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Assessment of Groundwater Quality in the Berrechid Aquifer, Central Morocco, Using Multivariate Statistics and Water Quality Indices

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ABSTRACT

Groundwater salinity is a serious problem for water quality in the irrigated parts of arid and semi-arid regions, especially in the aquifers of Berrechid, Morocco. This study used a variety of techniques, including the Water Quality Index (WQI) and World Health Organization (WHO) recommended limits, Principal Component Analysis (PCA), and Geographic Information System (GIS) to evaluate the quality of the groundwater for irrigation and domestic use in the Berrechid region in central Morocco. The goal of this study was to evaluate the quality of groundwater for irrigation and human consumption. The collection and analysis of twenty-two samples for ions was carried out, including, EC, Cl-, NO_3^-, NH_4^+, NO_2^-, Ca^{2+}, Mg^{2+}, pH, SO_4^{2-}, Na^+, K^+, CO_3^-, HCO_3^-, and Mn^{2+}. The Water Quality Index (WQI) was used to classify the water quality vis: excellent, good, average, poor and very poor. The research area's water quality index (WQI) ranges from 43.89 to 439.34, with around 40.90% of samples having excellent water quality, 45.45% having poor water quality, 4.54% showing extremely bad water quality, and 9.09% having unsuitable quality for human consumption. The principal component analysis reveals that the average concentration of cations in groundwater was $Na^+ > Mg^{2+} > Ca^{2+} > K^+ > Mn^{2+} > NH_4^+$, whereas the concentration of anions was $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > NO_2^- > CO_3^{2-}$. The correlation matrix was created and analyzed to determine its significance in groundwater quality assessment. The primary sources of pollution are household waste, exposed septic tanks, landfill leachate, and excessive fertilizer usage in agriculture and industrial operations. The current analysis demonstrates that the deteriorating groundwater quality in the region needs pre-consumption treatment and contamination risk prevention.

Keywords: Berrechid Aquifer, GIS, IDW, PCA, WQI.

INTRODUCTION

Groundwater resources are essential natural resources that support the nation's socioeconomic development (Flörke et al., 2018). It is a significant water source for consumption, agriculture, industry, households, and the environment (Wu et al., 2017), particularly in dry and semi-arid areas where surface water and rainfall are sparse. In the world, about 65% of groundwater is used for human consumption, 20% for irrigation, and 15% for industrial uses (Adimalla & Venkatayogi, 2018; Salehi et al., 2018). In terms of consumption, agriculture is the world's largest consumer of groundwater (Siebert et al., 2010). Irrigated crops account for 60–80% of global water use and about 38% of food production (Shahinasi & Kashuta, 2008). To prevent agricultural losses, more than 2.7 million tons of pesticides are used every year (Naamane et al., 2020). This poses a significant threat to economic growth, as well as citizen health. This is caused by natural and anthropogenic activities including hydrogeology, topography, geological structures, evaporation, rainfall, rock-water interactions, elevation, industrial wastewater, agriculture, and chemical fertilizers that have a long- or short-term impact on groundwater quality (Bhattacharya & Bundschuh, 2015; Li et al., 2017; Alabjah et al., 2018; Mountadar et al., 2018; Houéménou et al., 2020; Wu et al., 2020; Moukhliss et al., 2021). These problems cause the chemical nature of water to deteriorate, rendering it unsuitable for irrigation and consumption. Therefore, the studies on water quality assessment and prediction are essential to promote rational use of water resources, environmental protection, as well as reduction of human health risks (Wu & Sun, 2016; Adimalla, 2019).

Within Morocco's Berrechid area, groundwater is the only water supply for drinking, households, agriculture, and industry. Berrechid had a population of only 712 people at the beginning of the twentieth century. However, in 2014, that number had risen to 484 518. Furthermore, this region contains many industrial sites the emissions of which contribute significantly to groundwater contamination (El Ghali et al., 2020). The existing factories operate in different sectors (textiles, surface processing, battery production, nickel plating, agriculture machinery painting, aluminum sheet painting, municipal abattoirs and tanneries). This aquifer is subjected to extreme pressures to meet domestic, industrial, and agricultural water needs, resulting in water quality degradation due to natural and human activity.

In the areas where groundwater meets the most agricultural need for water and the long-term use of these resources in irrigation, periodic water quality monitoring is critical. However, analyzing the many elements of water quality is expensive and time-consuming (Mustapha & Aris, 2012; Kazakis et al., 2017) . As a result, more effective and quicker procedures have emerged in the scientific literature. The Water Quality Index (WQI) is the most successful tool for evaluating the drinking water quality in rural, urban and industrial areas. (Horton, 1965) and (Brown et al., 1970) developed the WQI based on an arithmetic calculation to compare the quality of watercourses. The WQI is a number without dimension with values between 0 and 100. Additionally, a number of multivariable statistical techniques that involved identifying the sources of pollution and associated regressors were utilized to evaluate the quality of the water (Zhang et al., 2017; Gulgundi & Shetty, 2018). These multivariate statistical approaches included cluster analysis (CA), factor analysis (FA), principal component analysis (PCA), and multivariate linear regression (MLR). PCA is the most commonly applied multivariate statistical tool for identifying relevant characteristics and potential sources of contamination in datasets on groundwater by extracting the primary components (Bencer et al., 2016; Bhutiani et al., 2016; Kumar et al., 2016; Ravikumar & Somashekar, 2017; Ayed et al., 2017; Samson & Elangovan, 2017; Taoufik et al., 2017; Shafiullah & Al-Ruwaih, 2020). The goal of the study is to use a GIS interpolation technique and a statistical approach to the study region to determine groundwater's WQI in order to identify if it is suitable for human consumption and irrigation, and to compare the results to World Health Organization standards (WHO, 2017). The results of this study will aid decision-makers in developing effective management strategies for preserving contaminated groundwater by identifying pollution sources and better understanding the changes in groundwater quality over the last decade.

STUDY AREA

The Berrechid aquifer is situated in the watershed of the Atlantic coast, between Rabat and Azemmour, with a surface area of around 10,470 km^2 (Royaume du Maroc, 2003). The aquifer is a part of a quadrilateral formed by Settat, El Gara, Mediouana, and the center of Bouskoura. This area is classified as semi-arid and receives between 280 and 320 mm of precipitation annually, with more than 90% of that falling between October and April, the temperature ranges from 6.5°C in January to 38°C in August. The basin is endoreic; it is naturally fed by rainfall and streams that enter from the south and disappear under the plain (Moullard, 1960). This watershed has a flat topography, with elevations and slopes varying from 140 m and 0.2% in the north to 350 m and 0.8% in the south (El Assaoui et al., 2015).

MATERIALS AND METHODS

Water sampling

Twenty-two samples were collected for this study in two sessions in spring and summer (Figure 1), the depth of the wells ranged from approximately 40 to 140 meters.

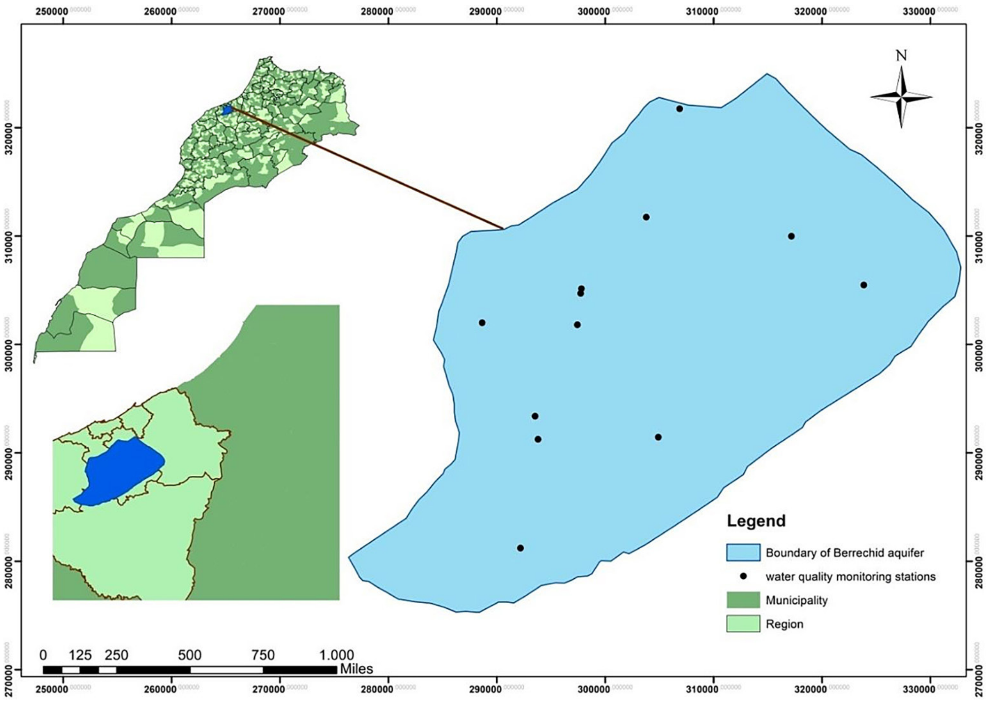

Figure 1. Study area and sampling stations

For sample collection, the authors utilized one-liter polyethylene bottles that had been prewashed and labeled. The following parameters were measured in these samples: Electrical Conductivity (EC), Chlorides (Cl^-), Nitrates (NO_3^-), Ammonium (NH_4^+), Nitrites (NO_2^-), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), pH, Sulfate (SO_4^{2-}), Sodium (Na^+), Potassium (K^+), Carbonates (CO_3^-), Bicarbonates (HCO_3^-), and Manganese (Mn^{2+}). The location coordinates (X, Y coordinates) of collecting points were measured with a portable global positioning system (GPS). The samples were sent to the laboratory for analysis. Conductivity was measured with a YK-2001PH intelligent conductivity meter according to EN ISO 78-90 January 1997 (T 90-045), and nitrate was determined by the spectrometric method in the presence of sulfosalicylic acid. Determination of ammoniacal NH_4^+ was performed by the spectrophotometric method with indophenol blue, according to AFNOR NF T 90-015 January 1997. Identification of chloride was achieved by the MOHR method, according to AFNOR 90-014. Determination of bicarbonate and carbonate was carried out by titration in the presence of H_2SO_4 (0.02 N), a solution of NaOH (0.1 N), phenolphthalein, and methyl orange indicator. Sulfate determination was performed using the spectrophotometric method (shimadzu UV 1800 model). Potassium was determined by a flame photometer (Elico model CL 22 B flame photometer) and KCl reagents. Sodium was assayed by a flame photometer (Elico model CL 22 B flame photometer). Calcium was determined by EDTA titrimetric analysis. Magnesium dosage was carried out by concentration in TH and Ca. The hydrogen potential (pH) of the solutions was determined by an "Accumet Basic AB15" pH meter. The dosage of manganese was carried out by hydrochloric acid and manganese powder added with demineralized water. The dosage of nitrite was determined by the action of nitrite (NO_2^-) on sulfanilamide in an acid medium and the formation of a diazonium salt, and the reaction of the diazonium salt on N(1Naphthyl) ethylenediamine (NED) in a hydrochloric medium (pH <2). The final compound was pink and could give rise to a colorimetric determination.

For spatial analysis of water quality data, ArcGIS software version 10.2.2 was used. This allowed interpolating the groundwater quality parameters and various water quality indices to be calculated over the study area using Inverse Distance Weighted (IDW) spatial interpolation method.

STATISTICAL ANALYSIS

Multivariate statistical analyses, by including correlation matrix analysis (CMA) and principal component analysis (PCA), were executed with IBM SPSS Statistics 23 software. The correlation coefficient (*r*), which varies from -1 to 1, was used to measure the degree of dependence between two factors; if the *r* value is close to 0, there is no correlation between the variables. The correlation coefficient is written as:

$$r = \frac{\sum_{i=1}^{n}(Xi - \overline{X})(Yi - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(Xi - \overline{X})^2}\sqrt{\sum_{i=1}^{n}(Yi - \overline{Y})^2}} \quad (1)$$

where: *X* and *Y* – represent the means of *X* and *Y*, respectively, and represent the total number of variables.

Calculation of WQI – the relative weight (W_i) is then determined by equation:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (2)$$

where: W_i – represents relative weight, wi is the weight of each physicochemical parameter, *n* – indicates the number of parameters considered.

Then, for each parameter, a quality rating (q_i) is assigned by dividing its concentration in each water sample by the WHO (2017) limit values and multiplying the result

$$q_i = \frac{C_i}{S_i} \times 100 \quad (3)$$

where: q_i – represents the quality rating, C_i – represents concentration of each chemical parameter (mg/l), and S_i represents the WHO (2017) standard for each chemical parameter.

To calculate WQI, firstly the SI_i value should be determined with the following equation:

$$SI_i = W_i \times q_i \quad (4)$$

Finally, the WQI is calculated using the sub-index (SI_i),

$$WQI = \sum_{i=0}^{n} SI_i \quad (5)$$

RESULTS AND DISCUSSIONS

Physicochemical assessment of groundwater

Table 1 presents the results of the physicochemical analysis using World Health Organization standards (WHO, 2017).

Hydrogen ion concentration (pH)

In water chemistry, pH (hydrogen potential) is one of the essential parameters. It provides a primary role in acid and base neutralization, precipitation, and water softening. The pH of water is generally influenced by the watershed geology and the buffering capacity of water. The values attained range from 7 to 8.2 with an average of 7.56, indicating the pH of the sampled water was neutral (Figure 3a, Figure 4a); the recommended pH range for human consumption is 6.5–8.5 (Table 2).

Electrical conductivity (EC)

The electrical conductivity of water (EC) ranged from 910 to 7100 µS/cm, with 4250 µS/cm (Figure 3a, Figure 4a), which exceeds the limits recommended by (WHO, 2017) (Table 2). Indeed, the circulation of groundwater in aquifer voids increases the concentration of chemical elements and can be considered poor quality for human consumption. The main origin of this mineralization is due to the high concentration of cations and anions, probably caused by the drainage of saline Triassic soils rich in gypsum on the one hand; on the other hand, depending on human activity and various urban and industrial discharges, organic matter degrades in the same compartment and in the vicinity of wells. Similar results have been obtained in previous studies on the Doukkala, Haouz and Chaouia aquifers (Najib et al., 2016; Jamaa et al., 2020; Kamal et al., 2021).

Chloride (Cl^-)

The chlorine content of water ranges from 183 to 2409 mg/l, with a mean of 1266 mg/l (Figure 3a, Figure 4a), which exceeds the recommended limits (250 mg/l) (Table 2). The chloride peak in groundwater is caused by land geology (gypsum and clay leaching), agricultural pollution (pesticides), household and industrial wastes, and percolation in saline lands, then penetration of irrigation water (Kholtei, 2002); (Kholtei, 2003). Additionally, numerous studies show that chlorides have been described as a conservative element in groundwater because they do not participate in chemical processes like ion exchange or produce insoluble precipitates (Najib et al., 2016).

Nitrite (NO_2^-)

Nitrite concentrations varied from 0.014 to 1.18 mg/l, with a mean of 0.095 mg/l (Figure 3b,

Table 1. Major cations and anions of the groundwater samples

Date	IRE	Ca^{2+}	Mg^{2+}	pH	CE	Cl^-	NO_3^-	NH_4^+	SO_4^{2-}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Mn^{2+}	NO_2^-
16/03/2018	102/27	182	164	7.65	3970	1120	46.8	<0.021	171	507	3.56	0	299	<0.1	0.054
07/03/2018	3942/20	100	102	7.8	3300	1024	17.5	<0.020	134	512	2.83	0	195	<0.1	0.22
20/02/2018	5168/20	235	244	7.6	5760	1833	85.2	0.057	175	756	2.7	0	336	<0.1	0.036
28/02/2018	5169/20	144	134	7.7	4200	1385	65.4	<0.020	166	741	4.98	0	220	<0.1	0.038
16/03/2018	671/20	234	186	7.05	5700	1394	135	<0.021	163	732	0.448	0	549	<0.1	0.021
17/03/2018	R-1951/27	190	149	7.1	3310	818	69	<0.021	95	362	2.36	0	348	<0.1	0.025
16/03/2018	R-2845/20	156	131	8.05	3780	1043	37.8	<0.021	150	553	3.3	0	354	<0.1	0.04
17/03/2018	R-3100/27	180	180	7.5	4140	1150	23.9	<0.021	150	553	3.3	0	354	<0.1	0.04
16/03/2018	R-565/20	224	237	8.2	6570	2043	71.4	<0.021	256	970	2.32	0	287	<0.1	0.045
07/03/2018	R-804/28	136	101	8.05	2090	595	29	<0.020	62.9	201	2.29	0	268	<0.1	0.015
16/03/2018	R-907/20	172	168	7.3	3870	1021	76.7	<0.021	137	490	1.9	0	342	<0.1	0.037
16/08/2018	102/27	186	166	7.7	3840	1177	44.9	0.041	176	475	3.04	0	336	<0.1	0.05
20/07/2018	5168/20	204	238	7.3	5520	1695	93.5	<0.020	156	597	2.16	0	284	<0.1	0.014
10/08/2018	5169/20	112	95	7	4470	1182	37.8	<0.020	137	698	5.5	0	214	<0.1	0.11
16/08/2018	R-1951/27	164	148	7.1	3330	956	78.5	0.021	104	360	2.48	0	354	<0.1	<0.015
17/08/2018	R-2845/20	160	134	7.05	3600	1124	22.6	<0.020	156	505	305	0	366	<0.1	<0.015
16/08/2018	R-3100/27	164	175	7.3	4110	1262	23.4	0.057	229	533	2.45	0	229	<0.1	0.018
28/08/2018	R-565/20	246	267	7.25	6670	2250	74.2	<0.020	296	1004	0.402	0	329	<0.1	<0.015
31/08/2018	R-671/20	398	274	7.6	7100	2409	190	0.046	89	945	1.11	0	183	<0.1	1.18
18/08/2018	R-804/28	62.1	52.2	8.05	910	183	<5	0.026	116	77	5.13	0	171	<0.1	<0.015
31/08/2018	R-907/20	170	163	7.85	3970	1124	80.8	0.021	128	523	2.78	0	354	<0.1	0.106
17/08/2018	R-3942/20	94.2	113	8.05	3290	1065	21.8	<0.020	140	501	<0.1	0	195	<0.1	<0.015

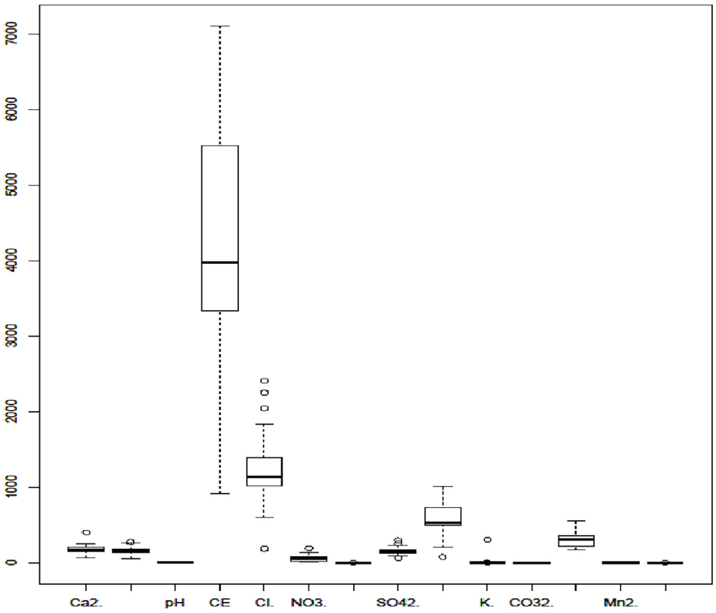

Figure 2. Box plots of minimum, maximum and average for the physico-chemical data

Figure 4a). The average of these values is within WHO standards (≤ 0.1 mg/l) (Table 2). In the obtained results, the nitrite content is low. As a result, it can be said that the studied boreholes are free of recent seepage water contamination.

Nitrate (NO_3^-)

NO_3^- concentrations ranged from 5 to 190 mg/l, with an average of 60.46 mg/l (Figure 3a, Figure 4a), compared by global health standards

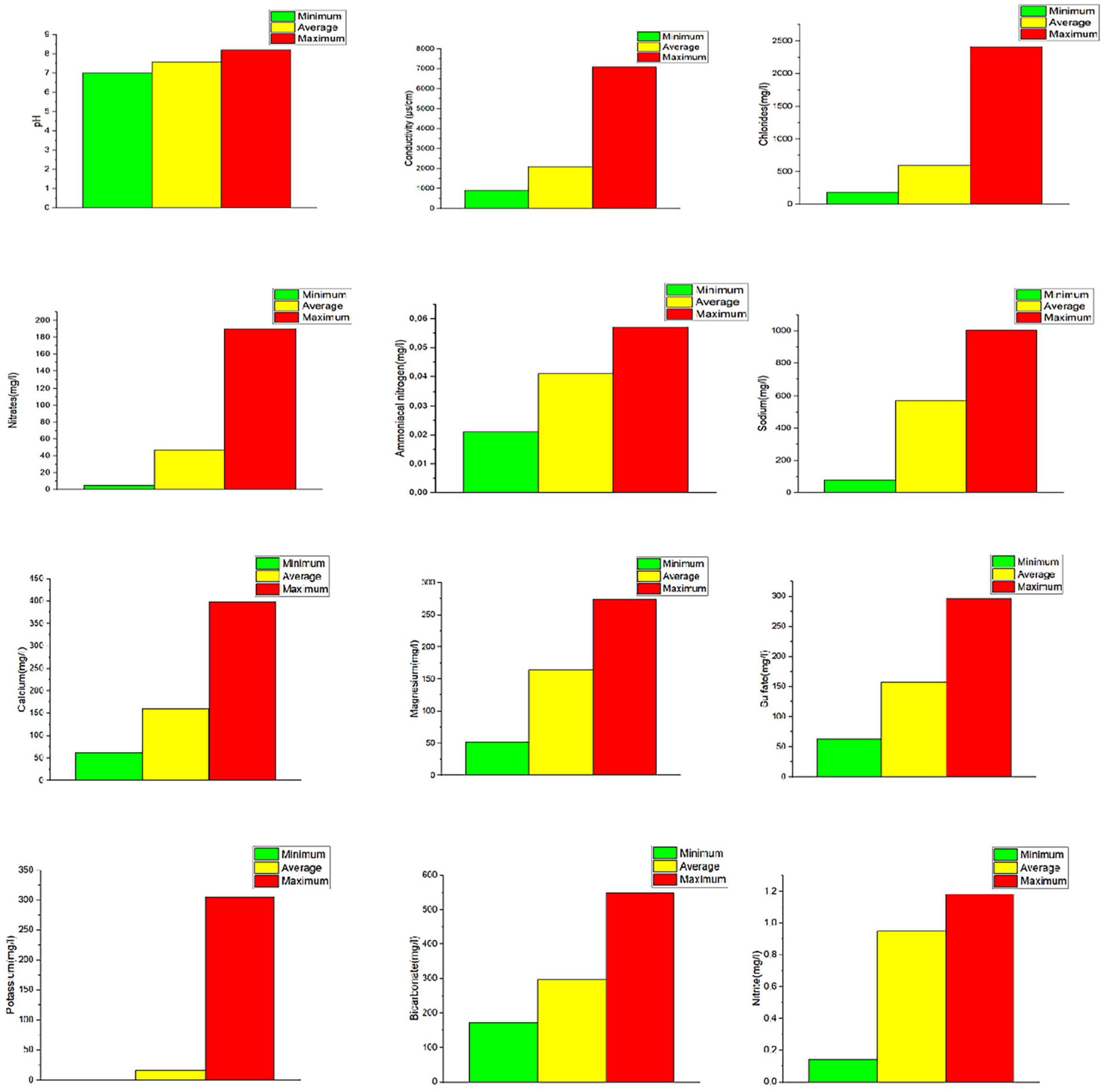

Figure 3. Physical-chemical parameters

(WHO, 2017) (Table 2). This increase was due to anthropogenic activities such as fertilizers or wastewater tanks, soil organic matter by mineralization and organic additions such as manure and other waste all contribute to nitrate pollution.

Ammonium (NH_4^+)

The variation in ammonia nitrogen ranged from 0.02 to 0.057 mg/l, with an average of 0.026 mg/l (Figure 3a, Figure 4a), consistent with WHO standards (≤ 0.1 mg/l) (Table 2). This indicates that ammonia nitrogen was oxidized to (NO_3^-).

Sodium (Na^+)

The sodium values range from 77 to 1004 mg/l with a mean of 572.5 mg/l (Figure 3a, Figure 4b) that surpasses the limits recommended by WHO standards (≤ 200 mg/l) (Table 2); this is related to the geology of the land.

Calcium (Ca^{2+})

The element calcium (Ca^{2+}) ranging between 62.1 and 398 mg/l with a mean of 159.79 mg/l (Figure 3b, Figure 4b), which exceeds the limits recommended by (WHO, 2017) (Table 2), These high Ca^{2+} values are due to intense agricultural activity, surface seepage pollution, and the geology of the area.

Magnesium (Mg^{2+})

Magnesium concentrations range from 52.5 to 274 mg/l on average of 164.6 mg/l (Figure 3b, Figure 4b), which is high when compared to global norms (WHO, 2017) (Table 2). The high concentration of

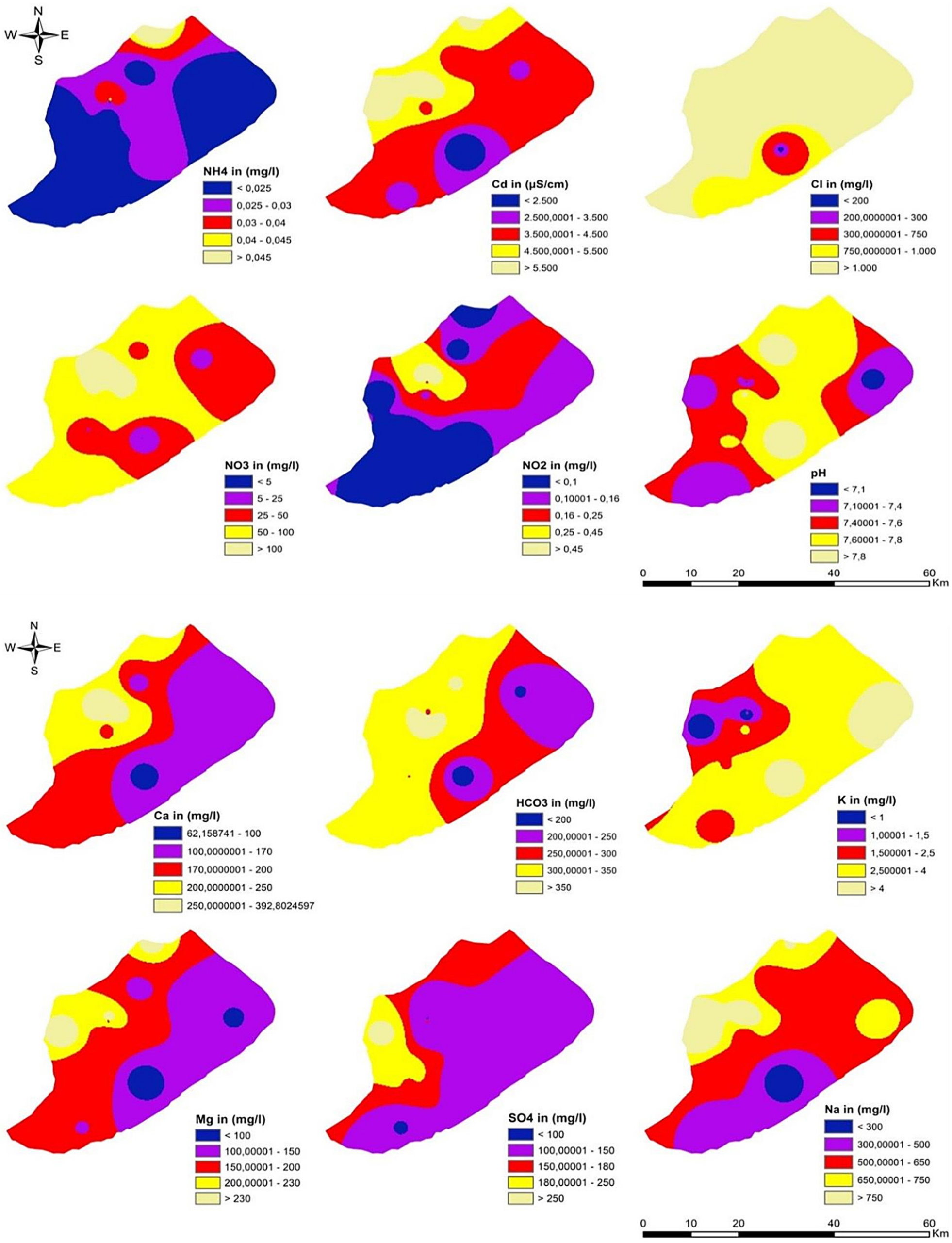

Figure 4. Groundwater quality maps

this element results from the dissolution of carbonate deposits rich in magnesium (Dolomites). In fact, there are three potential sources for magnesium:

- the alteration of ferromagnesian minerals,
- the dissolution of the dolomites,
- the phenomenon of magnesium-aluminum substitution between the magnesium released from TALC (a magnesium silicate) and the released aluminum released by the weathered rocks.

Sulfate (SO_4^{2-})

Sulfate varies from 62.9 to 296 mg/l with an average of 157.27 (Figure 3b, Figure 4b), which is high when compared to global standards (WHO, 2017) (Table 2), this mineralization due to dissolution of mineral salts.

Potassium (K^+)

Potassium ions play a minor role in water mineralization, it is present in trace amounts with variations between 0.1 and 305 mg/l and an average of 16.32 mg/l (Figure 3b, Figure 4b), which exceeds the limits recommended by the WHO (2017) (Table 2). This high mineralization may be due to the dissolution of KCl in fertilizers.

Table 2. Statistical variables and extreme values

Variables	Units	WHO (2017)	Minimum	Maximum	Mean	Ecart type
Ca^{2+}	mg/L	75	62.1	398	159.79	132,6
Mg^{2+}	mg/L	50	52.5	274	164.6	93,5
pH	-	6,5–8,5	7	8.2	7.56	27,8
CE	µS/cm	750	910	7100	4250	2309,8
Cl^-	mg/L	250	183	2409	1266	842,2
NO_3^-	mg/L	50	5	190	60.46	107,1
NH_4^+	mg/L	≤0.1	0.02	0.057	0.026	4,5
SO_4^{2-}	mg/L	250	62.9	296	157.27	133,9
Na^+	mg/L	200	77	1004	572.5	361,8
K^+	mg/L	100	0.1	305	16.32	57,8
CO_3^{2-}	mg/L	-	0	0	0	0,7
HCO_3^-	mg/L	200	171	549	298.22	240,9
Mn^{2+}	mg/L	0.3	0.1	0.2	0.15	1,5
NO_2^-	mg/L	≤0.1	0.014	1.18	0.095	4,6

Bicarbonate (HCO_3^-)

Bicarbonate is the predominant anion in groundwater, ranging between 171 and 549 mg/l with an average of 298.22 mg/l (Figure 3b, Figure 4b). It is produced when carbon dioxide reacts with water on carbonate rocks like limestone and dolomite. The presence of bicarbonate in the groundwater is caused by carbon dioxide in the soil reacting with rock-forming minerals, resulting in an alkaline environment.

Manganese (Mn^{2+})

It can be found in groundwater, particularly in anaerobic environments. The Mn concentrations in groundwater are influenced by rainfall chemistry, aquifer lithology, geochemical environment, groundwater flow routes and residence period, among others, which can vary significantly over time and location. In addition, it can be released into groundwater by leaching overlying soils and minerals from underlying rocks and the aquifer itself. Manganese concentrations ranged between 0.1 and 0.2 mg/l, with an average of 0.15 mg/l, well below the permitted limit (0.3 mg/l). The boxplot of the variables (Figure 2) shows the evolution of the different variables, focusing mainly

Table 3. WQI classification ranges and rating class (Brown et al., 1972; Chatterjee & Raziuddin, 2002)

WQI	Rating class
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
>100	Unsuitable

Table 4. WQI classification of groundwater in the study area

IRE	WQI	Rating class
102/27	58,5995428	Poor water
3942/20	112,945055	Unsuitable drinking purposes
5168/20	64,7836409	Poor water
5169/20	53,0287999	Poor water
671/20	47,6984411	Good water
R-1951/27	48,8231953	Good water
R-2845/20	54,0012731	Poor water
R-3100/27	53,9269524	Poor water
R-565/20	56,0151703	Poor water
R-804/28	45,2517061	Good water
R-907/20	52,8854066	Poor water
102/27	63,8907914	Poor water
5168/20	45,1608647	Good water
5169/20	43,8918151	Good water
R-1951/27	45,5304664	Good water
R-2845/20	52,0627703	Poor water
R-3100/27	58,472172	Poor water
R-565/20	45,5618297	Good water
R-671/20	439,347672	Unsuitable drinking purposes
R-804/28	47,1137373	Good water
R-907/20	75,8477069	Very poor water
R-3942/20	45,2487914	Good water

on the first quartile, third quartile, etc. According to the boxplot obtained, 25% of the conductivities are between 0 and less than 2000. On the other hand, the other values exceed 2000, while the other variables do not exceed 2000 and take the lowest values.

Water quality index (WQI)

The WQI was computed to determine the current state of groundwater for drinking in the research area. According to the WQI study, 40.90% of samples have a good water quality (WQI between 26 and 50), 45.5% have poor quality water (WQI between 51–75), 4.54% have water of very poor quality, and 9.09% have a quality unfit for human consumption (Figure 2, Figure 5a, Table 3, Table 4). For this publication, a score of 100 is the highest WQI appropriate for human consumption (drinking). Groundwater quality will be examined based on the WQI values, as given in Table 3.

The results suggest that about 40.90% of the water samples are probably suitable for human consumption. In contrast, about 59.08% of the samples are not suitable. As discussed earlier, the demand for groundwater resources will increase with time. Therefore, more precautions must be taken to minimize the rate of groundwater contamination, which could have significant effects in the future, as shown in Table 4.

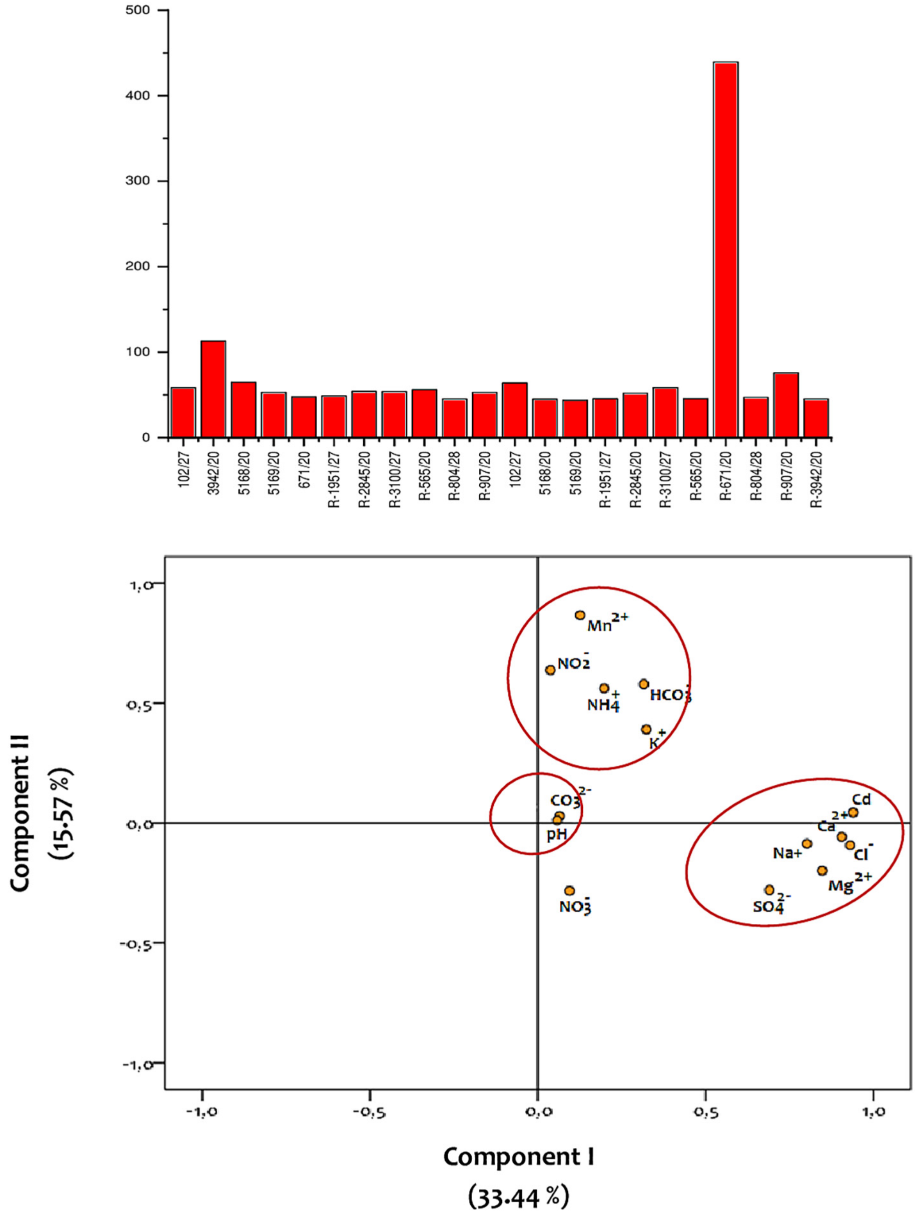

Figure 5. (a) WQI index value in the study area, (b) projection of the variables in the space of the axes F1 and F2

STATISTICAL ANALYSIS

In order to better interpret the obtained results related to physicochemical parameters, a statistical study was conducted through a multivariate analysis method: principal component analysis (PCA) was performed using IBM SPSS Statistics 23 software. The objective of PCA is to convert correlated quantitative data into new uncorrelated quantitative variables called principal components (Mounjid et al., 2014). The variation reflected by the F1 and F2 factorial axes is large enough to examine the overall behavior of the observations (49.01%) (Figure 5b). The numerical results of this PCA show that the first component, which accumulates 33.44% of the total inertia, is essentially defined according to Table 5 in its positive part by CE (0.940), Ca^{2+}(0.802), Cl^- (0.931), Na^+(0.905), Mg^{2+}(0.847), SO_4^{2-} (0.690). This category represents the mineralization associated with anthropogenic activity (agricultural, domestic) and water-rock interaction. These factors influence the alteration of silicate and calcimagnesian rocks and ion exchange processes. Analysis of this mineralization axis reveals a relatively low affinity between pH and CO_3^{2-} and NO_3^- ions. The second component represents 15.57% of the total inertia (Figure.7). Indeed, Table 6 shows that this component is defined in its positive part by Mn^{2+} (0.866), NO_2^- (0.637), NH_4^+ (0.591), HCO_3^- (0.579), K^+ (0.390). This suggests that the alteration of potassium-rich rocks, including feldspar, calcite and dolomite, is the main cause. In addition, the area is fertilized with readily soluble fertilizers comprising 15.5% nitrogen and 18% calcium. The use of fertilizers accelerates plant growth initially, but the fertilizer residues are later completely dissolved, contaminating the groundwater.

Table 5. Correlations between variables and main axes

Compound	F1	F2
HCO_3^-	0.316	0.579
Ca^{2+}	0.802	-0.086
Mg^{2+}	0.847	-0.199
CE	0.940	0.044
pH	0.065	0.029
SO_4^{2-}	0.690	-0.280
Na^+	0.905	-0.058
Cl^-	0.931	-0.093
K^+	0.323	0.390
CO_3^{2-}	0.058	0.011
NH_4^+	0.198	0.561
Mn^{2+}	0.126	0.866
NO_2^-	0.037	0.637
NO_3^-	0.094	-0.283

The correlation coefficient is a popular tool for determining and measuring the link of two variables. It is a simple statistical method for determining the degree to which one variable is dependent on another. The examination of the fourteen-variable correlation matrix (Table 6) demonstrates that conductivity is substantially linked with Mg^{2+}, Na^+, and Cl^-. Similarly, there is a substantial link between Mg^{2+} and Cl^-, as well as Mg^{2+} and NO_2^-.On the other hand, a weak

Table 6. Matrix of inter-elemental correlations

Compound	HCO_3^-	Ca^{2+}	Mg^{2+}	Cd	pH	SO_4^{2-}	Na^+	Cl^-	K^+	CO_3^{2-}	NH_4^+	Mn^{2+}	NO_2^-	NO_3^-
HCO_3^-	1													
Ca^{2+}	0.191	1												
Mg^{2+}	0.071	0.689	1											
Cd	0.278	0.657	0.748	1										
pH	-0.019	0.147	0.064	-0.004	1									
SO_4^{2-}	0.003	0.555	0.566	0.596	-0.056	1								
Na^+	0.262	0.583	0.753	0.876	0	0.588	1							
Cl^-	0.172	0.682	0.785	0.924	0.036	0.563	0.863	1						
K^+	0.574	0.142	0.083	0.265	0.239	0.025	0.281	0.274	1					
CO_3^{2-}	-0.019	-0.027	0.015	0.023	-0.004	0.087	0.022	0.089	0.156	1				
NH_4^+	0.442	0.239	0.04	0.147	-0.008	-0.037	0.094	0.1	0.08	-0.008	1			
Mn^{2+}	0.268	0.09	-0.009	0.174	-0.006	-0.072	0.026	0.03	0.123	-0.008	0.438	1		
NO_2^-	-0.023	-0.03	-0.025	0.122	-0.003	-0.024	-0.001	-0.013	0.015	-0.004	-0.001	0.836	1	
NO_3^-	-0.159	0.367	0.028	0.054	0.082	0.078	-0.008	0.038	-0.083	-0.039	-0.082	-0.082	-0.053	1

correlation is registered between Ca^{2+} and Na^{+}, between HCO_3^- and K^+, between SO_4^{2-} and Na^+ as well as between SO_4^{2-} and Cl^-.

CONCLUSIONS

Water Quality Index (WQI), Principal Component Analysis (PCA), and Geographic Information System (GIS) were used to assess groundwater quality for domestic and irrigation purposes. The water quality status indicates 45.45% of samples have an acceptable water quality, 45.45% have poor water quality, 4.54% have extremely poor water quality, and 9.09% have the water that is unsuitable for human consumption. The sources of contamination as well as the key factors to groundwater pollution have been discussed. The primary sources of contamination were agricultural activities, household wastewater, and industrial effluent, which resulted in increasing NO_3^-, NO_2^-, and NH_4^+ concentrations in groundwater. Intensive fertilizer application along with agricultural development was the primary cause of elevated NO_3^- concentrations, resulting in record high agricultural pollution distributions in 2018. Reduced nitrogen leaching to groundwater requires effective nutrient management strategies, such as optimizing fertilizer application.

The parameters primarily responsible for poor water quality for drinking in the research region include anions (Cl^-, NO_3^-, and HCO_3^-) and cations (Mg^{2+}, Na^+, Ca^{2+}). Several groundwater samples in the research area are not suitable for irrigation due to their high salinity. In this case, the following recommendations are required to manage the zone water quality. Agricultural runoff should be minimized by farmers as much as possible. The government should start raising awareness about the dangers of excessive fertilizer used. Anthropogenic activities should be regulated by the government, managed, and maintained, and water supplies should be transported to avoid contamination.

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