



Groundwater quality in Zagora southeast of Morocco by using physicochemical analysis and geospatial techniques

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Abstract Groundwater in Morocco is restricted because of the semiarid to arid climatic conditions; it is under threat from organic and inorganic pollution. Furthermore, it is considered the only source of potable water as well as having different usages, making its quantitative and qualitative protection an urgent priority. The present study focused mainly on the anthropogenic impact on the natural resources and groundwater quality around Zagora city. Fifteen samples were collected from wells during rainy and dry seasons in 2 years 2020–2021 and the analysis of the groundwater

quality of studied stations. The suitability of the aquifer Fezouata was investigated using drinking and irrigation water quality indices. The results showed that sulfate and chloride are the dominant anions in the groundwater samples. While the mean abundance of major cations is $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$, the sodium ion is dominant and K^+ is the least abundant. The physicochemical parameters show that conductivity, nitrate, and sulfate exceed the limit fixed by WHO. Hydrogeochemical plots indicate that 93% of samples belong to Na-Cl facies and only 7% are mixt Cl-Mg-Ca in

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2021, the results are similar except for two samples which are 13% belong Cl-Mg-Ca. The Water Quality Index suggests that 28.55% are good quality water, 23.90–47.55% are poor and very poor quality water, respectively, and 40.24% are unsuitable in 2020. Furthermore, the WQI of the 2021 campaign showed that only 17.48% were considered good quality water and 38.94% (43.58%) were poor or very poor quality water, respectively. However, 33.21% are unsuitable. Based on irrigation indices, the majority of groundwater samples can be used for agricultural purposes, notably those of the upstream part of the study area.

Keywords Groundwater quality · Physicochemical parameters · WQI · Drinking water · Irrigation · Zagora

Introduction

Groundwater resources correspond to one of the most vital materials in the world and represent 97% of all liquid sweet water on a global scale (L'Vovich, 1974). It is an essential resource for diverse uses, especially for drinking, irrigation, and domestic purposes. It is critical to preserving natural balance, assuring access to water for human life, and fostering sustainable economic development (Liu et al., 2020; Gao et al., 2020; Rao et al., 2022a). Compared with surface water, groundwater provides several benefits, including good microbiological quality stability, less turbidity, widespread distribution, simplicity of use, and less vulnerability to contamination (Subba Rao, 2021). Furthermore, groundwater buffers change rainfall rates over time, effectively maintaining fluvial flows during dry and evaporative periods in surface water table areas.

In aquifers, the quality of recharged water depends on atmospheric precipitation, inland surface water, and subsurface geochemical processes that all affect groundwater quality. However, many papers recently have shown that a lot of diseases, such as dysentery, polio, cholera, typhoid, and diarrhea, are the result of the consumption of contaminated drinking water

(Egbueri, 2018; Li & Wu, 2019; Mgbenu & Egbueri, 2019; Rao et al., 2022b).

Morocco is now one of the nation's most vulnerable to the negative effects of climate change and water shortages (Dahan, 2017). Irrigation is responsible for the utilization of 90% of water; as a consequence, water resource management is a principal variable for the present and future of Morocco against climate change. Hence, the demand for groundwater is increasing in response to factors such as increased surface irrigation using groundwater pumping, urbanization, pollution, and climate change at a particular level of evaporation. Therefore, the development of groundwater resources in the last 50 years has increased; more than 2 billion people in the world depend on groundwater to drink (Murali & Elangovan, 2013). A succession of droughts occurred in this area. Indeed, the number of wells throughout the Draa Basin was estimated at only 205 in 1965 and has increased from 4200 in 1977 with the use of motor pumps to 10,000 in 2011 (Karmaoui et al., 2016).

In arid and semi-arid regions such as the city of Zagora, water is a commodity that is becoming more and scarcer, and people living there are hit by severe shortages. Surface water is scarcer. Indeed, since the construction of the Mansour Eddahbi dam in 1972, the natural environment of Drâa has changed absolutely. Subsequently, in the Drâa oases, particularly that of Fezouata (Fig. 1), groundwater salinization has become a limiting factor for cultivated development and long-term sustainability. Groundwater contaminations have a huge effect on the environment and create a risk to human health (Pattnaik & Reddy, 2010; Karmakar et al., 2021; Unigwe et al., 2022; Gugulothu et al., 2022). Nevertheless, the anthropogenic effects are originating from various anthropogenic sources such as fertilizer and industrial wastewater, and additionally the leaked sewage. Besides, natural causes are related to the nature of the soil, geochemical processes and seawater intrusion, temperature, weathering, precipitation, etc. (Chung et al., 2012; Tayfur et al., 2008; Shim et al., 2002).

Geographic Information Systems (GIS) provide a method of interpolation and are used to assess pollution levels and monitor groundwater properties to prepare spatial fluctuation maps (Egbueri et al., 2021; Ouzerbane et al., 2022; Thirumurthy et al., 2022; Ramirez et al., 2023; Bahrami & Zarei, 2023). In addition, the spatial analysis extension of GIS plays

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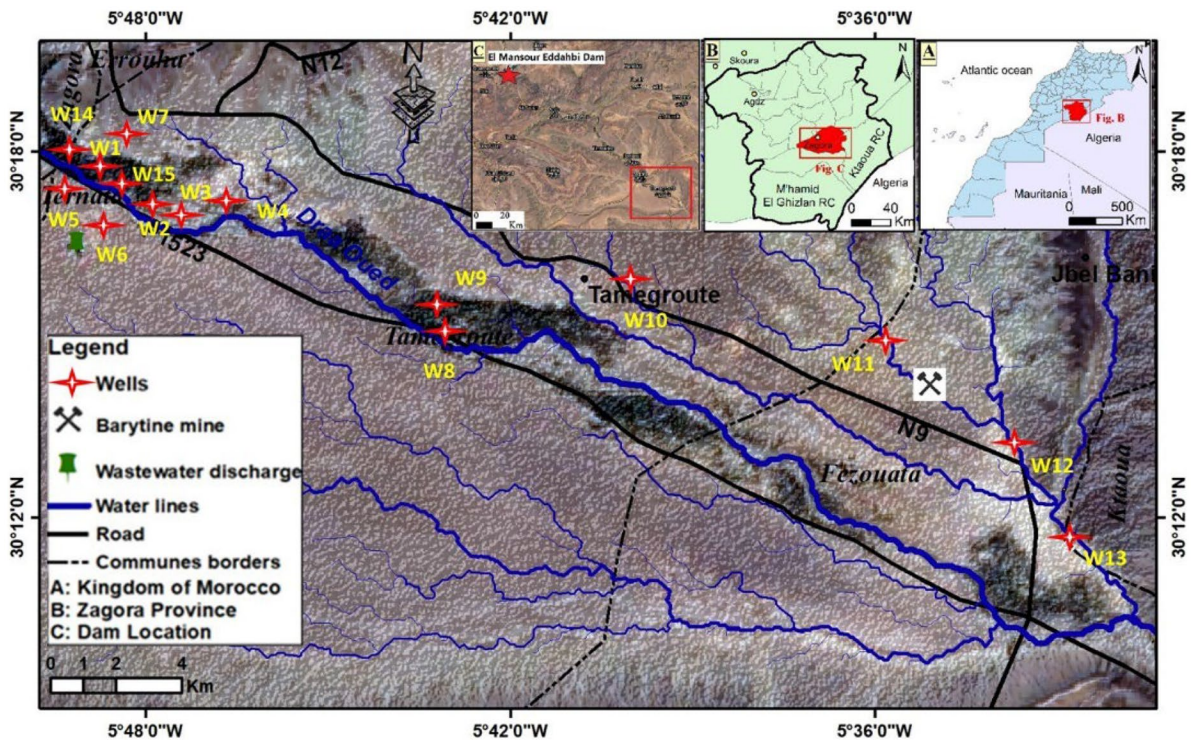


Fig. 1 Study area (w = wells)

an important part in mapping the suitability associated with WQI and can be predicted groundwater quality (Dawood et al., 2022) and identify changes (Jumaah et al., 2021, 2022; Moumane et al., 2021) generating models (Rabeyi et al., 2018; Karmaoui et al., 2022; El Moustaine et al., 2021; Egbueri & Agbasi, 2022a, b; Habbeb et al., 2022; Egbueri, 2022; Egbueri et al., 2022).

The water quality index (WQI) is considered to be a mathematical tool to significantly reduce water quality data based on some physicochemical parameters and provide a single classification value that describes the water quality status of water bodies or the degree of pollution (Ravindra et al., 2022). It is primarily proposed by Horton (1965) and later developed then developed by Brown et al. (1970), essentially in the majority of the papers on the water quality monitoring of all around the world (Singh & Noori, 2022; Laishram et al., 2022; El Moustaine et al., 2021; Abbasnia et al., 2019; Madhav et al., 2018; Bora & Goswami, 2017; Kaviarasan et al., 2016; Amiri et al., 2014; Pei-Yue et al., 2010; Ramakrishnaiah et al., 2009; Pradhan et al., 2001;

Horton et al., 1965). The majority of authors are using the geospatial techniques for the spatial estimation of groundwater parameters. However, it can be used to define water quality for various purposes such as agricultural water supply, several water bodies, and navigation.

In the study area, groundwater understanding the only source for various purposes (irrigation, drinking water, and development). However, this area knows many pressures influencing groundwater quality and the environment, like the disposal of wastewater and exploitation of mining (Barite). Recently, our study area was the first at the national level to export watermelon and to date, no study about hydrogeochemical has been approved to assess the spatial distribution and evaluate the hydrochemistry of groundwater in the aquifer of Fezouata. The main objective of the current study is to investigate the quality of Fezouata water for drinking and irrigation purposes by using integrated tools (hydrochemical, multivariate statistical approaches, and the Water Quality Index) to evaluate water quality and also for rational management in arid areas.

Material and methods

Study area

The Draa basin extends to an area of 14,380 km² and a width of 1200 km, traversed by Draa river, the longest river in Morocco with 1100 km in length. It is supplied by the Mansour Eddahbi dam above the middle Draa valley (MDV). The Drâa river valley is of great importance because of its cultural heritage and natural has been recognized as an UNESCO World Heritage Site and RAMSAR Site.

The Drâa River naturally collects the surface waters of the Atlas Mountains. These water resources have allowed the establishment of a chain of six oases which extend for 200 km in the upper part of the Wadi Draa, varying from 100 m to 10 km in width upstream to downstream (Mezquita, Tinzouline, Ternata, Fezouata, Ktaoua, and M'Hamid).

Zagora city situated in southern-east of Morocco with a surface of 23,000 km², covering 3.55% of the total of the country. It is the last part of the aquifer of Tarnata and the upstream part of the aquifer of Fezouata, this region is marked by the ancient geological chain of Anti-atlas. The climate is dominated by a hyperaridity marked by low rainfall, a stormy character, and large daily and yearly fluctuations in temperatures. According to the 2014 census, the province is home to 305,510 inhabitants with a habitat density of 14 per km² (Morocco Planning High Commission, 2014).

Fezouata area situated in the south-east of Morocco, in the central Anti-Atlas part (06° W meridian and below the 30° N), has been known by metal exploitation at least along 10 km. Since 2014, this activity would enhance changing the groundwater quality by oxidation of tailings by water and atmospheric oxygen allowed, in the absence of neutralizing agent's effluents. As a result, water is acid and enriched by particular elements that can intensify the conductivity especially sulphate. The Zagora's STEP (water treatment station) is installed upstream of the study area.

Sampling methods

The groundwater samples were collected for 2 years 2020 and 2021: in the wet season (December–April) and in the dry season (June–October) at each sampling station. Samples were preserved and analyzed according to

Rodier et al. (2009). Water sampling every well was collected in 1000 ml polyethylene bottles and transported in a cooler at approximately 4 °C to the laboratory.

In this study, the pH, conductivity, and total dissolved solids (TDS) of the water were measured in situ with a multi-parameter probe HI 9829 (HANNA). The other physicochemical parameters such as nitrates (NO₃⁻) and SO₄²⁻ were measured by spectrophotometer. The magnesium (Mg²⁺), calcium (Ca²⁺), sodium (Na⁺), and potassium (K⁺) were measured by flame spectrophotometer when the bicarbonate (HCO₃⁻) is obtained by the titrimetric method in the laboratory to evaluate the groundwater quality. In the Fezouata area, we collected fifteen groundwater samples by using a GPS device. The results are shown in Tables 2 and 4. Concerning water quality, we have used the criteria recommended by WHO in 2011.

Estimation of water quality index

WQI is adopted in order to recapitulate a large amount of water quality information into a single number and clear format (Štambuk-Giljanović, 1999) and its suitability for drinking purposes (Saedi et al., 2010; Rao et al., 2021). Moreover, WQI is extensively used for evaluating groundwater quality for drinking water, in relation to the hydro-geological and chemical parameters as well as heavy metal contamination (Liu et al., 2020). In the present study, this method is used to assess the quality of groundwater based on 10 parameters. The recorded values of WQI were calculated by using the weighted arithmetic index method as described by Cude (2001). The number 5 as a maximum weight has been given to the parameters like TDS and nitrate in favor of their significant importance in water quality assessment (Srinivasamoorthy et al., 2008; HemaLatha et al., 2012), pH, and sulfate were assigned the weight 4 (Al-Mashagbah, 2015; Srinivasamoorthy, 2008; Ketata et al., 2012). Sodium and bicarbonate was given a weight 3. Concerning K⁺, Ca²⁺, and Mg²⁺ were given the weight of 2 as they had little impact on the water quality testing (Ketata et al., 2012; Rokbaniet al., 2011) (Table 3 and Table 5).

In the second step, the relative weight (*Wi*) of each parameter is estimated by following Eq. (1):

$$W_i = \frac{w_i}{\sum_1^n w_i} \quad (1)$$

Table 1 Water quality based on WQI value

WQI value	Water category
0–25	Excellent water quality
26–50	Good water quality
51–75	Poor water quality
76–100	Very poor water quality
> 100	Unsuitable for drinking purpose

where w_i is the weight of each parameter, n is the number of parameters, and w_i is the relative weight. Weights (w_i), calculated relative weight values (W_i), and WHO criteria for each parameter are shown in Table 2.

Water quality rating scale q_i were calculated by the following formulae using Eq. (2).

$$q_i = \frac{C_i}{S_i} \times 100 \tag{2}$$

where q_i is the quality score, C_i is the concentration physicochemical parameter, and S_i is the drinking water standard of each physicochemical parameter according to the 2011 WHO guidelines.

Next, to calculate the WQI value of each parameter, the water quality sub index (SI_i) is calculated using Eq. (3).

$$SI_i = W_i q_i \tag{3}$$

Finally, the water quality sub-index assists to compute the WQI using Eq. (4).

$$WQI = \sum_1^n SI_i \tag{4}$$

Table 2 The mean value of physicochemical parameters composition of groundwater in the aquifer of Fezouata (2020)

	W1	W2	W3	W4	W5	W6	W7	W8
pH	7.00	7.39	7.22	7.49	7.36	6.95	7.45	6.93
Ec	6100.25	2205.75	2559.50	2331.75	3109.00	2626.00	2003.50	5785.50
TDs	3148.00	1043.00	1215.50	1131.00	1468.50	1304.50	964.50	3043.50
NO ₃ ⁻	4.20	2.75	4.16	1.22	2.21	28.86	44.07	6.66
PO ₄ ²⁻	0.21	0.30	0.15	0.45	0.41	0.82	0.38	0.34
SO ₄ ²⁻	962.67	740.00	860.25	832.50	989.13	551.38	1067.00	1085.88
HCO ₃ ⁻	112.12	196.72	202.98	233.90	285.56	538.98	294.10	519.86
Cl ⁻	321.25	142.00	242.35	137.50	141.40	198.80	109.10	514.75
Na ⁺	213.08	182.41	252.64	138.36	390.45	606.61	158.43	577.45
K ⁺	10.86	8.83	10.97	11.29	10.96	14.53	11.29	18.37
Ca ²⁺	45.51	28.17	61.53	64.35	115.69	53.42	69.03	94.40
Mg ²⁺	144.50	48.80	34.70	44.70	24.80	39.00	16.90	245.90
	W9	W10	W11	W12	W13	W14	W15	
pH	4.28	7.50	6.03	6.90	6.91	7.10	7.20	
Ec	7894.67	6387.33	4978.75	8146.00	8186.75	6381.67	6730.00	
TDs	4108.00	2385.00	2481.00	5014.50	3931.00	2984.00	3264.00	
NO ₃ ⁻	31.97	107.02	9.78	4.66	1.51	1.23	2.38	
PO ₄ ²⁻	0.74	1.42	0.68	0.90	1.43	0.61	0.47	
SO ₄ ²⁻	1281.00	1064.67	1201.63	1271.25	1191.50	1197.00	805.00	
TAC	319.73	620.74	321.68	285.56	268.96	460.68	519.56	
Cl ⁻	816.50	312.40	430.95	408.25	724.20	261.50	979.20	
Na ⁺	461.15	517.46	445.37	760.14	799.15	522.46	821.49	
K ⁺	22.36	9.78	10.98	7.11	14.18	6.98	12.07	
Ca ²⁺	160.84	72.92	122.63	148.52	83.72	71.41	58.24	
Mg ²⁺	310.00	175.90	33.90	106.20	70.80	94.80	37.50	

Table 3 The weight and relative weight used for calculated WQI in 2020 period (Al-Mashagbah, 2015; HemaLatha et al., 2012; Ketata et al., 2012; WHO, 2011)

Parameters	Unit	Min	Max	Mean	SD	WHO standard (2011)	Weight (wi)	Relative weight (Wi)
pH	pH units	4.28	7.50	6.91	0.82	6.5–8.5	4	0.11428571
TDs	(mg/L)	964.50	5014.50	2499.07	1281.76	500	5	0.14285714
NO ₃ ⁻	(mg/L)	1.22	107.02	16.85	28.30	45	5	0.14285714
SO ₄ ²⁻	(mg/L)	551.38	1281.00	1006.72	213.81	250	4	0.11428571
HCO ₃ ⁻	(mg/L)	112.12	620.74	345.41	149.63	120	3	0.08571429
Cl ⁻	(mg/L)	109.10	979.20	382.68	268.47	250	5	0.14285714
Na ⁺	(mg/L)	138.36	821.49	456.44	232.77	200	3	0.08571429
K ⁺	(mg/L)	6.98	22.36	12.04	4.04	12	2	0.05714286
Ca ²⁺	(mg/L)	28.17	160.84	83.36	38.04	75	2	0.05714286
Mg ²⁺	(mg/L)	16.9	310	95.23	87.91	50	2	0.05714286
							35	1

These index values classify groundwater quality into five types, “excellent” water, and “unsuitable for consumption” as shown in Table 1 (Ramakrishnaiah et al., 2009).

Results and discussion

Physicochemical parameters

pH, electrical conductivity, and total dissolved solids

This study indicates that values of spatial fluctuation of the groundwater quality parameters in the Zagora area were recorded in samples of water from each well (Tables 2 and 4). pH is the strength of the alkalinity or acid of the aqueous solution; this parameter is an essential indicator that can be used to evaluate water quality and the level of pollution in water bodies, measured based on the $-\log$ of H⁺ concentration (Trivedy & Goel, 1984). The pH values, varying from 4.28 to 6.91 in 2020 and 7.26 to 7.79 in 2021, show that the water of Fezouata is nearly neutral to relatively alkaline nature, with the lowest mean value of 4.28 observed at W9, while the highest values were recorded at W4 and W2, respectively (7.90–7.79). The pH results indicate the values are within the guidelines of the WHO and BIS except at one well W9 located close to Douar Bni khallouf; this last is located near septic tanks. Though pH values between 6.5 and 8.5 generally designate good water quality, it

is characteristic of most watersheds around the world (UNEP/GEMS, 2007) (Table 3).

The electrical conductivity values generally depend on the entire dissolved salts during measurement (Jubouri and Saeed, 2009). The values of electrical conductivity (EC) varied from 2003.50 to 8186.75 μ S/cm in 2020 and 1879.83 to 7990.11 μ S/cm in 2021 (Tables 2 and 4), reflecting a high mineralization level in upstream to downbound, and indicating a salt enrichment in the study area (Prasanth et al., 2012). This fact is agreeing with results obtained by Cherkaoui et al. (2007) and Warner et al. (2013). All groundwaters samples values above the norm recommended by WHO 2011 (1000 μ S/cm).

The total dissolved solids (TDS) determination of the components, salts, minerals, cations, and anions content in the water samples. The high value of TDS can reason stomach infection, and lengthy-time period of use can result in coronary heart ailment and kidney stones in human beings (Jain et al., 2003). The present study shows that TDS concentrations ranged from 964.50 to 5014.50 in 2020 with an average value of 2499 ± 1281 and 939.92 to 3996.83 mg/L in 2021 with an average value of 2339.84 ± 1144 . Except for one sample all groundwater samples are above 1000 mg/L, classify 8 samples i-e 53.33% as useful for irrigation (TDS ranging from 1000 to 3000) and 6 as unfit for drinking and irrigation according (Davis & Dewiest, 1966). Higher TDS values in the study area are due to leaching of salts from soil, it means geological composition of soils (Table 5).

Table 4 Mean value of physicochemical parameters in the study area during (2021)

	W9	W10	W11	W12	W13	W14	W15	
pH	7.32	7.57	7.61	7.56	7.59	7.60	7.52	
Ec	7529.11	3796.89	3551.50	7990.11	7739.83	6807.44	7330.89	
TDs	3762.44	1899.67	1775.81	3996.83	3869.69	3404.22	3665.56	
NO ₃ ⁻	16.43	72.65	6.42	4.12	0.52	2.12	1.90	
PO ₄ ²⁻	0.43	0.45	0.10	0.18	0.19	0.13	0.14	
SO ₄ ²⁻	943.58	640.14	909.14	1131.28	1106.42	1040.69	844.61	
HCO ₃ ⁻	335.84	342.87	143.93	217.12	206.11	327.84	297.76	
Cl ⁻	560.00	126.00	399.00	681.00	816.00	613.00	867.00	
Na ⁺	890.08	331.02	498.44	957.98	904.66	837.69	856.91	
K ⁺	16.32	27.71	8.69	10.61	21.47	17.83	17.36	
Ca ²⁺	106.92	76.15	155.83	175.67	227.99	187.66	183.26	
Mg ²⁺	64.07	119.03	72.98	77.06	72.08	84.41	113.03	
	W1	W2	W3	W4	W5	W6	W7	W8
pH	7.26	7.78	7.76	7.79	7.61	7.54	7.65	7.31
Ec	6204.00	1879.83	2649.33	2609.22	3455.83	2517.72	2228.44	5274.33
TDs	3097.50	939.92	1325.33	1304.94	1727.64	1259.03	1113.78	1955.28
NO ₃ ⁻	7.05	2.39	3.78	1.51	2.49	61.01	59.03	5.01
PO ₄ ²⁻	0.25	0.16	0.26	0.08	0.13	0.19	0.14	0.30
SO ₄ ²⁻	862.67	571.58	672.63	690.67	751.66	440.84	712.92	996.03
HCO ₃ ⁻	462.47	151.99	230.60	210.10	219.43	395.68	224.36	437.80
Cl ⁻	700.00	56.00	161.00	133.00	259.00	154.00	119.00	527.00
Na ⁺	416.75	217.88	284.02	360.70	491.25	287.40	262.40	840.43
K ⁺	25.65	11.02	10.67	11.27	11.55	9.92	11.24	14.93
Ca ²⁺	112.25	51.95	77.58	68.54	92.00	76.57	81.17	193.78
Mg ²⁺	174.00	42.72	50.42	58.00	59.69	65.13	50.22	156.20

Major anions

Nitrate (NO₃⁻)

The nitrate content in groundwater intended for human consumption is the most important parameter in water quality testing for the reason that its high values in drinking water have an impact on bottle-fed infants, for example, cyanosis (discoloration of the skin) and methemoglobinemia (Comly, 1945), goiter, hypertension, gastric cancer, and birth malformations (Majumdar and Gupta, 2000; Shigut et al., 2017). In the study area, all samples' results show that values of the nitrate ranged from 1.22 to 107.02 mg/L with means value 16.84 ± 28.30 in 2020, but in 2021, the nitrate values ranging between 0.52 and 72.64 mg/L with an average value of 16.43 ± 25.18 mg/L. Relatively high values are recorded in W10 (107.02 mg/L)

and W7 (44.07 mg/L) likely originating from anthropogenic sources, agricultural wastewater, and septic tank discharge (Barakat et al., 2018). NO₃⁻ concentration of all the groundwater samples does not exceed the permissible limit (50 mg/L) as per WHO (2011), except for W6, W7, and W10 where the values are well above the limit recommended by WHO; these results are given for the first time, especially after the installation of the STEP of Zagora the opposite of some Douar of the Tamegroute commune like Ait khadou, Inkizat, and Sarte.

Sulfate (SO₄²⁻)

Sulfate is some other essential chemical characteristic for water quality that is naturally present in water due to the leaching of gypsum and other common minerals (Sehar et al., 2011). It also influences taste and odor in

Table 5 The weight and relative weight of each chemical element in the 2021 period (Al-Mashagbah, 2015; HemaLatha et al., 2012; Ketata et al., 2012; WHO, 2011)

Parameters	Unit	Min	Max	Mean	SD	WHO standard (2011)	Weight (wi)	Relative weight (Wi)
pH	pH units	7.26	7.79	7.56	0.163	6.5–8.5	4	0.11428571
TDs	(mg/L)	939.92	3996.83	2339.84	1144.56	500	5	0.14285714
NO ₃ ⁻	(mg/L)	0.52	72.64	16.43	25.17	45	5	0.14285714
SO ₄ ²⁻	(mg/L)	440.84	1131.28	820.99	202.95	250	4	0.11428571
HCO ₃ ⁻	(mg/L)	143.93	462.47	280.26	99.87	120	3	0.08571429
Cl ⁻	(mg/L)	56.00	867.00	411.40	283.65	250	5	0.14285714
Na ⁺	(mg/L)	217.88	957.98	562.51	281.22	200	3	0.08571429
K ⁺	(mg/L)	8.69	27.71	15.08	5.92	12	2	0.05714286
Ca ²⁺	(mg/L)	51.95	227.99	124.49	56.804	75	2	0.05714286
Mg ²⁺	(mg/L)	42.72	174.00	83.94	39.36	50	2	0.05714286
							35	1

drinking water (Bouslah et al., 2017). SO₄²⁻ in aquifer systems generally originates from the weathering of the two main SO₄²⁻ bearing rocks, pyrite and gypsum, and input from anthropogenic activities (Ziani et al., 2017). High SO₄²⁻ levels in water may have a distinct flavor and may induce a laxative effect in accustomed consumers (WHO, 2017). The SO₄²⁻ concentrations in analyzed samples ranged from 551.38 to 1281 with an average of 1006.72 ± 213.81 in 2020 and 440.84 to 1131.28 with an average of 820.99 ± 202.95. These results show that all groundwater in Fezouta area exceeded the permissible limit of 250 mg/L. These results indicate that the groundwater samples analyzed are rich in sulfates, which could pose serious health risks such as dehydration and diarrhea, and that children are more susceptible to sulfates than adults (Kumar & Dua, 2009). Alkalinity is a crucial parameter of the buffering capacity of water, in natural waters Bicarbonate depends on temperature, pH, cations, carbon dioxide, and dissolved salts, high values may cause gastrointestinal irritation and disease with vomiting and nausea in addition to their impact on health (Wynn et al., 2010).

Bicarbonate (HCO₃⁻)

The alkalinity results were observed between 112.12 mg/L and 620.74 mg/L with an average of 345.41 ± 149.63 mg/L in 2020 and 143.93 to 462.47 in 2021 with means of 280.26 ± 99.88 mg/L; thus, values show that HCO₃⁻ exceeds the values permissible

(500 mg/L) by WHO (2011), except W1 in 2020 and all groundwater samples in 2021. The quantity of calcium and magnesium determines the total hardness (TH) of water. Calcium is one of the important components necessary to our body, the last requires a healthy quantity of calcium, and a deficiency can lead to hypocalcemia, muscle cramps, dry skin, etc. (Pravina et al., 2013). The calcium values in groundwater range from 28.16 to 160.84 mg/L, with a mean value of 83.36 ± 38.04 mg/L in 2020, and varied between 51.95 and 227.99 mg/L with an average of 124.49 ± 56.80 mg/L. Forty percent of samples exceed the standards recommended (75 mg/L) by World Health Organization (2011) in 2020 (W5, W8, W9, W11, W12, and W13), However, 73.33% of samples are exceeding this limit value. This may be due to carbonate rocks. It may also be a chemical decomposition of feldspars and calcium plagioclase pyroxenes (Ganyaglo et al., 2010). Magnesium is present naturally in water. Hypomagnesemia, hypertension, osteoporosis, headaches, etc. can all result from a magnesium deficiency (Al Alawi et al., 2018; Watson et al., 2012). In the study area, magnesium in groundwater comes from dolomite breakdown, amphiboles, pyroxene, and olivine dark-colored micas. The Mg²⁺ concentration results range between 16.9 and 310 mg/L with an average of 95.22 ± 87.91 mg/L in 2020 and between 42.72 and 174.00 mg/L with a median value of 83.94 ± 39.36 mg/L in 2021. Of the samples, 46.6% are within an acceptable limit in 2020 and 80% in 2021 exceed the maximum allowable limit.

Chlorides Cl⁻

Chlorides in groundwater can have a variety of sources, such as rock modification and sedimentary soil leaching, saline intrusion, household, and industrial waste discharges, etc. (Karanth, 1987). It is less than 30 mg/L, but in arid regions can reach 1000 mg/L (Nag, 2009). Chloride (Cl⁻) concentrations ranged from 109.10 to 979.20 mg/L with a mean value of 382.67±268.47 mg/L in 2020 and 56,00 to 867,00 mg/L with an average of 411.40±283.65 mg/L in 2021. However, 60% of groundwater samples are below the recommended level (250 mg/L) in 2020. As well as, 66% of groundwater analyzed in 2021 exceeds the maximum allowable limit. The dissolution of halite is primarily responsible for the high amounts of chloride (Bahir et al., 2017). Sodium (Na⁺) is the most common member of the group of alkali metals in the investigated groundwater. The sodium

concentration ranged from 138.36 to 821.49 mg/L, with an average of 456.44±232.77 mg/L in 2020, and 217.88 to 957.98 mg/L, with an average of 562.51±281.22 mg/L in 2021. 80% of samples exceed the value limit in 2020 and all samples are above the recommended limit in 2021 (200 mg/L).

Gibbs diagram

Gibbs diagram is extensively used to set up the reaction between the aquifer lithological characteristics and water composition (Gibbs, 1970). This method uses to estimate the origin of ions in groundwater by investigating the relationship between them. TDS and anions (Cl⁻, HCO₃⁻) firstly and between TDS and cations (Na⁺, Ca²⁺) secondly. This diagram is classified into three classes precipitation dominance, rock dominance, and evaporation precipitation. According to the results shown in Fig. 2, the origin of anions and cations in the samples of groundwater in the aquifer of

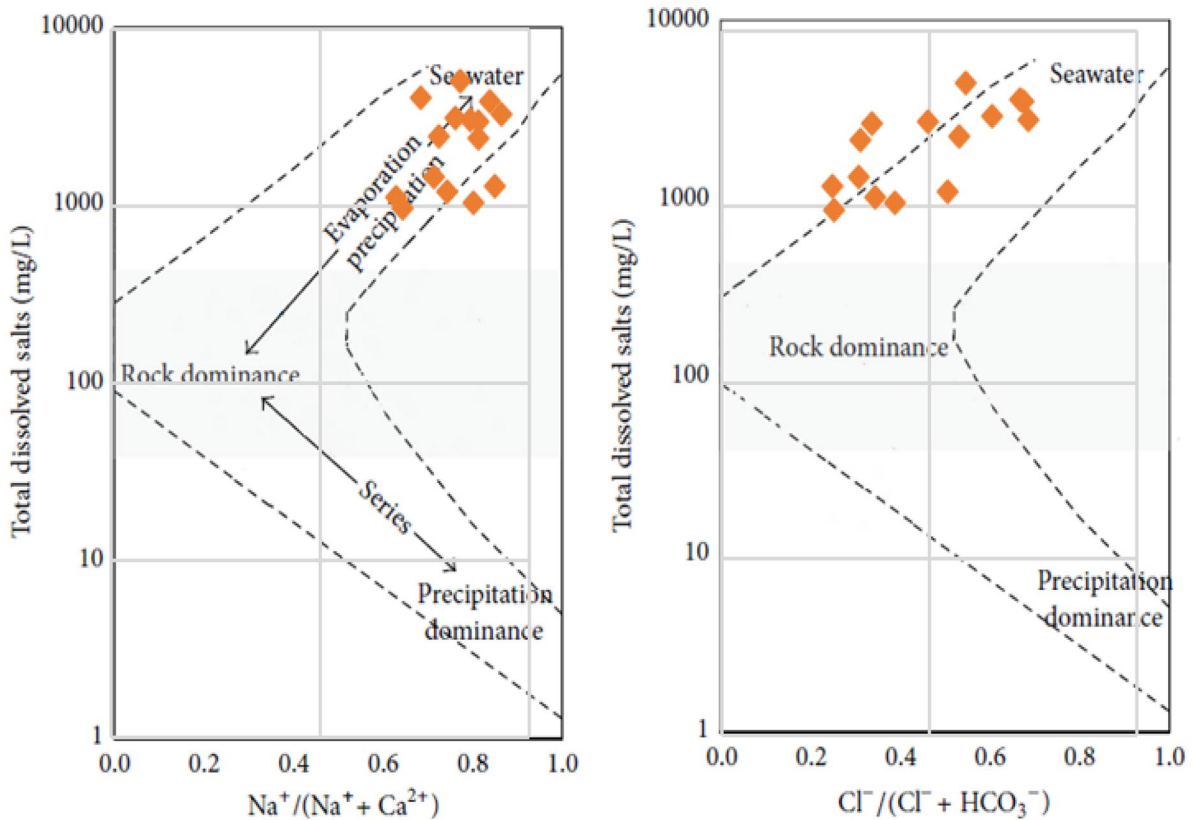
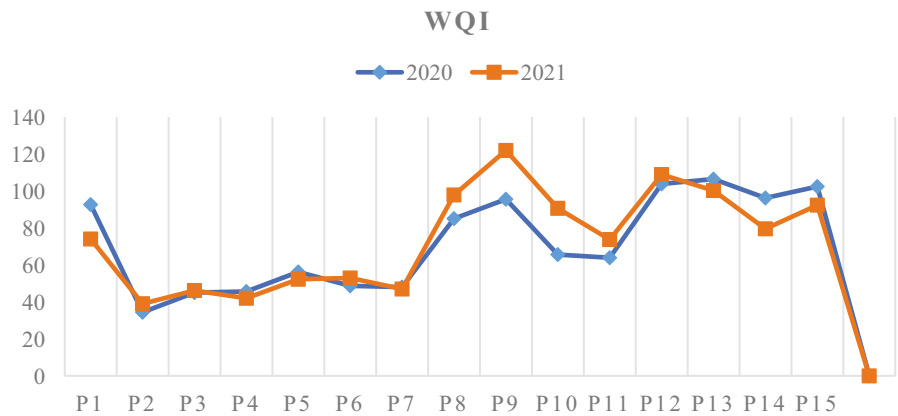


Fig. 2 Gibbs diagram in the groundwater study

Fig. 3 Evaluation of WQI for the groundwater during 2020 and 2021



Fezouata has been obtained mainly from evaporation dominance due to the arid and semi-arid environmental climate in the Zagora region.

Water evaluation for irrigation purposes

The suitability of the aquifer Fezouata was investigated using irrigation water quality indices like soluble sodium percentage (SSP), sodium adsorption ratio (SAR), magnesium hazards (MHs), permeability index (PI), and Kelley’s ratio (KR) (Fig. 3). The resulting concentration (Table 6) percentages, number

of groundwater samples are provided in Table 9, also the spatially varying maps shown in the Figs. 4 and 5.

SAR

The sodium absorption ratio (SAR) is the percentage of sodium content divided by the square root of half of the total concentration of calcium and magnesium, which is not equal to one degree of sodium relative to the amount of calcium and magnesium in a water sample. SAR indicates the suitability of water for use in agricultural irrigation. The high concentrations

Table 6 Assessment groundwater results for irrigation purpose

Site	SAR		SSP%		KR		PI %		HM%	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
W1	3.48	5.74	40.27	48.53	0.65	0.91	50.17	60.85	83.96	71.88
W2	4.82	5.42	60.08	61.51	1.46	1.55	82.98	78.74	74.07	57.55
W3	6.38	6.17	65.54	61.15	1.85	1.54	83.91	77.46	48.19	51.73
W4	3.24	7.75	47.79	66.10	0.87	1.91	73.49	79.40	53.39	58.25
W5	8.59	9.80	68.84	69.51	2.17	2.25	83.78	80.05	26.12	51.69
W6	15.40	5.83	82.00	58.15	4.49	1.36	97.77	78.26	54.63	58.38
W7	4.43	5.64	59.76	58.85	1.43	1.39	91.41	75.55	28.76	50.50
W8	7.11	10.89	50.64	62.12	1.01	1.62	60.64	69.92	81.12	57.07
W9	4.90	16.81	38.09	78.67	0.60	3.65	45.41	86.84	76.07	49.70
W10	7.48	5.52	55.68	52.63	1.24	1.06	69.20	66.94	79.91	72.05
W11	9.18	8.26	68.81	61.38	2.17	1.57	82.73	68.83	31.31	43.57
W12	11.64	15.16	67.30	73.52	2.05	2.76	74.89	79.25	54.11	41.97
W13	15.54	13.38	77.83	69.74	3.47	2.27	85.89	75.31	58.24	34.27
W14	9.53	12.76	66.84	69.34	2.00	2.23	80.73	76.89	68.64	42.59
W15	20.64	12.27	85.74	67.16	5.96	2.02	97.77	73.97	51.50	50.42
Min	3.24	5.42	38.09	48.53	0.60	0.91	45.41	60.85	26.12	34.27
Max	20.64	16.81	85.74	78.67	5.96	3.65	97.77	86.84	83.96	72.05
Means	7.48	8.26	65.54	62.12	1.85	1.62	82.73	76.89	54.63	51.69

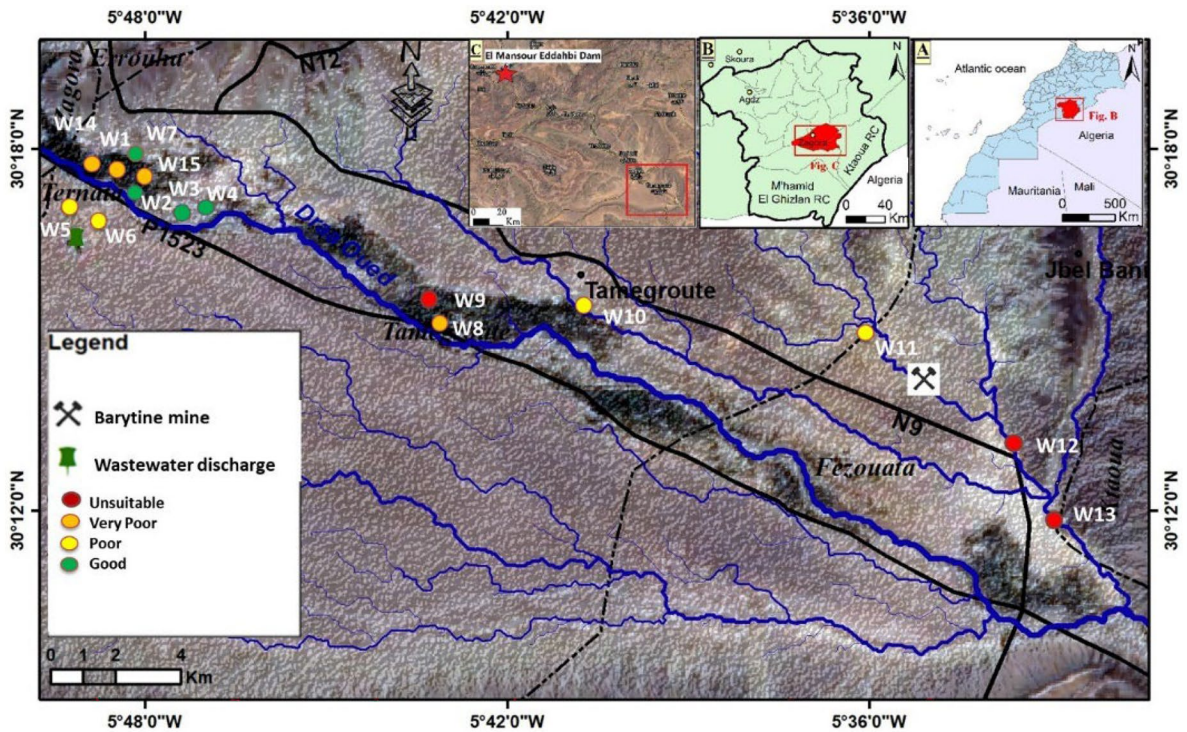


Fig. 4 Spatial distribution of WQI in the study area during 2020 (Boudellah et al., 2022)

of sodium in water affect soil permeability and can lead to water infiltration problems, thereby causing negative effects due to changes in soil properties and reduced permeability. (Schwartz, 1990; Ben et al., 2014; Aravinthasamy et al., 2020). SAR may also cause temporary surface soil saturation, high pH and soil erosion, inadequate nutrient availability, and increased risk of plant disease reducing soil permeability and the soil’s ability to form stable aggregates, leading to loss of soil structure (Prasanth et al., 2012). The sodium absorption ratio was computed employing Eq. (5) (Raghunath, 1987). All concentration of cations was given in meq/L.

$$SAR = \frac{Na^+}{(\sqrt{Ca^{2+} + Mg^{2+}})} / 2 \tag{5}$$

The SAR calculated value obtained of the groundwater of the Fezouata area varies between a maximum of 20.64 meq/L registered at W15 and a minimum of 3.24 meq/L recorded at W4 with a mean of 7.48 ± 5.05 in 2020. However, ratio of the sodium concentration

varied from 5.42 meq/L at (W2) to 16.81 meq/L, with an average of 8.26 ± 3.88 in 2021. Of all samples, 52.24% are considered “excellent” and 32.16% of samples groundwater are “good” for agriculture. However, 15.11% are doubtful for irrigation in 2020.

A total of 11 (42.53%) analyzed the groundwater samples in the “excellent” and 57.47% of samples are in the “good” for irrigation in 2021.

SSP

Sodium percentage results from natural water, it is a critical parameter in categorizing irrigation water based on soil permeability. The SSP was designed using Eq. (6) (Todd, 1980): where the concentrations of cations are in meq/L.

$$SSP = \frac{Na^+ + K^+}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100 \tag{6}$$

There are three categories are purposes: good, admissible, and doubtful receptively 20–40 Na%, 40–60 Na%, 60–80 Na% (Doneen, 1964).

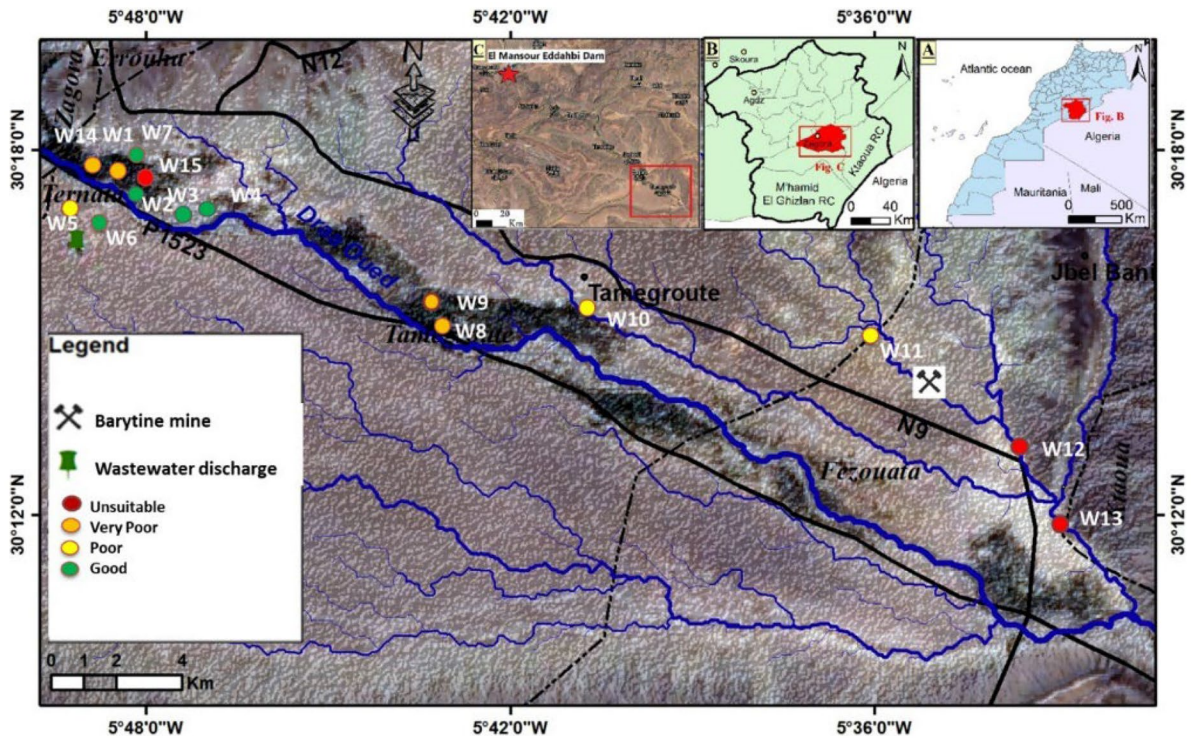


Fig. 5 Spatial distribution of WQI in the study area during 2021 (Boudellah et al., 2022)

The SSP value varied from 38.09 to 85.74%, with an average of $65.54 \pm 14.13\%$ in 2020 and ranged between 48.53 and 78.67%, with an average of $62.12 \pm 7.86\%$ in 2021. Witch suggested that 4.07% of groundwater samples are good, 31.25% are permissible, 50.82% are doubtful, and 17.94% are unsuitable for irrigation. However, in the 2021 period, 77.24% are doubtful and only 22.76 are permissible for irrigation. Thus, high values of sodium percentage can produce alkalinity and salinity in soils if associated with chloride and carbonate.

KR

Kelley's ratio (KR) determined excessive sodium on calcium and magnesium; according to Kelley (1963), the KR should not exceed 1 for irrigation water. It can be estimated using Eq. (7):

$$KR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})} \quad (7)$$

The KR values of all groundwater samples in the current study range from 0.6 to 5.97 meq/L, with an average of 1.85 ± 1.49 meq/L in 2020 and found between 0.91 to 3.65 meq/L, with an average of 1.62 ± 0.7 meq/L. Three (6.76%) samples were suitable, 93.24% were unsuitable for agriculture, and 64.64% were unsuitable for irrigation in 2020. However, only one (3.24%) of all samples is suitable for irrigation, 96.76% are unsuitable for irrigation in 2021.

PI

The contents of Ca^{2+} , Na^+ , Mg^{2+} , and HCO_3^- in the groundwater samples for agriculture purposes can affect the permeability of soil (Singh et al., 2015). The PI is classified into three classes: class I, class II, and class III. According to Nagarju et al. (2006), class I and II indicate good water quality for irrigation respectively ($> 75\%$, 25–75%), while class III (up to 25% permeability) water is considerate unsuitable for agriculture. This index can be calculated by Eq. (8):

Table 7 Correlation matrix of physicochemical parameters during 2020

	PH	EC	TDS	NO ₃ ⁻	PO ₄ ²⁻	SO ₄ ²⁻	HCO ₃ ⁻	Cl ⁻	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺
pH	1.000											
EC	-0.455	1.000										
TDS	-0.488	0.964	1.000									
NO ₃ ⁻	0.000	0.046	-0.106	1.000								
PO ₄ ²⁻	-0.133	0.552	0.434	0.517	1.000							
SO ₄ ²⁻	-0.472	0.676	0.677	0.076	0.356	1.000						
HCO ₃ ⁻	0.046	0.222	0.097	0.520	0.431	-0.056	1.000					
CL ⁻	-0.536	0.754	0.714	-0.095	0.298	0.327	0.256	1.000				
Na ⁺	-0.163	0.720	0.698	-0.018	0.603	0.257	0.564	0.692	1.000			
K ⁺	-0.682	0.203	0.195	0.070	0.045	0.095	0.162	0.516	0.144	1.000		
Ca ²⁺	-0.682	0.510	0.593	0.013	0.285	0.741	0.022	0.356	0.347	0.349	1.000	
Mg ²⁺	-0.616	0.584	0.554	0.296	0.187	0.469	0.231	0.423	0.165	0.630	0.443	1.000

$$PI = \frac{Na^+ + \sqrt{HCO_3}}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100 \tag{8}$$

The PI values in the studied area range from 45.41 to 97.77, with an average value of 82.73 meq/L in 2020 and ranging from 60.85 to 86.84 meq/L, with a mean value of 76.89 ± 6.36.

Based on this classification, the majority of groundwater samples, among nine 67.79% samples were in class I, and 32.20% in class II, but eleven samples 75.92% in 2021 are categorized exceeds 75%. In addition, 30.18% of all samples are in class II. This result shows that the groundwater samples of the aquifer in Fezouata area are used for irrigation purposes.

MH

The water is suitable for irrigation if magnesium hazard values are lower than 50% (Szabolcs & Darab, 1964). In addition, HM higher than 50% can increase the pH of the soil and affects plant growth. MH value is estimated in meq/L as follows:

$$MH = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \tag{9}$$

The samples analyzed in this study have a maximum of 83.96 to 26.12, with a mean of 54.62 ± 19.19 meq/L, which indicated that only 15.44% of samples had MH values below 50% in 2020. Though, 26.79% are less than 50% in 2021. Consequently, the sampling analysis extended to

permissible water, as a result of many factors like: geological contacts of groundwater, most irrigation pumping plants have excessive operating and groundwater dilution by releasing from dams of Mansour Dehbi, which explains the results obtained in 2021.

Correlation analysis

Statistical analysis is performed between different parameters, and the results are shown in Table 7. The high significant positive correlation is observed between electric conductivity and TDS (r=0.96), with chloride (r=0.75), with Na⁺ (r=0.72), among sulfates and calcium (r=0.74), a moderate correlation also was obtained between TDS with sulfates (r=0.67), with Na⁺ (r=0.698), too among chloride and sodium (r=0.69), potassium and magnesium (r=0.63). This suggests that all samples collected within the study area are of a similar geological nature. In addition, the elevated correlations of TDS and conductivity with sodium, chloride, and sulfates indicate that these levels are the major contributors to conductivity in the Fezouata aquifer.

Groundwater assessment for drinking using WQI

The water quality means values computations during the study period are shown in Table 8. The computed WQI values of sampling groundwater of Fezouata range from 34.42 to 106.43 with a mean value of 72.63 ± 25.58 during 2020 and range from 39.04 to 121.91, with an average of 74.57 ± 26.82 in 2021.

Table 8 Classification of water quality using WQI calculation

	WQI in 2021		WQI in 2020	
W1	92,64	Very poor water	74,00	Very poor water
W2	34,42	Good water	39,04	Good water
W3	45,04	Good water	46,18	Good water
W4	45,66	Good water	42,02	Good water
W5	56,23	Poor water	52,30	Poor water
W6	48,68	Good water	52,93	Poor water
W7	48,00	Good water	46,98	Good water
W8	85,02	Very poor water	97,86	Very poor water
W9	95,56	Very poor water	121,91	Water unsuitable
W10	65,56	Poor water	90,63	Very poor water
W11	63,89	Poor water	73,73	Poor water
W12	103,79	Water unsuitable	108,85	Water unsuitable
W13	106,43	Water unsuitable	100,25	Water unsuitable
W14	96,19	Very poor water	79,52	Very poor water
W15	102,39	Water unsuitable	92,31	Very poor water

In comparison with WQI values in 2021 (Fig. 3), there are no significant changes between this concentration. However, a marked decrease in mineral contents in some wells situated in the distal area of mining exploitation, 40.24% of all samples is unsuitable for drinking during 2020 related to 33.21% in 2021. Therefore, this decline was caused by natural geological, the dilution of the aquifer (Lasagna et al., 2013) and pumping water for irrigation.

The maximum WQI has been calculated for the samples taken in the W13 closely to the mining Tin-fou site (Table 8). They are followed by W12 and W15 with WQI of 103.79 and 102.39, respectively, taking in mind that they have been taken in upstream about 3 km from the mineral exploitation zone. Indeed, this increase is related firstly to the higher concentration of TDS occurring in the wells W12, W9, and W15 (with 5014.5, 4108, and 3264 mg/L, respectively), and secondly, the noticeable conductivity levels (with 8146, 7894.6, and 6730 $\mu\text{S}/\text{cm}$). This allows classifying these groundwater samples as unsuitable for drinking purposes at W12, W13, and W15 and as very poor water quality into four wells (W1, W8, W9, and W14) accounting for 47.55% of the total samples, 23.90% are considered poor water quality for potable water. Nevertheless, in the aquifer of Fezouata, the wells situated upstream of the source of pollution are relative of good quality and nearly all

of the samples are in excellent quality or good quality water, representing 28.55%. Furthermore, 33% samples are unsuitable for drinking water in 2021, 38.94% are in poor quality, 43.58% are very poor, and 17.48% are good.

In the current study, the groundwater, for instance, located upstream of aquifer testing is typically less classified as loaded waters; the quality in this part is good for drinking with WQI generally below 50, except for W1. The WQI can help to assess and knowledge the degree of contamination in order to evaluate the spatial variation in addition to temporal variation. Downstream, the groundwater samples have WQI less than 100, and several of the wells in this region nearby to mining exploitation are unfit for drinking water (Boudellah et al, 2022), particularly W12 and W13, which could account for the high value seen in W1 and W15 in the western part of the aquifer of Fezouata.

Water quality is defined by a number of quality parameters depending on the purpose and different pollution kinds. That's why this study is based on ten parameters such as TDS, pH, NO_3^- , SO_4^{2-} , HCO_3^- , Cl^- , Na^+ , Mg^{2+} , Ca^{2+} , and K^+ . Even so, it is indispensable to complete deeply the assessment of the groundwater, to minimize the risk of alterations to water resource quality.

Table 9 Assessment quality using irrigation indices (SAR = sodium adsorption ratio; SSP = soluble sodium percentage; PI = permeability index; KR = Kelley’s ratio; MH = magnesium hazard)

Indices in meq/L	Classifications	Sampling number		Percentage of samples	
		2020	2021	2020	2021
SAR (Richards, 1954)	0–10 Excellent	11	9	52.24%	42.53%
	10–18 Good	3	6	32.16%	57.47%
	18–26 Doubtful	1	0	15.11%	0%
	> 26 Unsuitable	0	0	0%	0%
SSP (Wilcox, 1955)	< 20 Excellent	0	0	0%	0%
	20–40 Good	1	0	4.07%	0%
	40–60 Admissible	6	4	31.25%	22.76%
	60–80 Doubtful	7	10	50.82%	77.24%
	> 80 Unsuitable	2	0	17.94%	0%
PI (Doneen, 1964)	> 75% Class I Excellent	0	10	0%	69.81%
	25–75% Class II Good	6	5	32.20%	30.18%
	Below to 25 Class III Unsuitable	9	0	67.79%	0%
KR (Kelley, 1963)	Lower to 1 suitable	3	1	6.76%	3.24%
	Exceed to 1 unsuitable	12	14	93.24%	96.76%
MH (Raghunath, 1987)	Lower to 50%	4	5	15.44%	26.79%
	More than 50%	11	10	74.66%	73.21%

The geospatial techniques seem suitable and successful in groundwater studies. Our findings/results in the area of Zagora may remain a reference for coming studies in the monitoring of the water resource in this area and elsewhere to control the anthropic impact factor (Table 9).

Conclusion

This study aims to evaluate groundwater quality in the Fezouata region using irrigation indices and WQI techniques. It is a suitable method of mapping groundwater distribution by using physicochemical parameters; the first aim is to characterize a good groundwater source for drinking purposes. Furthermore, it also presents a comparative assessment of the water quality of sampling stations in time and space. The abundance of major ions is $SO_4^{2-} > Na^+ > Cl^- > HCO_3^- > Mg^{2+} > Ca^{2+} > NO_3^- > K^+$ with Na^+ among the cation being dominant and K^+ being a minor element. While the sulfates are the

most dominant anion and NO_3^- is the lowest. The physicochemical parameters like EC suggest a high mineralization of the samples’ groundwater. In fact, all samples exceed $1500\mu S/cm$ recommended for drinking. Concerning the sulfate and nitrate, all sampling sites exceeded the standards fixed by the WHO (2011) of 250 mg/L and 45 mg/L, respectively. The hydrogeochemical facies indicated that the nature of groundwater is Na-Cl type in the study area. The controlling factor that affects the chemical composition of groundwater in the aquifer of Fezouata was identified as evaporation dominance. The results of the WQI show that 17.48% to 28.55% are good and then recommended for drinking purposes, 23.90% to 38.94% are poor water quality, 43.58% to 47.55% are in very poor quality, and 33.21 to 40.24% are unsuitable for drinking purposes. The high value of WQI recorded in the downstream part of the study area is due to higher values of chloride, sulfate, sodium, and calcium.

Regarding agriculture water, the irrigation indices like SAR, the majority of samples are good to

excellent, 84% and 100% in 2021. While, the SSP, 22% of groundwater samples in 2020, and 35% are permissible for irrigation. Although, the permeability index shows that 67% is unsuitable for agriculture in 2020 and all samples are good to excellent. However, The KR and HM indices show that the vast majority of samples are unsuitable for irrigation, thus suggesting that groundwater samples located upstream of the study region are suitable for drinking and irrigation. Moreover, in some study wells, the geological nature of soil as groundwater flow through the soil is the origin of the level values recorded. In the southern part of the studied area mining exploitation is a factor controlling the chemical element in the aquifer in addition to irrigation water dumping. Therefore, our findings suggest that the groundwater quality in the Fezouata area is influenced by anthropogenic factors (septic tanks) and geochemical causes, such as higher SO₄²⁻ and Ca²⁺ levels caused by gypsum and halite. In addition, education for people living in this arid climate is obligatory and urgent plans for management are necessary with this increased salinity to protect this scarce resource. As a perspective, the evaluation of groundwater quality in Fezouata should be more developed by using microbiological and metal parameters in WQI calculations and water quality monitoring.

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Data availability All data will be made available on reasonable demand.

Declarations

Ethics approval Not applicable. All authors have read, understood, and have complied as applicable with the statement on

“Ethical responsibilities of Authors” as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

Conflict of interest The authors declare no competing interests.

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