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Seasonal study of pollution and water degradation in the Sebou River basin Gharb region – Morocco

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Abstract: This study investigates the physicochemical characteristics of raw surface and groundwater in the Upper Sebou region to evaluate their suitability for irrigation and identify pollution sources. Seasonal field measurements were conducted in summer and winter, analyzing parameters such as pH, electrical conductivity, and major ion concentrations, including nitrates, chlorides, sulfates, sodium, calcium, magnesium, potassium, bicarbonates, and ammonium. Surface waters exhibit high mineral content year-round. The pH ranges from 8.06 to 8.65, indicating slightly basic conditions suitable for irrigation. Electrical conductivity varies between 520 and 16,320 µS/cm, with higher values in summer likely due to low river discharge and increased evaporation. Nitrate, chloride, and sulfate concentrations are generally elevated, reaching up to 830.88 mg/L, 868 mg/L, and 312.65 mg/L, respectively. Sodium levels reach 1,870 mg/L, reflecting contributions from both natural rock dissolution and anthropogenic activities. Groundwater shows seasonal pH variation, with slightly more acidic values in summer. Electrical conductivity ranges from 202 to 22,210 µS/cm, increasing during dry seasons due to ion concentration. Nitrate levels in wells exceed recommended thresholds in all samples, with maximum values of 884.10 mg/L in summer, suggesting contamination from fertilizers, organic waste, and domestic discharge. Ammonium exceeds WHO guidelines in 40% of wells; chloride and sodium surpass limits in 41% of samples. The findings confirm that both geochemical processes and human activities contribute to persistent nitrogen and salt pollution. Although some irrigation standards are met, elevated ion concentrations highlight the need for improved groundwater protection and wastewater management in the region.

Keywords: *Gharb region–Morocco, Groundwater, Physicochemical, Seasonal, Sebou watershed.*

1. Introduction

The Sebou River basin, covering an area of approximately 34,000 km² in northern Morocco, represents one of the country's most important water resources. Originating in the Middle Atlas Mountains as Oued Guigou and flowing over 600 kilometers to the Atlantic Ocean, the Sebou watershed supplies an estimated 6.6 billion cubic meters of water annually. This basin plays a critical socio-economic role, supporting agriculture, industry, and urban populations in the Gharb region. However, rapid population growth, intensive agricultural practices, and expanding industrial activities have increasingly stressed the water quality, leading to rising concerns over contamination and its impacts on human health and ecosystem sustainability [1].

Previous studies have documented elevated levels of mineral and nutrient pollutants such as nitrates, ammonium, chlorides, and sulfates in both surface and groundwater sources within the Sebou

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basin. These contaminants are linked to natural geochemical processes, including the dissolution of carbonate and karstic substrates, as well as anthropogenic inputs from agricultural runoff, domestic waste, and industrial effluents [2, 3]. While seasonal variations in physicochemical parameters such as pH and electrical conductivity have been observed, existing research has not fully elucidated the extent of mineral contamination across different seasons nor adequately addressed the combined effects of natural and human influences on water quality in the Upper Sebou region.

The present study aims to fill this knowledge gap by conducting a comprehensive seasonal assessment of physicochemical water parameters in the Upper Sebou basin. The key research question is to what extent mineral contamination varies between dry (summer) and wet (winter) seasons and which factors most significantly affect water quality. Specifically, this study tests the hypothesis that seasonal hydrological changes influence mineral concentration patterns, exacerbating pollution during dry periods due to reduced dilution and increased evaporation. Identifying these seasonal trends and contamination sources is crucial for developing targeted water management and pollution mitigation strategies in this vital watershed.

By systematically analyzing a broad range of parameters, including pH, electrical conductivity, and major ions such as calcium, magnesium, sodium, potassium, carbonates, bicarbonates, chloride, sulfate, ammonium, and nitrates, this research will provide a detailed characterization of the mineral contamination status. The findings are expected to support policymakers, water managers, and local stakeholders in implementing effective interventions to protect water resources and ensure sustainable agricultural and urban development in the Gharb region.

2. Study Area and Methods

2.1. Geographic Location of the Study Area

The Sebou basin, covering an area of approximately 40,000 km², is one of the most important basins in the kingdom and currently hosts a total population of nearly 6.2 million inhabitants (2004 census), with 49% living in urban areas and 51% in rural areas. The basin has an agricultural and industrial economy that contributes significantly to the national economy. The prevailing climate across the basin is Mediterranean with oceanic influence, while the climate becomes more continental toward the interior of the basin.

The average annual rainfall in the basin is 600 mm, with a maximum of 1000 mm/year in the Rif Mountains and a minimum of 300 mm in the Upper Sebou and Baht valleys. The Sebou watershed is one of the richest in water and is among the best-endowed regions in terms of irrigated land and industries. The cultivated potential amounts to 1,750,000 hectares. The irrigable areas are estimated at 375,000 hectares, of which 269,600 hectares are currently irrigated. The Sebou basin experiences highly developed industrial activity. Major industrial units within the basin include sugar factories, paper mills, oil mills, tanneries, cement plants, and the textile industry [4].

2.2. Study Instruments

2.2.1. Sampling and Water Analysis

The sampling campaign was conducted taking into account the lithological diversity of the Sebou Basin and the distribution of anthropogenic activities.

Within the framework of this study, two sampling campaigns were carried out during the rainy and dry seasons (August and December 2021). During each campaign, ten surface water samples and ten groundwater samples were collected along the Lower Sebou (regions of Magran, Sidi Allal Tazi, Souk Tlet). Water samples were collected in 1.5-liter bottles, transported in a cooler, and stored at approximately 4 °C according to the method described by Rodie et al. [5]. Twelve physico-chemical and chemical parameters were measured for the collected samples. These parameters are: pH, electrical conductivity (EC), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), ammonium (NH_4^{+}), nitrate (NO_3^{-}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^{-}). All analyses were performed in the laboratory of the Faculty of Sciences at Ibn Tofail University, Kenitra,

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using chemicals and equipment such as digital burettes, a flame photometer, a spectrophotometer, a nitrogen distillation apparatus, a pH meter, a conductivity meter, and other materials.

3. Results and Discussion

- Data on physico-chemical parameters

The results of the physicochemical data of the waters of the Sebou basin are presented in Table 1.

3.1. Hydrogen Potential (pH)

In the study area, the pH values of groundwater vary between 8.09 and 8.42 in winter, and between 7.9 and 8.66 in summer (Figure 2). These results indicate a seasonal variation in pH values, although this variation remains minor. In summer, the lower pH values can be attributed to a high production of CO_2 in the soil, due to intense biological activity. In winter, the pH decrease is also influenced by the increase in the partial pressure of CO_2, resulting from significant precipitation [6]. During the study period, the pH values measured at most sampled water points remained below the maximum admissible value (MAV) of 8.5, according to the Moroccan standard for water intended for human consumption [7]. Regarding surface waters, pH values range between 8.12 and 8.40 in winter and between 8.06 and 8.65 in summer (Figure 2). These results do not reveal any significant seasonal variation. Similarly, most analyzed samples comply with the MAV of 8.5 set by Moroccan regulations.

3.2. Electrical Conductivity (EC)

Electrical conductivity values measured in surface waters vary between 624 µS/cm and 16,320 µS/cm in summer and between 520 µS/cm and 13,750 µS/cm in winter (Figure 3). These results show a slight seasonal variation. The increase in conductivity during the warm season can be attributed to a decrease in river flow, leading to higher concentrations of mineral salts, as well as increased evaporation [3]. Conversely, the minimum values recorded after winter precipitation are explained by a dilution phenomenon, mainly due to recharge from groundwater sources originating from the Middle Atlas and the high plateaus, such as the Jorf Lahmam spring [8]. In groundwater, electrical conductivity varies between 202 µS/cm and 19,333 µS/cm in winter, and between 250 µS/cm and 22,210 µS/cm in summer (Figure 3). These results show a notable seasonal variation for most wells studied. The evolution of water mineralization follows rainfall variations: the highest values are explained by mineralization phenomena linked to the infiltration of recent waters, either slightly or highly mineralized, mixing with older flows [6].

3.3. Ammonium (NH_4^+)

In surface waters, ammonium concentrations during summer range from 0.08 mg/L to 15.44 mg/L, while in winter they vary between 0.06 mg/L and 15.3 mg/L (Figure 4). These results indicate minor seasonal variations. Ammonium levels generally comply with the standards set by the Moroccan Ministry of Water and Environment (< 8 mg/L) for irrigation in 2007, except at station S10, where the concentration reaches 15.44 mg/L, exceeding the permissible limit. In groundwater, ammonium concentrations in summer range from 0.17 mg/L to 2.54 mg/L, and in winter from 0.11 mg/L to 2.4 mg/L (Figure 4). Approximately 40% of wells exhibit concentrations above the WHO standard of 0.5 mg/L, suggesting nitrogen pollution potentially caused by organic waste, agricultural fertilizers, and domestic or industrial discharges. Consequently, the groundwater in this region is no longer suitable for potable use without appropriate treatment.

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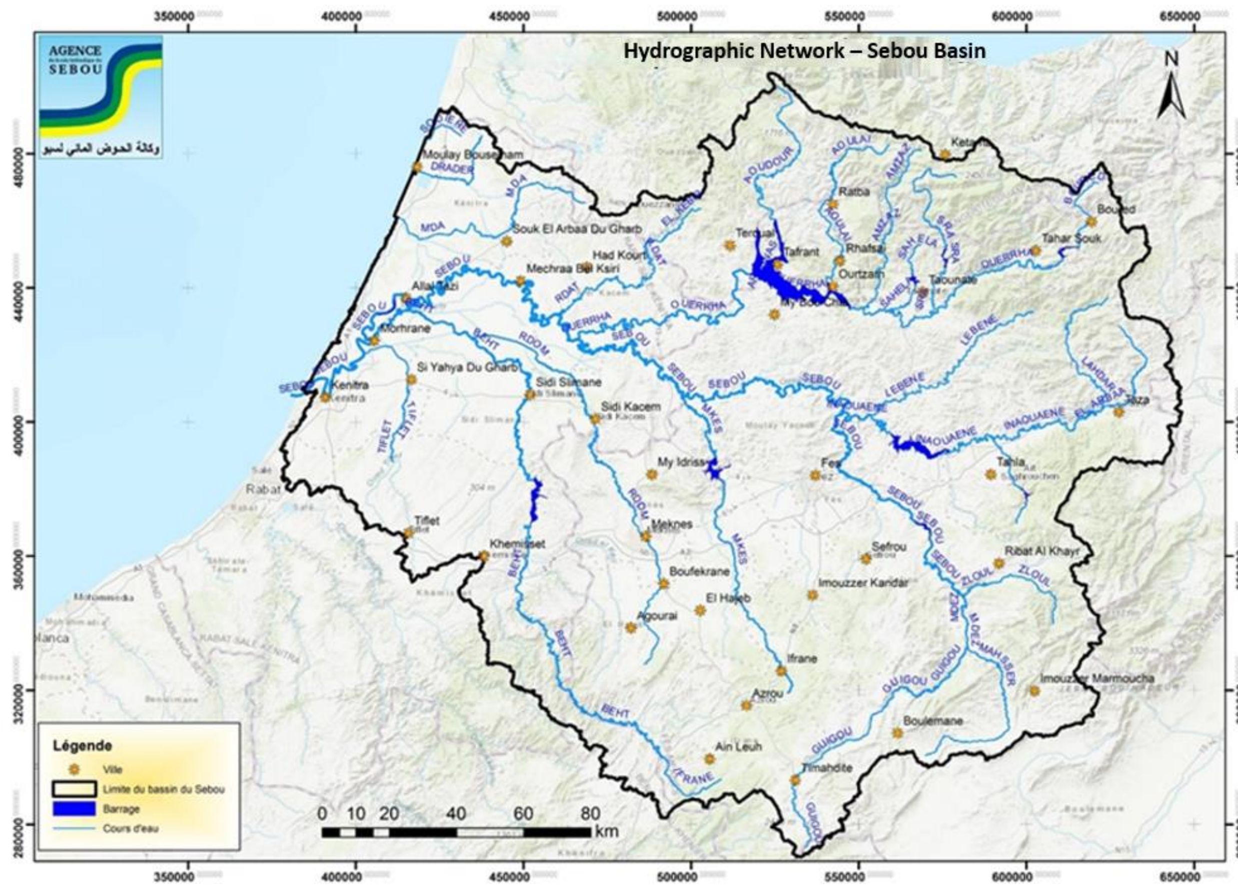

Figure 1.
Map of the study area (ABHS).

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Table 1.
Taux physico-chimiques des Cations et Anions dans les eaux de surface et de souterraines du Bassin Versant de Sebou

Stations		pH	NO3- mg/L	CL – mg/L	SO4-- mg/L	HCO3- mg/L	CO3- mg/L	Ca2+ mg/L	Mg2+ mg/L	K+ mg/L	Na+ mg/L	NH4+ mg/L	CE µs/cm
S1	Summer	8.40	9.30	215	312.65	230	13	97.8	88.70	7.15	1430	0.17	1160
	Winter	8.65	7.33	204	302.11	227	12	91.22	84.3	4.57	1301	0.11	1002
S2	Summer	8.32	10.36	160	150.75	210	14	120	43.60	2.84	1220	0.48	1120
	Winter	8.52	8.33	150	147.33	207	13	113.11	41.2	2.64	1110	0.33	912
S3	Summer	8.32	0.47	200	142.27	211	5	127.7	54.40	5.64	1500	0.08	1225
	Winter	8.40	0.4	185	130.33	213	5	122.3	52.1	5.64	1292	0.06	813
S4	Summer	8.30	17.20	150	131.18	270	0	166.4	15.78	4.82	1350	0.24	1240
	Winter	8.50	10.66	138	123.12	266	0	160.3	15.3	4.82	1190	0.16	928
S5	Summer	8.4	63.44	240	172.15	240	0	152.3	41.50	9.58	1870	0.19	1410
	Winter	8.6	48	228	160.5	241	0	145.5	40.3	9.50	1684	0.11	1123
S6	Summer	8.06	20.44	202	141.21	360	10	169.8	64.70	4.57	1330	0.67	1470
	Winter	8.12	18.34	210	134.11	363	9	161.1	63.4	4.52	1202	0.56	1011
S7	Summer	8.3	86.93	275	175.14	240	21.12	147.6	50.40	4.57	1455	0.50	2334
	Winter	8.64	69	260	150.33	236	21	143.44	48.7	7.30	1301	0.44	1566
S8	Summer	8.2	190.50	376	229.47	322	13	225.4	109.70	12.78	1855	0.67	624
	Winter	8.40	149.44	370	211.11	313	12	220.4	103.4	11.89	1706	0.56	520
S9	Summer	8.12	830.88	239	103.18	76	0	220.3	15.6	3.74	52	1.64	16320
	Winter	8.44	730.33	230	91.11	59	0	215.4	13.6	4.11	47	1.34	13750
S10	Summer	8.23	265.22	868	110.17	122	18	916.7	23.00	5.08	140	15.44	11750
	Winter	8.43	230.66	855	100.14	114	17	905.33	18.4	5.11	116	15.3	9215
P1	Summer	8.42	240.20	268	38.48	100	0	148.6	22.54	6.85	188	0.55	11770
	Winter	8.65	155.33	260	30.11	95	0	142.22	21.3	5.71	163	0.44	9218
P2	Summer	8.32	884.10	475	268.14	90	0	150.8	36.40	17.68	370	2.54	22210
	Winter	8.52	698.22	456	249.22	84	0	146.5	33.4	16.27	332	2.4	19333
P3	Summer	8.32	93.51	476	346.42	258	45	317.8	110.70	9.54	2553	1.26	2220
	Winter	8.76	60.44	459	323.22	245	43	312.22	108.3	8.89	2210	1.1	812
P4	Summer	8.05	164.21	396	435.25	178	43	170.6	65.80	15.85	130	1.28	16540
	Winter	8.5	120.44	388	402.22	165	40	162.2	60.4	14.22	93	1.3	12889
P5	Summer	8.4	58.85	303	238.5	242	13	145.7	92.60	8.12	400	1.54	1750
	Winter	8.6	38.44	291	230.11	234	13	143.22	88.3	7.38	311	1.38	1123
P6	Summer	8.06	686.85	147	55.42	105	15	174	400.00	2.73	107	1.50	730
	Winter	8.12	544.66	140	50.2	94	14	170.4	387.3	1.98	73	1.3	611
P7	Summer	8.3	396.25	148	58.45	103	18	178	100.50	3.14	109	1.80	840
	Winter	8.64	263.33	143	51.22	93	16	164.2	93.4	2.88	82	1.5	723
P8	Summer	7.9	62.47	138	298.4	148	13	180.4	120.50	6.54	430	0.87	250
	Winter	8.4	43.11	133	280.22	142	11	170.33	118.3	5.22	399	0.67	202
P9	Summer	8.09	118.54	128	148.24	118	30	165.4	63.80	5.24	120	0.25	1030
	Winter	8.49	87.55	120	120.3	118	27	160.3	61.3	4.01	103	0.2	912
P10	Summer	8.23	136.2	173	160.24	16	10	250.4	66.90	4.63	230	0.17	1230
	Winter	8.66	89.33	170	130.22	15	7	242.1	63.6	3.33	205	0.11	1002

Note: S : Stations des eaux de surface / P : Stations des eaux souterraines.

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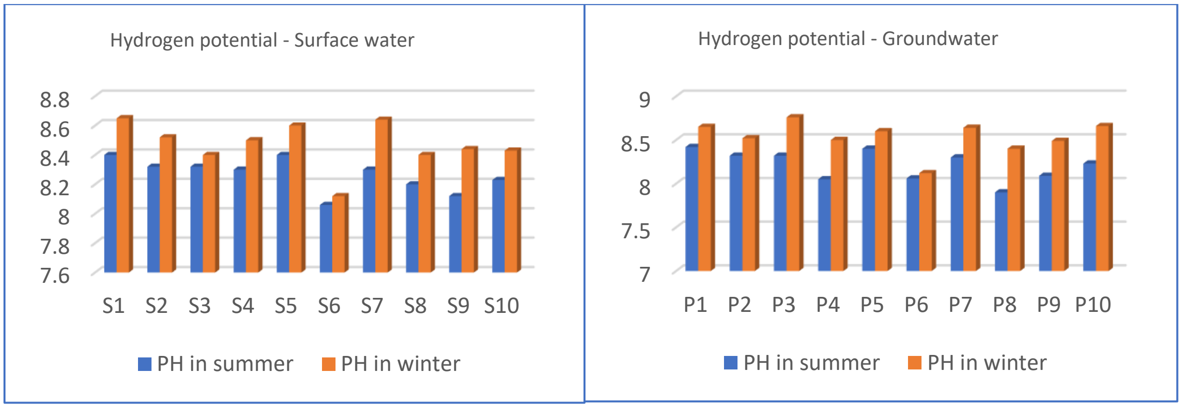

Figure 2.
Spatial variation of pH values in surface and groundwater in the Lower Sebou watershed.

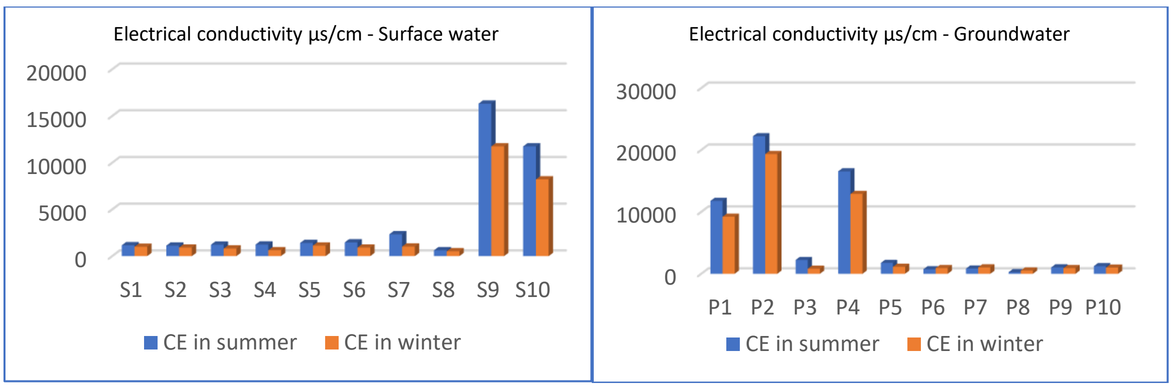

Figure 3.
Spatial variation of electrical conductivity (EC) values in surface and groundwater of the Sebou watershed.

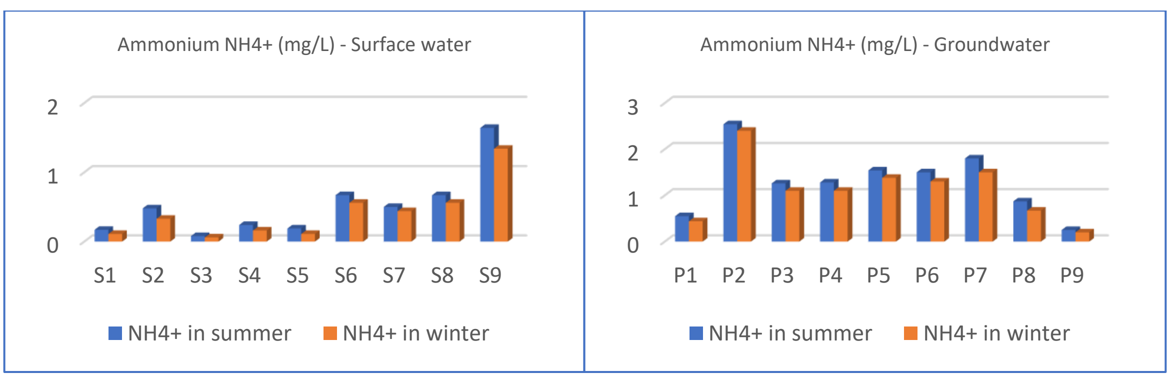

Figure 4.
Spatial variation of ammonium concentrations in surface and groundwater of the Sebou River basin.

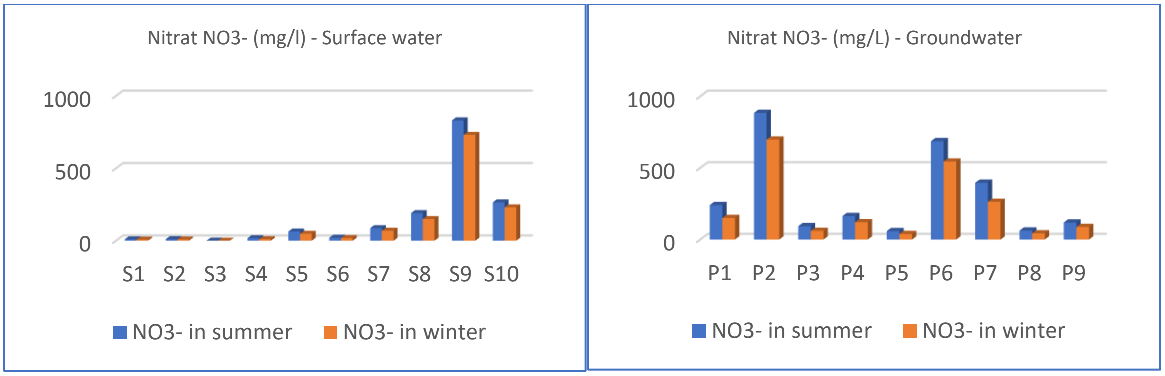

Figure 5.
Spatial variation of nitrate concentrations in surface and groundwater of the Sebou River basin.

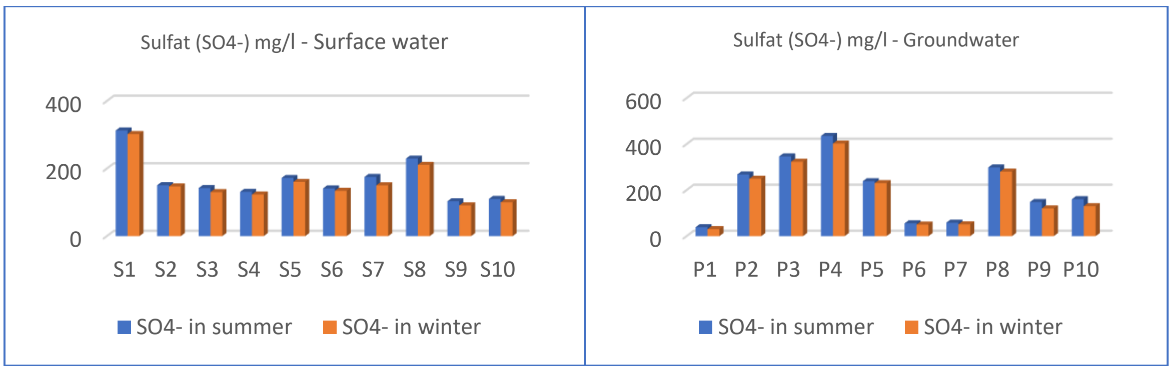

Figure 6.
Spatial variation of sulfate concentrations in surface and groundwater of the Sebou River basin.

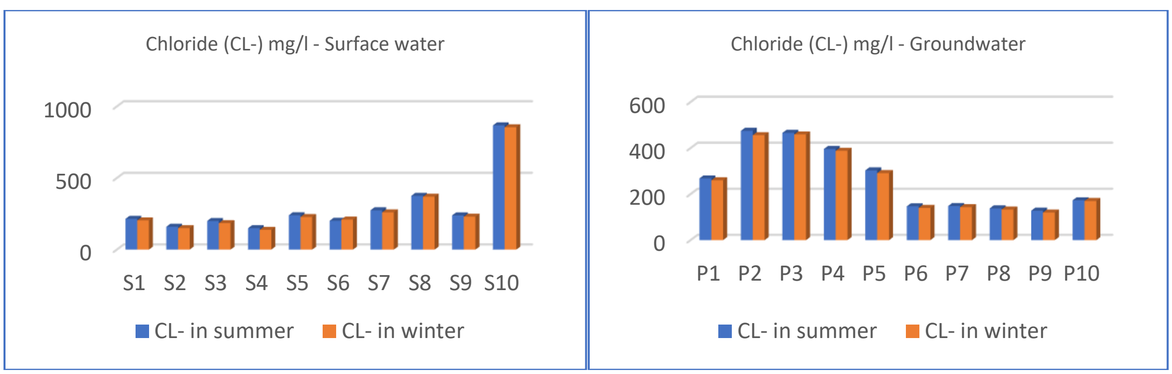

Figure 7.
Spatial variation of chloride concentrations in surface and groundwater of the Sebou River basin.

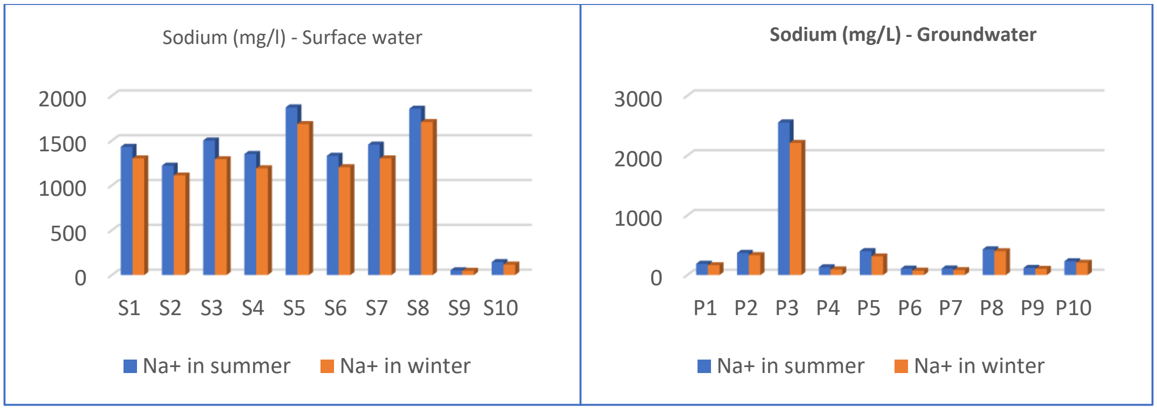

Figure 8.
Spatial variation of sodium concentrations in surface and groundwater of the Sebou River basin.

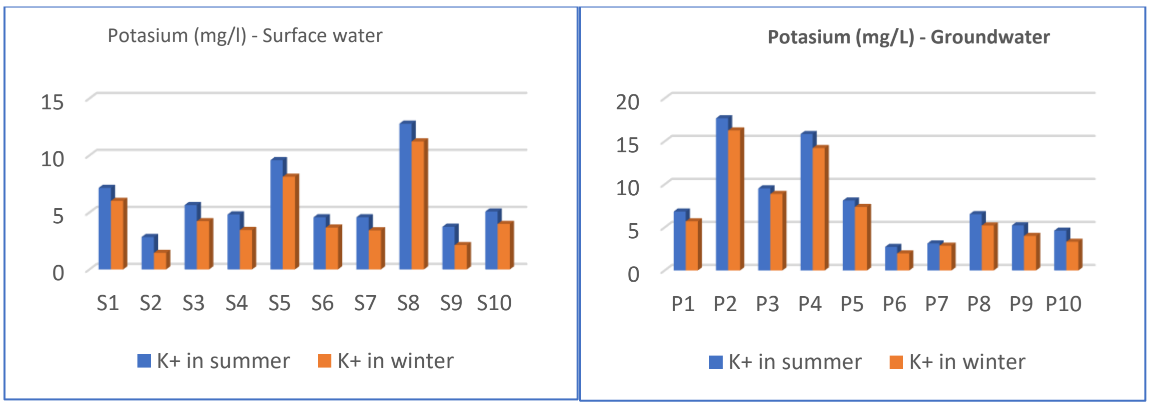

Figure 9.
Spatial variation of potassium concentrations in surface and groundwater of the Sebou River basin.

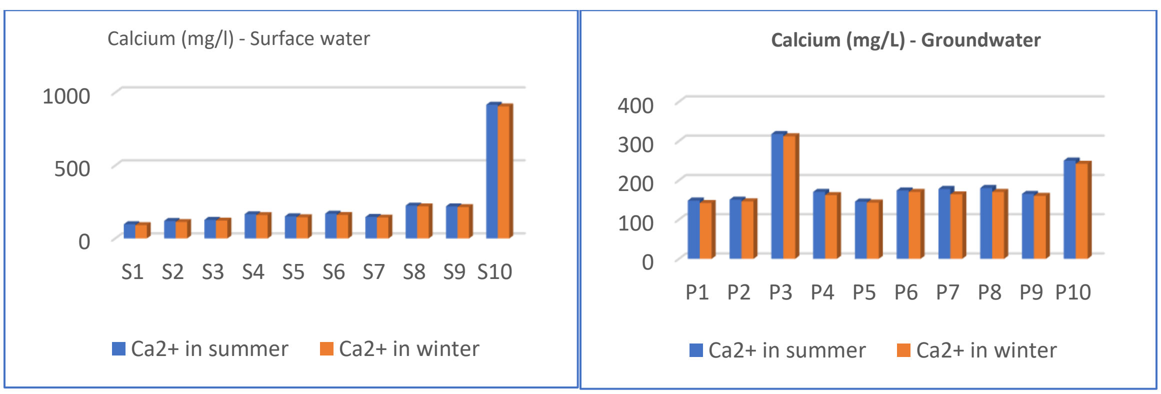

Figure 10.
Spatial variation of calcium concentrations in surface and groundwater of the Sebou River basin.

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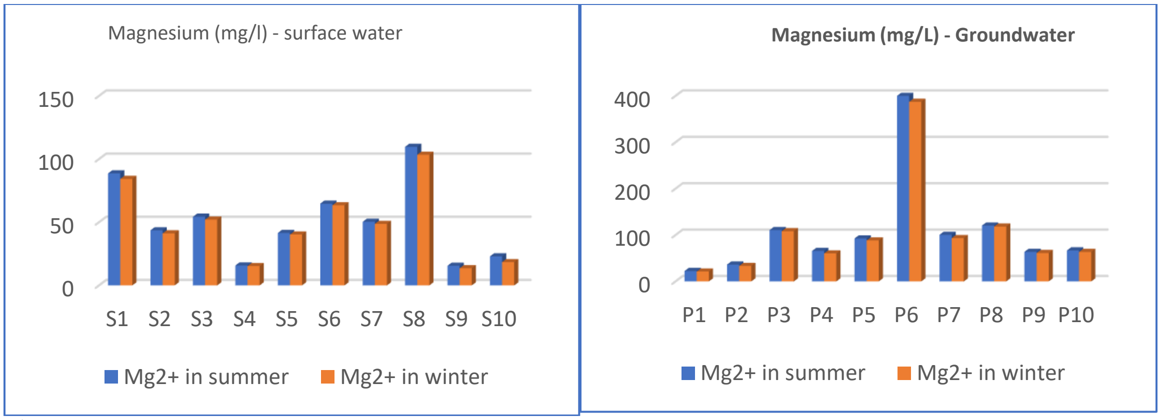

Figure 11.
Spatial variation of magnesium concentrations in surface and groundwater of the Sebou River basin.

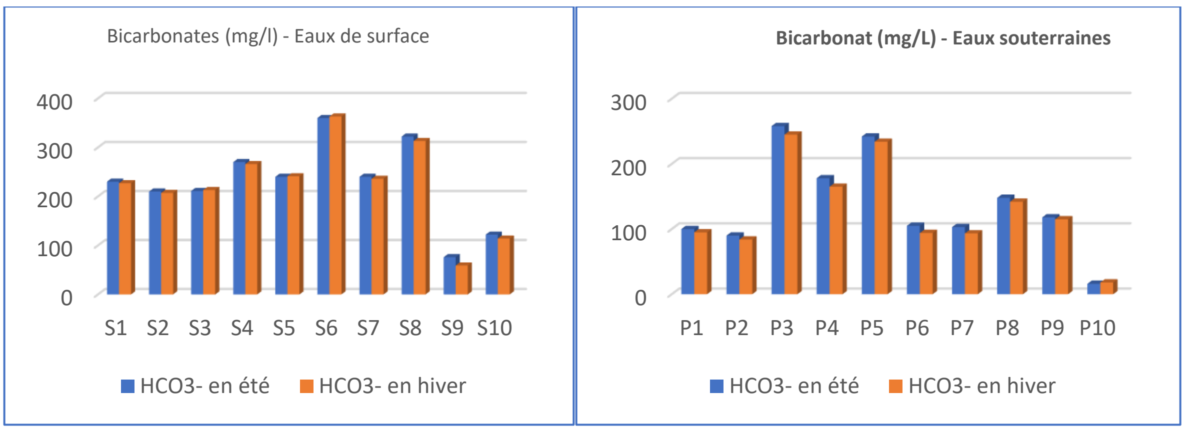

Figure 12.
Spatial variation of bicarbonate levels in surface and groundwater in the Sebou River basin.

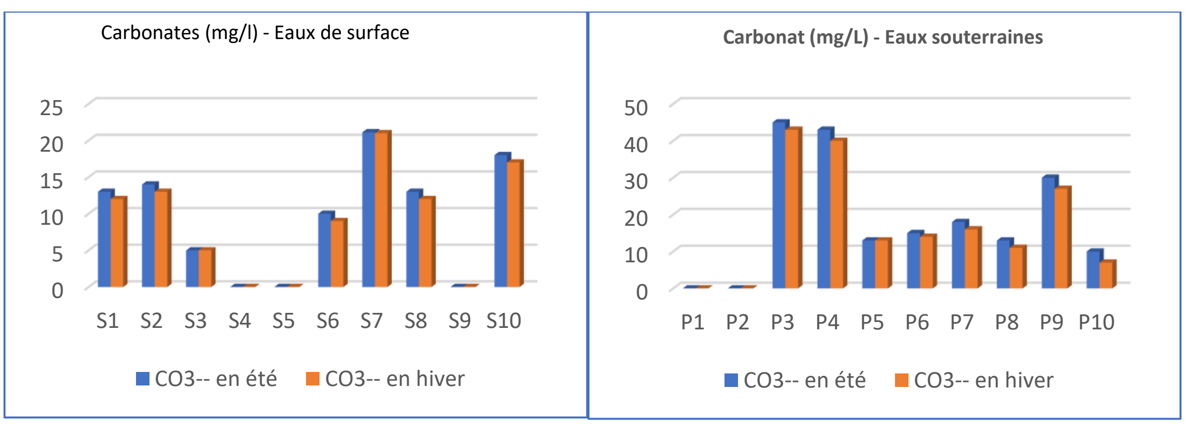

Figure 13.
Spatial variation of carbonate levels in surface and groundwater in the Sebou River basin.

3.4. Nitrates (NO_3^-)

In surface waters, nitrate concentrations range from 0.4 mg/L to 730.33 mg/L during the winter period and from 0.47 mg/L to 830.88 mg/L during the summer period (Figure 5). The results show relatively low seasonal variations. The low nitrate concentrations could be attributed to the limited use of chemical fertilizers and pesticides in local agricultural activities. In groundwater, nitrate concentrations range between 58.85 mg/L and 884.10 mg/L in summer, and between 38.44 mg/L and 698.22 mg/L in winter (Figure 5). Here too, seasonal variations remain minor. The results indicate that only 50% of the samples collected during the two studied seasons comply with the Moroccan standard for irrigation water. It is important to note that several stations do not meet Moroccan standards [9], particularly, the winter standard for drinking water is < 50 mg/L. Nitrate concentrations found in the groundwater of the study area are similar to results obtained in the Lower Moulouya, confirming an anthropogenic origin of nitrates [6]. Abnormally high nitrate levels have also been reported in other regions, such as Laafou et al. [10], the sources of El Kharmouz et al. [11] as well as in the groundwater of the cities of Kahoul et al. [12] and Abbou et al. [13]. Similar concentrations have been reported in groundwater from Taza [14, 15]. The increase of nitrates in groundwater is mainly due to the use of chemical fertilizers in agriculture. Furthermore, heavy rainfall and the absence of vegetation cover promote nitrate leaching into the Sidi Taibi aquifer [16].

The winter period represents a critical phase for the leaching of excess nitrogen into groundwater, particularly in the Rhine Valley in France [17]. In our study, nearly all analyzed water sampling points exceed the maximum allowable value (MAV) of 50 mg/L, as defined by both the Moroccan standard [15] and the WHO guidelines for drinking water [10]. These results indicate a significant deterioration in water quality within the study area.

3.5. SULFATES ($SO4^{2-}$)

The sulfate concentrations in surface waters range from 103.18 mg/L to 312.65 mg/L in winter and from 91.11 mg/L to 302.11 mg/L in summer (Figure 6). These values show minor seasonal variations. According to this study, 90% of the analyzed samples comply with the Moroccan standard for irrigation (<250 mg/L). In groundwater, sulfate concentrations vary between 38.48 mg/L and 435.25 mg/L in summer, and between 30.11 mg/L and 402.22 mg/L in winter (Figure 6). These results show slight seasonal variations. However, 100% of the wells in the region comply with the WHO standard for drinking water (<500 mg/L).

3.6. CHLORIDES (Cl^-)

In the surface waters of Upper Sebou, chloride concentrations vary between 150 mg/L and 868 mg/L in summer and between 138 mg/L and 855 mg/L in winter (Figure 7). These results do not show significant seasonal variations. About 25% of the sampled stations do not comply with the Moroccan standard for irrigation (350 mg/L, Ministry of Environment, 2007). In groundwater, chloride concentrations range from 120 mg/L to 459 mg/L in winter and from 138 mg/L to 476 mg/L in summer. Seasonal variations remain small (Figure 7). According to the WHO standard, the maximum recommended concentration for drinking water is 250 mg/L. According to this study, 41% of wells exceed this limit, indicating strong mineralization of groundwater in the study region.

3.7. SODIUM (Na^+)

Sodium concentrations in the surface waters of Upper Sebou range from 52 mg/L to 1,870 mg/L in winter and from 47 mg/L to 1,684 mg/L in summer. These results show marked seasonal variations (Figure 8). About 85% of sampled stations exceed the Moroccan standard for irrigation (<350 mg/L, [9]. In groundwater, sodium concentrations vary between 73 mg/L and 2,210 mg/L in winter and between 107 mg/L and 2,553 mg/L in summer. These results show significant seasonal variations (Figure 8). All analyzed water points exceed the guideline value of 20 mg/L recommended for drinking water [18]. These results are consistent with those obtained in the Mrzuq aquifer in Libya [19]. The deterioration of water quality in the studied region can be attributed to discharges containing high amounts of sodium, as well as intensive use of this element in agriculture. It should be noted that the alkalinity of irrigation water is assessed using the SAR (Sodium Adsorption Ratio). A high SAR indicates an increased risk of soil sodicity, due to exchange between sodium in the soil solution and calcium/magnesium in the adsorptive complex [20].

3.8. POTASSIUM (K^+)

Potassium contents in surface waters of Upper Sebou in winter range from 2.84 mg/L to 12.78 mg/L (Figure 9) and in summer range from 2.84 mg/L to 12.78 mg/L. These results do not show large seasonal fluctuations. It is observed that, except at station (S8) in both seasons, there is a slight increase in potassium concentrations. Apart from this, all contents do not exceed the usual threshold in natural waters (10 mg/L) [5]. Potassium levels recorded in the studied groundwater vary in winter from 1.98 mg/L to 16.27 mg/L and in summer from 2.73 mg/L to 17.68 mg/L. These results do not show significant seasonal variations (Figure 9). During the study period, in both seasons, potassium ion values in all sampled water points, except station (P2), are below the maximum admissible value of 15 mg/L according to the Moroccan standard related to drinking water quality. These results allow us to conclude that the chemical quality of groundwater in the study region is acceptable in terms of potability.

3.9. CALCIUM (Ca^{2+})

Calcium contents in surface waters of the Upper Sebou vary from 97.8 mg/L to 916.7 mg/L in summer and from 91.22 mg/L to 905.33 mg/L in winter. These results do not show significant seasonal variation. In groundwater, analyses show calcium contents varying from 145.7 mg/L to 317.8 mg/L in summer and from 143.22 mg/L to 312.22 mg/L in winter (Figure 10). According to WHO standards related to drinking water, optimal calcium concentrations are between 70 and 200 mg/L. The results indicate that calcium contents in 80% of the studied wells, during both seasons, comply with the WHO drinking water standards.

3.10. MAGNESIUM (Mg^{2+})

Measured magnesium [Mg^{2+}] values in examined surface waters range from 15.6 mg/L to 109.7 mg/L during the summer season and between 13.6 mg/L and 103.4 mg/L during the winter season. These results do not show notable large seasonal fluctuations. Magnesium [Mg^{2+}] values recorded in the studied groundwater range from 21.3 mg/L to 387.3 mg/L during the winter season and between 22.54 mg/L and 400 mg/L during the summer season (Figure 11). According to WHO standards related to drinking water, optimal magnesium concentrations are between 50 and 150 mg/L. The results show that magnesium contents in 90% of the studied wells comply with the WHO drinking water standards.

3.11. BICARBONATES ($HCO3^-$)

In surface waters, bicarbonate contents in stations sampled in summer ranged between 76 mg/L and 360 mg/L, and in winter between 59 mg/L and 363 mg/L. These results do not show notable large seasonal fluctuations. It is noted that 100% of stations studied in winter and summer comply with the Moroccan standard set at 518 mg/L for surface waters used for irrigation. Bicarbonate contents in the studied groundwater in summer ranged between 16 mg/L and 258 mg/L (see Figure 12), and in winter between 15 mg/L and 245 mg/L. These results do not show significant seasonal differences. The maximum recommended concentration by WHO for bicarbonates in drinking water is 400 mg/L. According to this study, 100% of sampled wells comply with this WHO guideline, indicating acceptable water quality for human consumption.

3.12. CARBONATES ($CO3^{2-}$)

In surface waters, carbonate contents in stations sampled in summer ranged between 0 mg/L and 21.12 mg/L, and in winter between 0 mg/L and 21 mg/L (Figure 13). These results do not show significant seasonal differences. All analyzed stations comply with the Moroccan standard for surface waters used for irrigation.

In groundwater, carbonate contents in studied wells ranged in summer from 0 mg/L to 45 mg/L, and in winter from 0 mg/L to 43 mg/L (Figure 13). These results do not show notable large seasonal fluctuations. It is observed that 100% of wells comply with the WHO guideline.

4. Conclusion

The physico-chemical characterization of the raw surface waters of the upper Sebou basin showed that this Oued (river) is heavily loaded with mineral matter both in summer and winter. Regarding pH, there is a seasonal variation but it is not very significant; the average pH ranges between 8.06 and 8.65, so it is basic but remains acceptable according to irrigation standards. Concerning electrical conductivity, the results show a noticeable but small seasonal variation. There is a wide variation in the chemical composition of the waters, which varies between a minimum of 520 µS/cm and a maximum of 16,320 µS/cm. The increase in conductivity during the hot period can be related, on one hand, to the low flow rate of the Oued, which leads to increased concentrations of mineral salts, and on the other hand, to strong atmospheric evaporation [3]. Conversely, the minimum values recorded during the rainy period could be attributed to precipitation, which causes a dilution effect on the waters mainly due to underground runoff sources originating from the mountains of the Middle Eastern Atlas and the high plateaus, such as the Jorf Lahmam spring, according to Nassali et al. Nitrates vary from 0.40 to 830.88 mg/L, chlorides vary from 138 to 868 mg/L, sulfates vary from 91.11 to 312.65 mg/L, and sodium varies from 47 to 1870 mg/L; none of these elements show significant seasonal variation.

We conclude that the upper Sebou sub-basin, whose mineralization closely follows the rates of dissolved salts, salinity, chlorides, sodium, and potassium, is subjected to various types of pollution mainly of natural origin primarily mineral pollution from the dissolution of the natural limestone substrate, karstic processes, Atlantic tides, and oceanic spray as well as anthropogenic pollution from agricultural, industrial, and urban activities. The values found are not always in compliance with irrigation standards. In conclusion, it appears that the surface waters of the upper Sebou carry a high mineral load but remain in conformity with Moroccan irrigation standards.

Analyses of groundwater show that pH varies from 8.09 to 8.42 during the winter season and from 7.9 to 8.66 during the summer season; these waters are slightly more acidic in the dry season than in the rainy season. This acidity variation could be due, on one hand, to the evaporation of well water, which is quite significant during the dry season [21], and on the other hand, the concentration of H+ ions and especially free CO_2 in the soil is significant. Indeed, in humid tropical zones, this acidity mainly results from the decomposition of plant organic matter, which produces CO_2 in the upper soil layers. The presence of soil-derived CO_2 in water facilitates the hydrolysis of silicate minerals and the formation of HCO_3^- ions [22].

Electrical conductivity values range from 202 µS/cm to 19,333 µS/cm during the winter period and from 250 µS/cm to 22,210 µS/cm in the summer season. The low mineralization of groundwater during the rainy season is attributed to dilution caused by rainwater input, as most wells are not developed and receive runoff water directly. Nitrate concentrations vary from 58.85 mg/L to 884.10 mg/L in summer and from 38.44 mg/L to 698.22 mg/L in winter; these nitrate ion results also exhibit minor seasonal variations. Nitrates are the dominant nitrogen compound in the sampled well waters. This variability in well water quality can be explained by the concentration during the dry season and dilution during the rainy season of the ions in the sampled waters.

Sodium contents in surface waters of the upper Sebou vary from 52 mg/L to 1870 mg/L, and from 47 mg/L to 1684 mg/L during the summer season; these recorded results show seasonal variations. Concentrations of nitrates (NO_3^-), sulfate ions (SO_4^{--}), calcium, magnesium, potassium, calcium (Ca^{2+}), and potassium (K^+) do not show significant fluctuations between winter and summer. Potassium (K^+) concentration varies from 1.98 to 17.68 mg/L; chloride ion concentration has a maximum value of 475

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mg/L and a minimum value of 120 mg/L; ammonium concentration varies between 0.11 and 2.54 mg/L. The maximum and minimum bicarbonate ion concentrations are 258 mg/L and 15 mg/L, respectively, and these concentrations are compatible with irrigation standards. For magnesium ion (Mg2+), the maximum value is 400 mg/L and the minimum is 21.3 mg/L; sodium ion concentrations in water vary between 73 mg/L and 2553 mg/L.

The results showed that ammonium concentrations in 40% of the wells during both seasons and nitrate concentrations in 100% of the wells during both seasons were above WHO standards, indicating the presence of nitrogen pollution possibly originating from organic waste and excessive fertilizers used in agriculture, as well as domestic or industrial discharges. Similarly, electrical conductivity in 40% of the wells during both seasons, chloride concentrations in 41% of the wells during both seasons, and sodium concentrations in 41% of the wells during both seasons are quite high, corresponding to strong mineralization generally resulting from the nature of the wells, cross-contamination, industrial, or domestic pollution. The results of the other analyzed parameters comply with WHO guidelines.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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