insights about ion-exchange reactions between groundwater and the hosting aquifer material, as well as information about freshening or salinizing processes of the groundwater (e.g. Tiwari et al., 2019; Abu-alnaeem et al., 2018; Stuyfzand, 2008). The CAI can be determined using the following equation (Schoeller, 1965):

$$CAI = (Cl - (Na + K))/Cl \quad (4)$$

where concentration is in meq/l

The CAI values could be negative or positive depending on whether the exchange of Na and K is from the water with Mg and Ca in rock/soil or vice versa (Tiwari et al., 2019). There are two types of ion exchange processes (Ayadi et al., 2018): the first one is known as reverse ion exchange process, where Na and K are sequestered onto the aquifer material, and Ca and Mg are released into the water. The CAI values in this case are positive, and there is a hardening of water (Zaidi et al., 2015). The second type of ion exchange processes is known as the base ion exchange process, where Ca and Mg are sequestered onto the aquifer material and Na and K are released into the water. The CAI values in this case are negative, and there is softening of water (Argamasilla et al., 2017). The CAI values of the groundwater in the study area ranged between -0.97 and 0.67 with an average of 0.01, and most of the samples cluster between -0.5 and 0.5(Figure 8), indicating that low level of the ion exchange process. Meanwhile, about 62% of the wells have positive CAI values, indicating hardening of the groundwater; about 38% have negative CAI values, indicting softening of the groundwater.

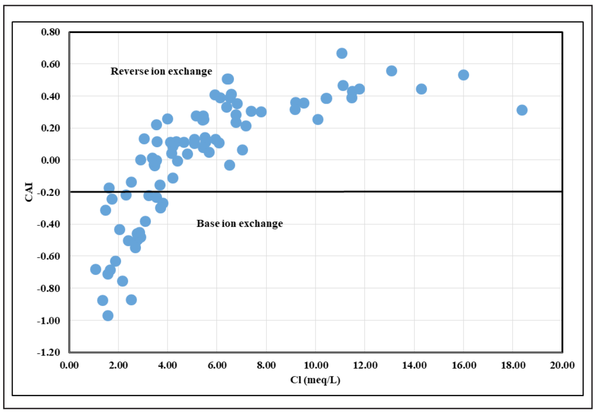

Figure 8. Chloride concentration vs. chloro-alkaline index (CAI).

Generally, areas with low salinity (means negative CAI values), signifying that the groundwater of these areas is undergoing freshening processes. Besides, the aquifer material released sodium into the groundwater and fixed calcium. About 67% of the samples collected from the B2/A7 has positive CAI values, and about 54% of the samples have negative CAI values, signifying to aquifer lithology effect on the groundwater chemistry.

The bivariate statistics of the physiochemical parameters of the groundwater are presented in Table (4). The terms, "strong" "moderate" and "weak" were used to describe the correlation coefficient values (r), and they refer to a range of >0.75, 0.5-0.7, and 0.3-0.5, respectively (Wang et al., 2007). EC is strongly correlated with Ca, Mg, Na, SO_4 and Cl, indicating that dissolution of these ions are the main source of the groundwater salinity. A moderate correlation exists between EC and NO_3, indicating that the more salinization of groundwater, the more accumulation of NO_3 in the groundwater. The Ca is strongly correlated with each of Mg and Cl, and moderately correlated with Na, NO_3 and SO_4. The Mg is strongly correlated with Cl, and moderately correlated with Na and SO_4. Na is strongly correlated with Cl and SO_4, and moderately correlated with NO_3. SO_4 is strongly correlated with Cl, and moderately correlated with NO_3. The weak correlation between HCO_3 and other hydrochemical parameters can be attributed to the sources of alkalinity, which includes dissolution of atmospheric and soil CO_2 (Moquet et al., 2011).

4.2 Cluster analysis and the WQI

The results of the k-means cluster analysis revealed two clusters with distinct ionic concentrations (Table 5). Cluster 1 includes 14% of the samples (7 samples: samples 1, 14, 24, 25, 37, 38, 39), whereas cluster 2 includes 86% of the samples (43 samples). Both clusters are of Ca-Mg-Cl water type (Figure 9). This water type can be related to the fourth group of Rimawi and Udluft (1985), which corresponds to freshwater mixed with saline water or freshwater which has passed through evaporates. The two clusters plotted in the no dominant zone in the cation facies (no one cation-anion pair exceeds 50%). On the other hand, the two clusters fell in the Cl-dominant zone in the anion facies. Based on the TDS, the two clusters can be classified as freshwater. However, cluster 1 has TDS content more than double than that of cluster 2. Additionally, cluster 1 has nitrate concentration much higher than the natural background concentration of 5-10 mg/L. The sources of nitrate in the study area include domestic wastewater and agricultural fertilizers.

Groundwater quality and its suitability for drinking were assessed using WQI. Eight hydrochemical parameters (TDS, Ca, Mg, Na, K, Cl, SO_4, NO_3) were taken into account for WQI calculation and considering the WHO (2011) guidelines for drinking water quality. The weights were assigned to calculate the WQI values for each hydrochemical parameter, depending on their prominence on water quality. TDS, Cl, SO4, and NO3 were assigned a weight of 5; Na was assigned a weight of 4, and K, Mg, and Ca were assigned a weight of 3. The relative weight of each parameter (Table 2) was calculated according to Eq. (3).

Table 4. Bivariate statistics of hydrochemical parameters.

Parameter	Ca	Mg	Na	K	HCO_3	SO_4	NO_3	Cl	EC	pH	TH	TDS
Ca	1	0.77	0.58	0.16	0.34	0.57	0.60	0.76	0.85	-0.73	0.94	0.90
Mg	0.77	1	0.53	0.43	0.09	0.50	0.38	0.80	0.85	-0.57	0.94	0.84
Na	0.58	0.53	1	0.36	-0.11	0.87	0.60	0.84	0.85	-0.28	0.59	0.78
K	0.16	0.43	0.36	1	-0.41	0.27	-0.05	0.50	0.42	-0.12	0.31	0.34
HCO_3	0.34	0.09	-0.11	-0.41	1	-0.13	0.18	-0.21	0.05	-0.12	0.22	0.29
SO_4	0.57	0.50	0.87	0.27	-0.13	1	0.67	0.78	0.78	-0.31	0.58	0.69
NO_3	0.60	0.38	0.60	-0.05	0.18	0.67	1	0.54	0.62	-0.23	0.52	0.62
Cl	0.76	0.80	0.84	0.50	-0.21	0.78	0.54	1	0.95	-0.60	0.83	0.86
EC	0.85	0.85	0.85	0.42	0.05	0.78	0.62	0.95	1	-0.59	0.90	0.95
pH	-0.73	-0.57	-0.28	-0.12	-0.12	-0.31	-0.23	-0.61	-0.59	1	-0.68	-0.61
TH	0.94	0.94	0.59	0.31	0.22	0.58	0.52	0.83	0.90	-0.68	1	0.92
TDS	0.90	0.84	0.78	0.34	0.29	0.69	0.62	.86	0.95	-0.61	0.92	1

Table 5. Final cluster Centers.

Parameter	Cluster no.		WHO (2011)
	1	2	
Ca (mg/L)	103.20	39.18	75
Mg (mg/L)	57.95	27.26	100
Na (mg/L)	164.74	89.08	200
K (mg/L)	6.31	5.43	10
HCO_3 (mg/L)	122.67	106.33	--
SO_4 (mg/L)	184.23	75.32	250
NO_3 (mg/L)	36.87	14.29	50
Cl (mg/L)	455.93	167.23	250
pH	6.77	7.33	6.5-8.5
EC (S/cm)	1829.1	861.8	--
TH (mg/L)	495.6	209.7	--
TDS (mg/L)	981.3	484.4	1000

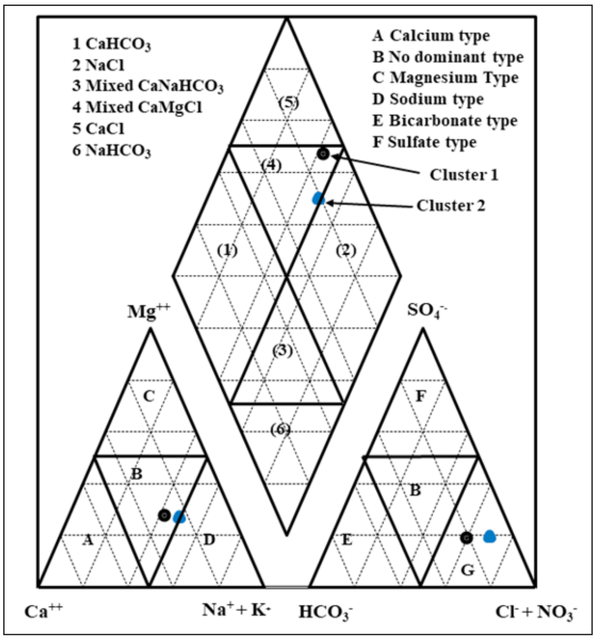

Figure 9. Piper diagram of the two clusters of the groundwater samples.

The WQI was computed following Eqs. (1) and (2). The results of WQI calculations indicated that it was in the range of 18.5 to 155.5 with an average of 50.6. Based on WQI values, the samples were categorized into three groups (Figure 10):

- Excellent: this groups comprised 26 samples, which forms about 46% of the sampled wells.
- Good: this group comprised 28 sampled wells, which forms 50% of the sampled wells.
- Poor: this group comprised only two wells, which forms 4% of the sampled wells.

The high values of WQI observed in two locations may be due to high concentrations of TDS, Cl, Ca, Na, SO_4 and NO_3. It is worth mentioning that cluster 1 members belong to the WQI classes good and poor, whereas cluster 2 involved both the WQI classes good and excellent

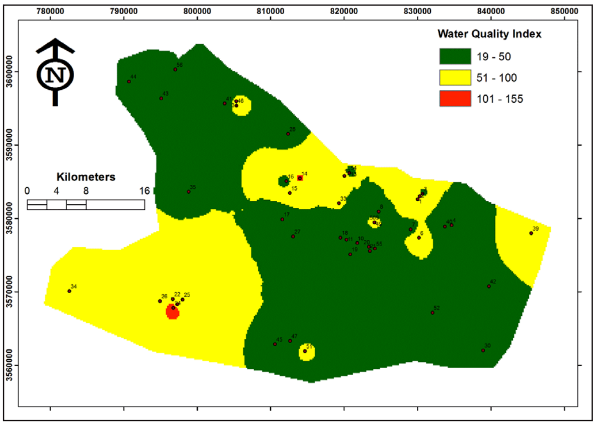

Figure 10. Spatial distribution of WQI of the groundwater samples. samples.

5. Conclusions

In arid areas, identifying the hydrogeochemical evolution of groundwater is essential for effective water resource management. So, the results of this study may form a baseline study for researches as well as relevant authorities responsible for groundwater management. Two hydrochemical facies were identified: mixed Ca-Mg-

Cl type, and Na-Cl, reflecting an interplay of complex geochemical processes in the aquifer. Gibbs diagram and CAI values revealed that the main geochemical processes influencing groundwater chemistry are rock weathering and ion exchange processes. Anthropogenic impacts on the water quality were limited. Based on WQI calculations, 96% of the sampled wells (54 wells) is of good-excellent water quality, authenticating the suitability for drinking.

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