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Article

Evaluation of spring water quality for drinking purpose within Brawary Shere District, Duhok Governorate, Kurdistan of Iraq

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Abstract
In this study, monthly samples were collected from the ten sources (S1÷S10) during August 2022÷March 2023. This article presents the assessment of spring water quality to determine its suitability for drinking, as it is consumed directly, without treatment. Our objective was to assess the spring water quality of Barwary village district and to determine water quality index and its criteria. Eighty water samples were collected and examined for a range of physical-chemical characteristics, including electrical conductivity, pH, temperature, dissolved oxygen, turbidity, total hardness, and various ions, following standard analytical procedures established by the American Public Health Association (APHA). The analytical results were compared with World Health Organization (WHO) drinking water limits. The results indicated contamination at several sampling locations, primarily due to elevated concentrations of zinc and lead. Other heavy metals, such as copper and iron, were detected at levels indicative of mild contamination. The final analysis classified the sampled locations into four main categories. According to the water quality classification, Site S4 (Jmanke) exhibited excellent water quality. Sites S2 and S6÷S8, together with Site S10, were classified as good, whereas Site S9 fell into the poor category. Sites S1 and S3 were categorized as very poor, while Site S5 was deemed unsuitable for drinking purposes. Lead removal treatment should be implemented at all sites, as the WHO guideline value of 10 µg/L is exceeded at every location.

Keywords*:* *drinking water, heavy metals, Kara Mountain, natural springs, Barwary Disrict*

INTRODUCTION

Water is essential to the growth of many different economic sectors, such as agriculture, fishing, forestry, the production of animal feed, the production of energy for industry, and many more creative endeavors [1]. Since water is the most necessary resource for both human and ecological survival, sustainable management of water resources is urgently needed [2]. The growing human population is causing excessive groundwater depletion and surface water contamination, which is increasing demand for water and endangering the sustainability of the freshwater supply [3]. This has led to severe water scarcity and poor water quality in many countries. Consequently, information regarding water resources and their suitability for human use is fundamental to the management of these resources. In arid and semi-arid regions with few water sources and declining average precipitation, this becomes increasingly important [4]. The quality of spring water varies from one spring to the next, leading to a variety of uses by consumers, including household, industrial, recreational, and agricultural applications. The quality of spring water is determined by a number of variables, including how the water interacts with the local geology, the minerals in an aquifer, how rocks and water interact, weathering products, the topography of the surrounding area, the climate, and human activity [5]. Unplanned development and population increase have adversely affected springs, leading to the depletion of this crucial water source across the whole Kurdistan region. Other climate changes, including less winter rainfall and higher air temperatures, also have an effect on spring water resources [6]. These days, access to clean water is the biggest problem facing society. The low quality of the water will produce an environment that is detrimental to humans and other living things health and safety. A decrease in water quality will also result in a reduction in the number of natural resources that are available due to the declines in carrying capacity, yield, productivity, and utility of water resources. Because of the various waste products from various human activities that pollute water, it is currently expensive to obtain clean water that satisfies standards. Water must satisfy a number of standards, such as quantity, quality, and continuity, in order to be utilized as a source of clean water and drinking water [7]. The global water quality index has been utilized to determine the general state of the water in a certain region [8]. Water quality assessing approaches are considerably based on the comparison of experimental parameter values with the values of the current guidelines [9].

In the Kurdistan region, springs, rivers, dams, and groundwater are the primary sources of water for human consumption. Geographical location and environmental factors, including soil formation, precipitation inputs, and the chemical composition of the underlying rocks, and the amount of time the water body has been trapped underground, all affect the quality and quantity of these water sources [10].

The most common source of drinking water for rural populations in the hilly Barwary District of the Duhok governorate consist in spring water, represented also the main source of freshwater for agriculture, and industry. In light of the aforementioned, the current study evaluates the physical-chemical parameters and uses the Water Quality Index as a useful instrument for spring water quality monitoring in the Barwary village of Kurdistan of Iraq.

MATERIALS AND METHODS

Case study

Spring water samples were collected from the Kara Mountain, situated in Barwary District of the Duhok Governorate in Iraq. Kara Mountain is situated in the Barwary District, which is 42 kilometers far from the governorate of Duhok and it is located in north Iraq, near the borders of both Syria and Turkey, at longitudes 43.20 and 44.10 and latitudes 36.40 and 37.20.

One water sample was collected monthly from each spring between August 2022 and March 2023. Barash (S1), Spendare (S2), Siare (S3), Jamanke (S4), Kanimaze (S5), Kavarky (S6), Shkafty (S7), Swratok (S8), Baramenk (S9), and Sedara (S10) were the springs selected and located within Kara Mountain. The locations of the sampling points are presented in Fig.1.

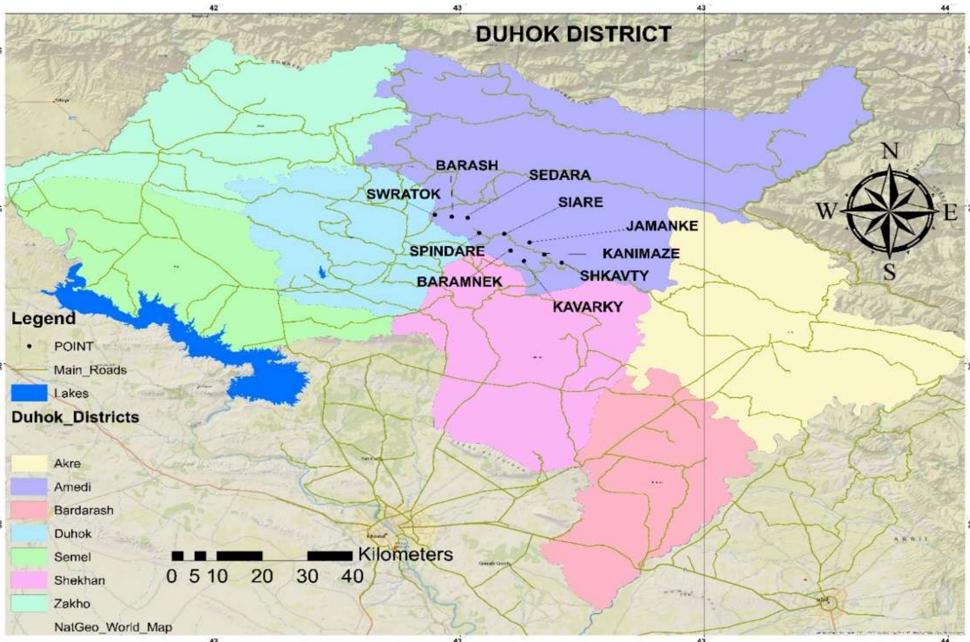

Fig.1. Study area (Barwary Shere, Duhok, Iraq)

Sample collection

In order to prevent any potential contamination during bottling, spring water samples were collected in one-liter polythene bottles individually, without the presence of air bubbles. Before the collection, the polythene bottles were carefully cleaned and rinsed with the sample. After collection, the bottles were securely sealed and labeled in the field. At the time of sample collection, the temperatures of the samples were recorded on the spot in the field. Finally, the samples were sent to Zakho University for analysis while being stored in a refrigerator at 4°C.

Physical and chemical determinations

To prevent significant physical and chemical changes, the collected samples were analyzed immediately in the environmental laboratory. Using conventional procedures, the samples were examined for total hardness (TH), pH, total alkalinity (TA), electrical conductivity (EC), total dissolved solids (TDS), sulfate (SO_4^{2-}), magnesium (Mg^{2+}), chlorides (Cl^-), and calcium (Ca^{2+}) [11].

Statistical analysis

To improve the reliability and accuracy of the results, each parameter was measured once per month for eight consecutive months, and the resulting data were subjected to statistical analysis. Each monthly measurement has been repeated 3 times and the mean of these three measurements has been considered. The results were expressed as mean ± standard deviation of three replicates. The collected data were analyzed using SPSS (version 15 Inc., USA). The values of $p<0.05$ were considered statistically.

Water quality index (WQI) calculations

WQI has been extensively utilized as a reliable approach for assessing and monitoring surface water and groundwater quality. It serves as a valuable tool in the design and implementation of water-quality improvement and management strategies. In addition, WQI facilitates the classification of water samples into five distinct quality categories based on a range of physicochemical parameters, including mineral content, heavy metal concentrations, and potential sources of contamination. The methodology adopted in this study aggregates data obtained from different sampling locations and time periods into a single index value, thereby providing an integrated representation of water quality across both spatial and temporal scales [12]. In addition, water quality index equation was applied and the resulted values were compared to WHO limits for drinking water quality, the equation used and the categorization of the water sample is shown in the equation (1) [13].

$$WQI = \sum_{i=1}^{i=n} w_i \times q_i / \sum w_i \quad (1)$$

where: w_i: the relative weight of each water quality parameter; q_i: a measure of the degree of quality for each water quality parameter.

The relative weight (w_i) value was calculated using the following equation (2):

$$w_i = 1/s_i \quad (2)$$

where: s_i is the recommended value from the WHO.

q_i value was calculated using the equation (3):

$$q_i = c_i / s_i \times 100 \quad (3)$$

where: c_i is measured value for each water quality parameter and s_i is the recommended value from the WHO.

The computed WQI values were then classified into five categories in order to determine the water quality status (WQS) as shown in Table (1).

Table 1. Classification of water quality depending on WQI values [14]

Water Quality Index Level	Water Quality Status
< 50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
> 300	Unsuitable

RESULTS AND DISCUSSION

Water temperature (T, ºC)

Among the various water-quality parameters, temperature is of particular importance, as it governs many of the chemical, physical, and microbiological changes that occur within a water body [15]. The temperature of the spring water varied from 11.0°C to 22.6°C, according to the measured data (Fig. 2). At the Jamanke location, the greatest spring water temperature was measured in February, whereas at the Swaratoka location, the lowest temperature was measured in November. The observed values fell within the permissible ranges established by international guidelines. Comparable outcomes were documented by Mohammed et al. in 2020 [16].

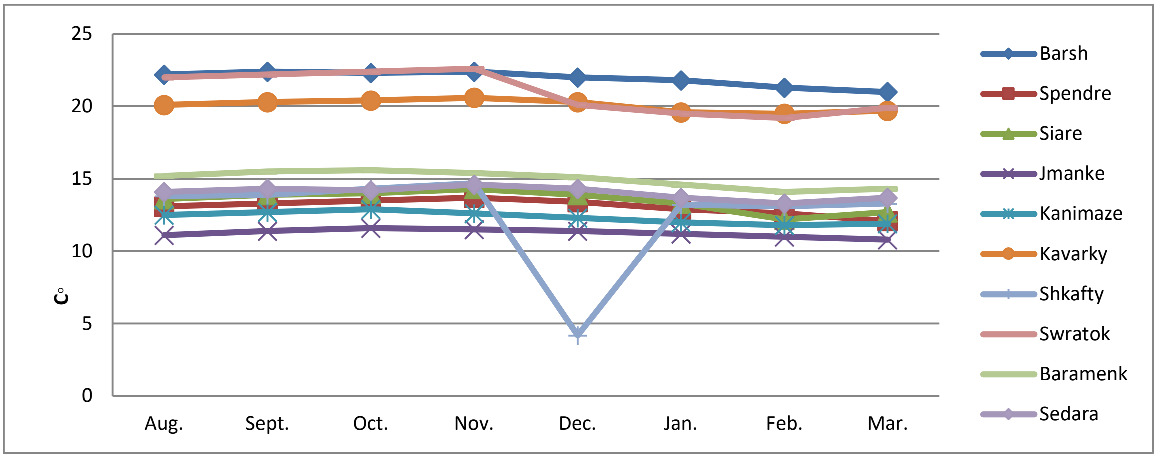

Fig. 2. Monthly variation of temperature (ºC) between selected spring water

Electrical conductivity (EC, µs/cm)

Temperature has a significant influence on EC because it affects the mobility of ions in solution. Electrical conductivity is an important indicator of water mineralization and varies according to the concentration of dissolved salts present in the water [17]. In the study area, EC values ranged from 444 to 999 µS/cm. These variations can be attributed to differences in soil composition, agricultural activities, and geological formations across the region. All measured EC values were below the permissible limit of 2000 µS/cm established by the WHO guidelines (Fig. 3) [18]. Accordingly, the spring water in the study area can be considered to be of good quality with respect to electrical conductivity. Furthermore, the recorded EC values were lower than those reported by Aniqa et al., indicating comparatively lower levels of dissolved mineral content in the investigated springs [19].

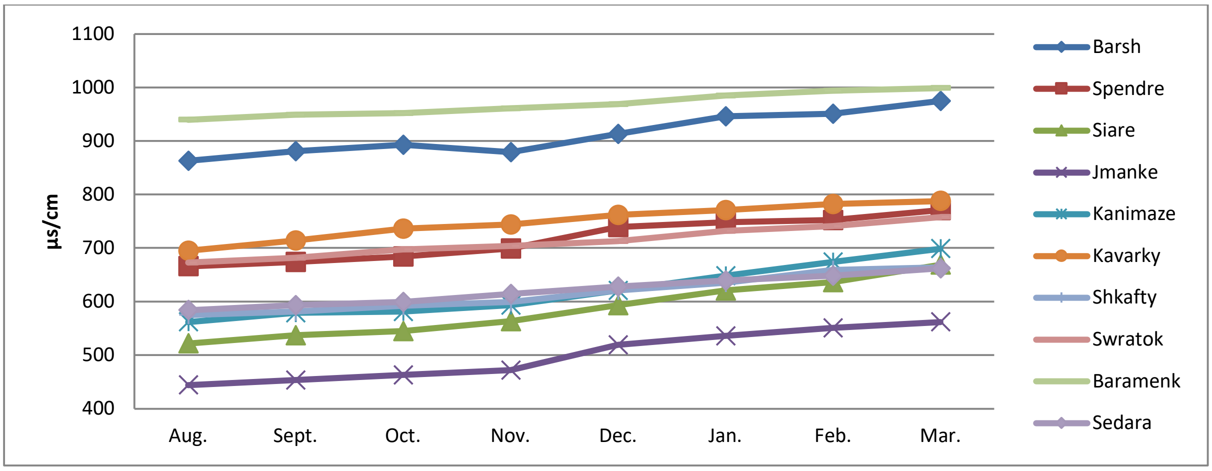

Fig. 3. Monthly variation of Electrical conductivity of spring water µS/cm

Total dissolved solid (TDS, mg/L)

The TDS in the current study ranges from 284 to 639 mg/L (Fig. 4). In the summer and winter, TDS concentrations in spring water samples from two locations (Barash and Baramenk) are higher than the allowable limit of 500 mg/L [18]. The elevated concentration of TDS in the groundwater may be attributed to the geochemical characteristics of the geological formations through which the water flows, as well as to the application of agricultural fertilizers. The remaining results, however, were all within the WHO's recommended levels for drinking water [18]. Our findings differ from what Snehalata and Kiran reported in their study [20].

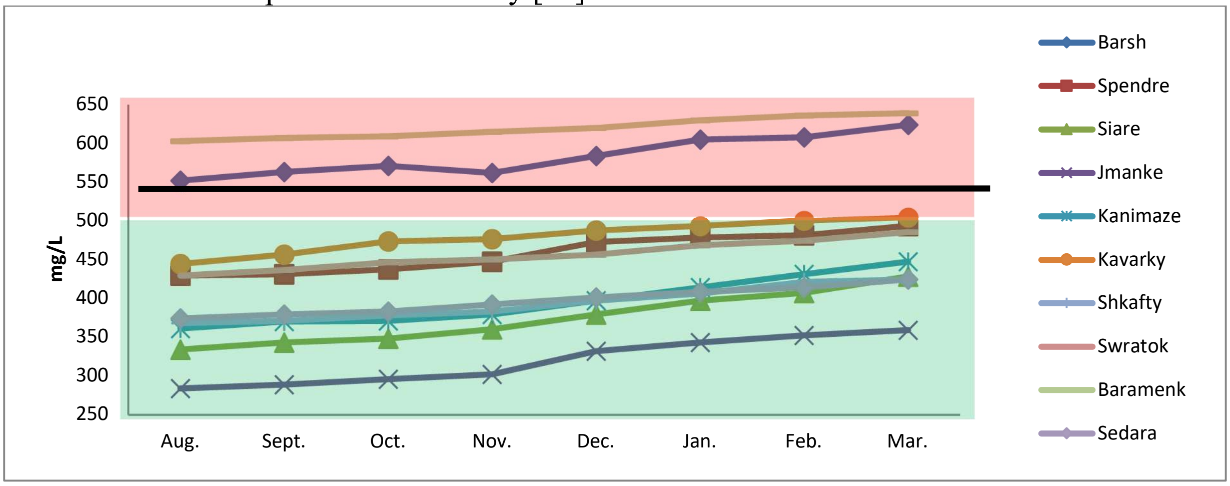

Fig. 4. Monthly variation of total dissolved solids of spring water mg/L

pH

The pH values of the spring water measured during the summer and winter seasons at the investigated sites ranged from 6.7 to 8.2 (Fig. 5). At all sampling locations, the pH values remained within the safe and acceptable range of 6.5÷8.5 recommended by WHO [18]. The lowest pH value was recorded in September, whereas the highest value was observed in February. These variations may be attributed to seasonal fluctuations and differences in the geological characteristics of the study area. Overall, the results indicate that the spring water was slightly acidic to moderately alkaline and suitable for consumption with respect to pH. Furthermore, the pH values reported in the present study were lower than those documented by Mohamed and Zahir [21].

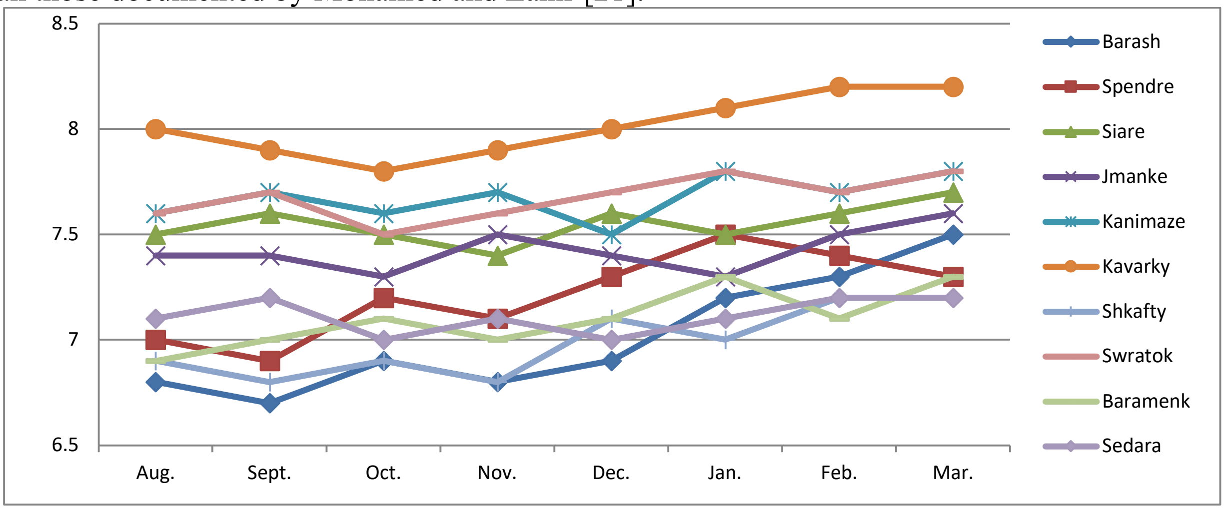

Fig. 5. Monthly variation of pH value between selected spring water

Dissolved oxygen (DO, mg/L)

The dissolved oxygen (DO) concentrations in the spring water samples ranged from 6.5 to 8.5 mg/L. The highest DO concentration was recorded at the Jamanke site in March, whereas the lowest concentration was observed at the Baramenk site in October. Variations in dissolved oxygen levels can be attributed to changes in water temperature and salinity, both of which influence oxygen solubility. Overall, the measured DO concentrations indicated good water quality across all sampling locations (Fig. 6). Furthermore, the dissolved oxygen levels recorded in this study were higher than those reported in previous studies [22]. Although WHO does not establish a health-based guideline value for dissolved oxygen in drinking water, DO concentrations above 6 mg/L are generally considered indicative of well-oxygenated water [18]. Therefore, all spring water samples examined in this study exhibited satisfactory dissolved oxygen levels.

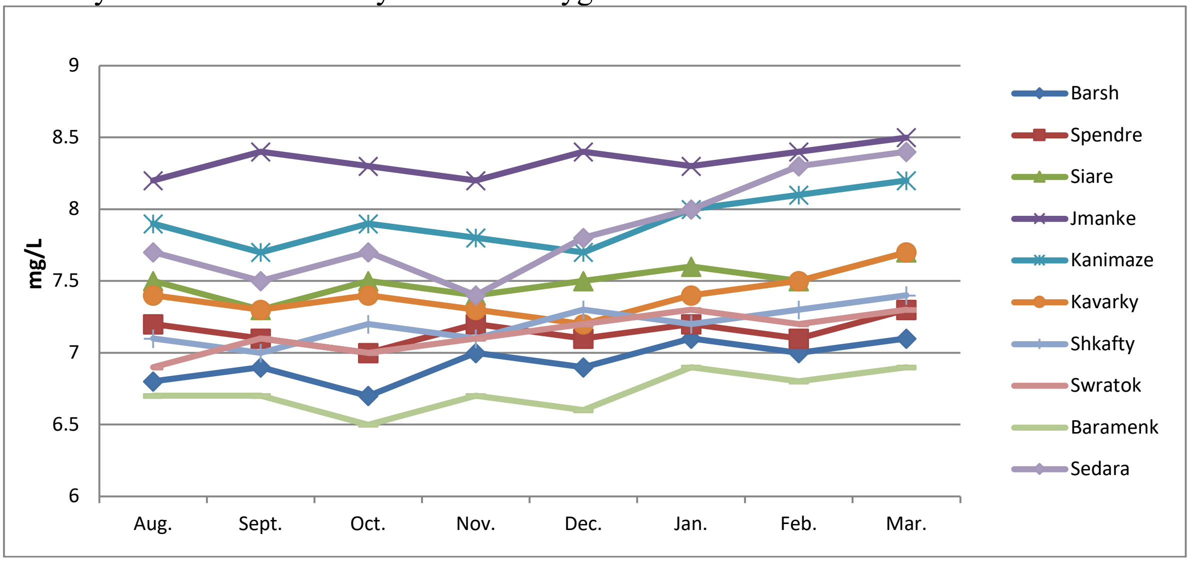

Fig. 6. Monthly variation of Dissolved oxygen between selected spring water mg/L

Total hardness as $CaCO_3$ (TH, mg/L)

The total hardness (TH) of spring water is largely influenced by the geological formations within the aquifer system. Spring water typically exhibits high hardness levels when it interacts with carbonate-rich rocks, such as limestone and dolomite. In the present study, total hardness values ranged from 222 to 483 mg/L. The highest TH concentration (483 mg/L) was recorded at the Barash site in March, whereas the lowest value (222 mg/L) was observed at the Jamanke site in August. The hardness of spring water is primarily attributed to the presence of bicarbonates, carbonates, chlorides, and sulfates of calcium and magnesium. According to the results presented in Fig. 7, water samples with hardness values between 200 and 300 mg/L were classified as *hard*, while those exceeding 300 mg/L were categorized as *very hard*. These findings are consistent with the results reported in previous studies [23]. The observed hardness levels reflect the hydrogeochemical interactions between groundwater and the surrounding rock formations, which contribute dissolved calcium and magnesium ions to the water.

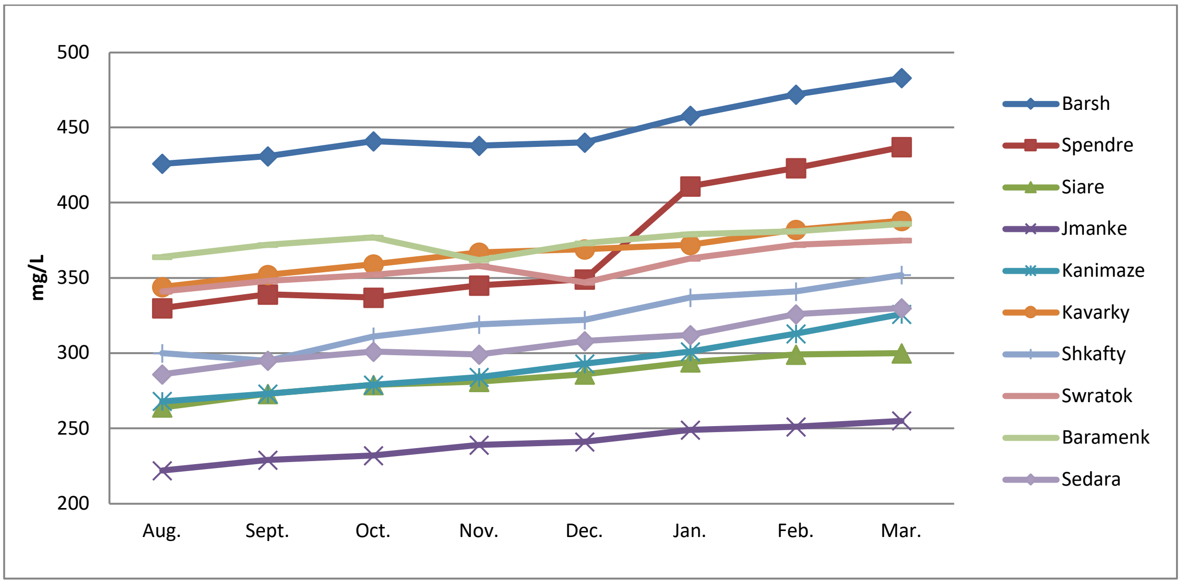

Fig. 7. Monthly variation of total hardness between selected spring water, mg/L

Calcium (Ca^{2+}, mg/L)

Calcium is the most abundant alkaline-earth metal and a major constituent of many common rock-forming minerals. It is an essential component of the dissolved solids present in most natural waters and plays a vital role in sustaining both plant and animal life. In sedimentary rocks, calcium predominantly occurs in the form of carbonate minerals. Calcite and aragonite, the two crystalline forms of calcium carbonate, have the chemical formula $CaCO_3$, while dolomite is represented by the formula $CaMg(CO_3)_2$. Carbonate rocks with a magnesium-to-calcium ratio approaching the theoretical molar ratio of 1:1 are classified as dolomite. Calcium is naturally present in groundwater as a result of the dissolution and weathering of these carbonate-bearing minerals. Calcium and magnesium are the principal contributors to water hardness. Calcium content in the investigated spring water ranged from 124 to 246 mg/L (Figure 8). The acceptable limit of Ca^{2+} according to WHO [18] is 75 mg/L. Ca^{2+} content in all spring water samples were situated above maximum permissible limit (Fig. 8), and the data obtained were higher than those reported by Hanumantharao et al [23].

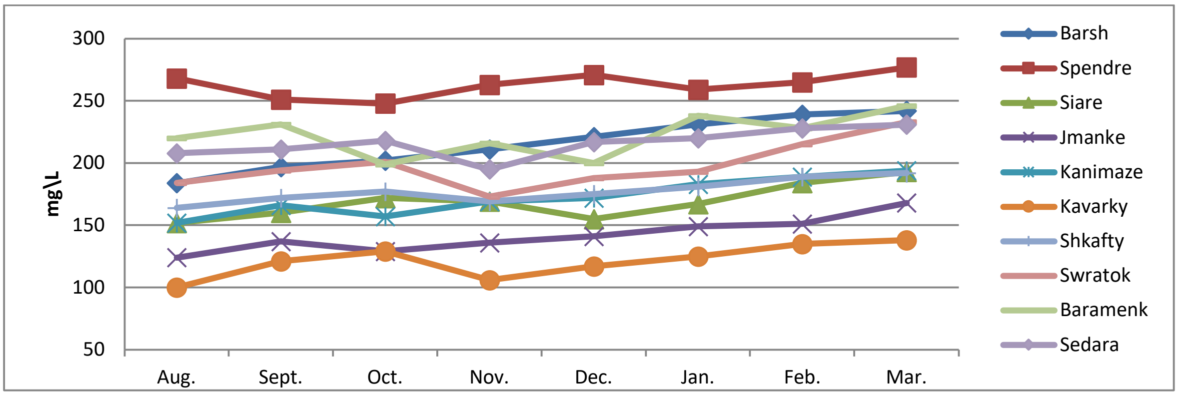

Fig. 8. Monthly variation of calcium hardness between selected spring water mg/L

Magnesium (Mg^{2+}, mg/L)

The water under investigation has magnesium concentrations ranging from 27,7 mg/L to 251 mg/L. The acceptable limit of Mg^{2+} according to WHO [18] is 30 mg/L. Throughout the study periods, there was a monthly change in the magnesium hardness of the examined springs (Fig. 9).

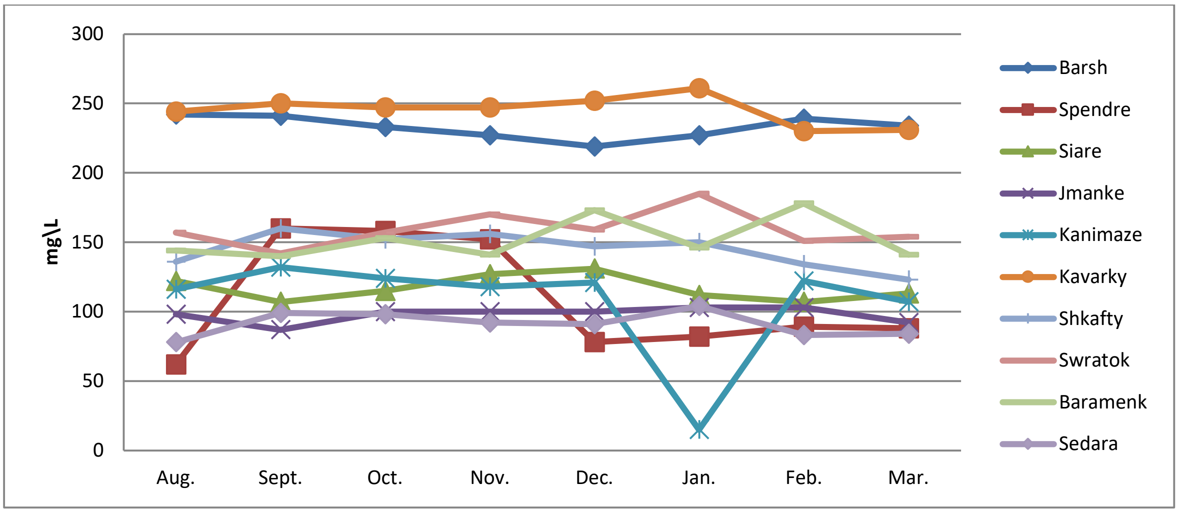

Fig. 9. Monthly variation of Magnesium hardness between selected spring water mg/L

Chloride (Cl^-, mg/L)

The chloride concentrations measured in the spring water samples ranged from 7.7 to 26.9 mg/L, all of which were within the permissible limits for drinking water (Fig. 10). The highest chloride concentration (26.9 mg/L) was recorded in March, while the lowest value (7.7 mg/L) was observed in November. Elevated chloride levels in groundwater may originate from both natural and anthropogenic sources, including the dissolution of geological materials, animal wastes, septic system effluents, landfill leachates, agricultural fertilizers, and industrial discharges. According to the World Health Organization (WHO), the recommended guideline value for chloride in drinking water is 250 mg/L [18]. All measured chloride concentrations were below this limit, indicating that chloride does not pose a concern for water quality in the study area. Furthermore, the chloride levels recorded in the present study were lower than those reported in previous studies [24÷26].

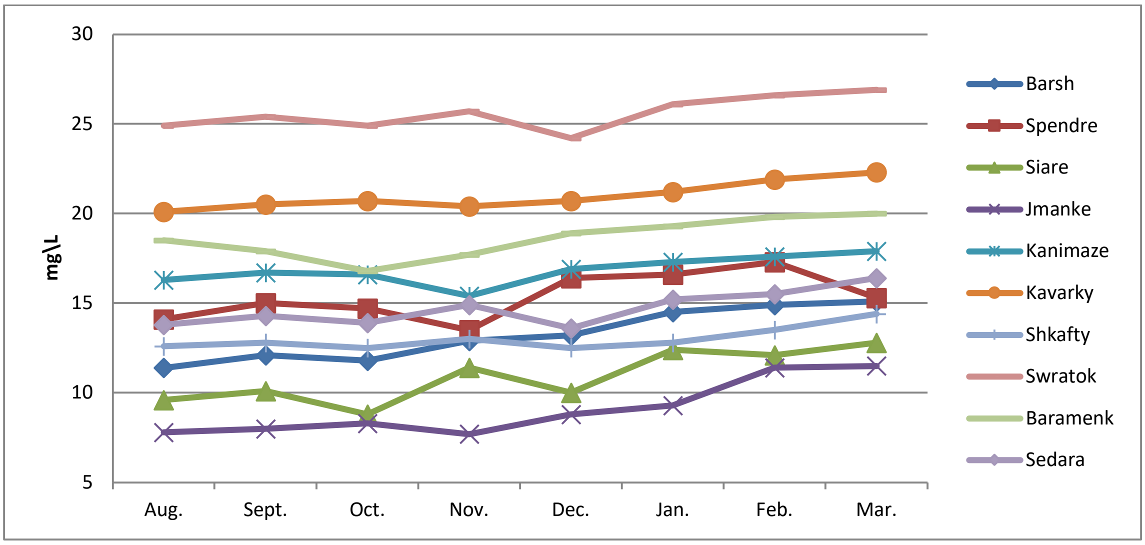

Fig. 10. Monthly variation of Chloride between selected spring water mg/L

Total alkalinity (TA, mg/L)

Alkalinity refers to the capacity of water to neutralize strong acids and is primarily attributed to the presence of bicarbonates, carbonates, and hydroxides of calcium, magnesium, sodium, and potassium. National and regional guidelines, based on the WHO framework recommendations, consider an alkalinity range of 30÷400 mg/L as $CaCO_3$ to be optimal for drinking water [18]. In the present study, total alkalinity values ranged from 195 to 462 mg/L. The lowest alkalinity concentration (195 mg/L) was recorded in August, whereas the highest value (462 mg/L) was observed in March. The results indicate that, only for the Spendre site, total alkalinity values exceeding the desirable limit of 400 mg/L. The elevated alkalinity levels may be associated with the dissolution of carbonate-rich minerals within the aquifer system. Furthermore, the alkalinity values obtained in this study were lower than those reported by Rochaddi et al [26].

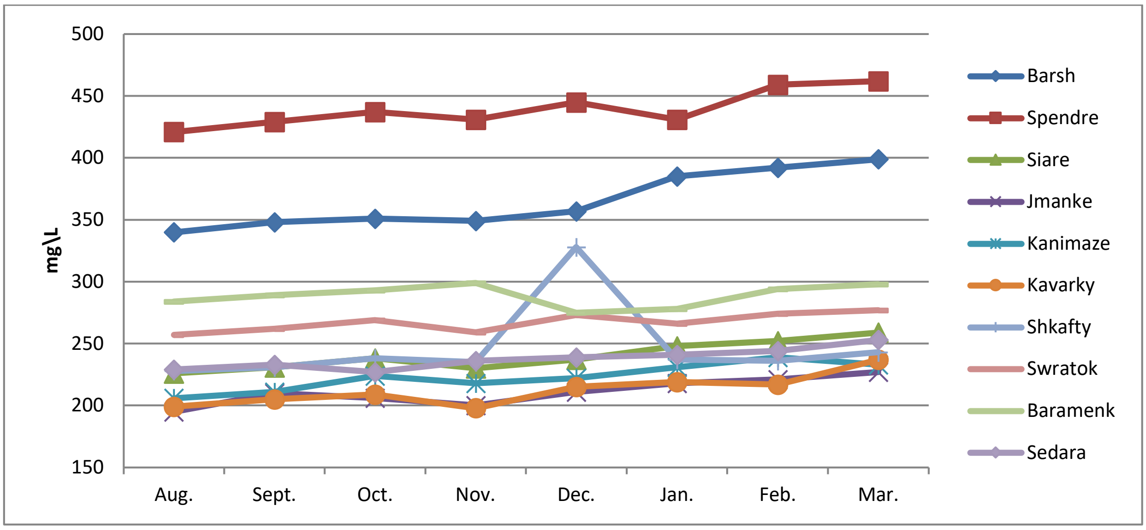

Fig.11. Monthly variation of total alkalinity between selected spring water mg/L

Sulfate (SO_4^{2-}, mg/L)

Sulfate minerals occur naturally in various types of rocks and soils. As groundwater flows through these geological formations, sulfate-bearing minerals may dissolve, contributing sulfate ions to the water. In the present study, sulfate concentrations in spring water samples collected during the summer and winter seasons ranged from 4.9 to 22.5 mg/L (Fig. 12). Furthermore, all sampling sites exhibited sulfate concentrations substantially lower than the World Health Organization (WHO) guideline value of 250 mg/L [18]. The low sulfate levels indicate minimal influence of sulfate-rich geological formations or anthropogenic contamination sources. Moreover, the sulfate concentrations reported in this study were lower than those documented by Umer et al [27].

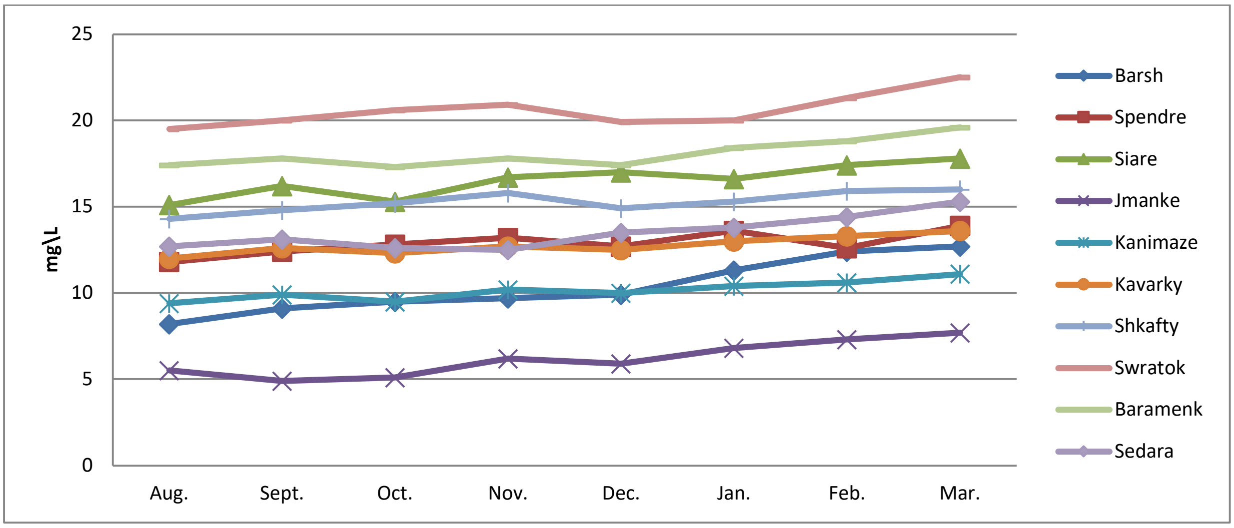

Fig.12. Monthly variation of sulfate between selected spring water, mg/L

Heavy metals

Zinc content in spring water samples ranged from 0.010 ± 0.104 to 1.534 ± 0.005 mg/L, which is within the 3.0 mg/L drinking water permitted limit set by the WHO on 2022 [18]. On the other hand, Fe concentrations were situated between 0.002 ± 0.001 mg/L and 0.142 ± 0.067 mg/L (Table 2). The acceptable level of Fe in drinking water is 0.3 mg/L, according to WHO [18]. In spring water samples, the average content of Cu varied between 0.005±0.023 mg/L and 0.029 ± 0.021 mg/L, the values being below the WHO's maximum allowable threshold of 2.0 mg/L. Additionally, in spring water samples was founded lead concentrations in the range from 0.027 ± 0.005 to 0.051 ± 0.013 mg/L. The WHO has established a provisional guideline maximum admissible value for Pb in drinking water of 10 µg/L. The mean concentrations of the metals in all spring water samples analyzed were significantly lower than the permissible limits set by standard for drinking water, exception should be highlighted for Pb values, which all exceed 0.01 mg/L [18].

Table 2. Concentration of Zn, Fe, Cu, and Pb in spring water samples, mg/L

Metals	Zn		Fe		Cu		Pb	
Sites	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S1-Barash	0.078	0.006	0.002	0.001	0.005	0.023	0.034	0.007
S2-Spendre	0.015	0.012	0.058	0.056	0.006	0.003	0.027	0.006
S3-Siare	0.259	0.007	0.035	0.063	0.008	0.005	0.029	0.019
S4-Jmanke	0.006	0.006	0.023	0.030	0.019	0.002	0.031	0.047
S5-Kanimaze	1.534	0.005	0.142	0.067	0.021	0.011	0.051	0.013
S6-Kavarky	0.025	0.011	0.084	0.030	0.024	0.003	0.042	0.048
S7-Shkafty	0.010	0.104	0.081	0.018	0.014	0.008	0.039	0.009
S8-Swratok	0.021	0.004	0.078	0.077	0.023	0.013	0.047	0.018
S9-Baramenk	0.044	0.009	0.081	0.041	0.016	0.007	0.050	0.006
S10-Sedara	0.010	0.003	0.108	0.033	0.029	0.021	0.044	0.011

Regarding heavy metals pollutants impact, the tested water can be used directly without specific treatment except for the lead which requires a specific treatment to reduce the pollution caused by the lead using well known techniques like activated carbon. The highest values were reported an Kanimaze and Baramenk. The value of toxic metals was ranked in order: Zn > Fe > Pb > Cu.
Based on the measured physicochemical parameters, the Water Quality Index (WQI) was calculated using the weighted arithmetic index method to evaluate the overall quality of the spring water samples. The WQI provides a comprehensive assessment of water quality by integrating multiple parameters into a single numerical value. As it reflects the overall status of water quality rather than the contribution of individual parameters, WQI is considered one of the most effective tools for communicating and interpreting water quality conditions [28].
Table 3 presents WQI values calculated for the spring water samples collected each month. The results indicate that the WQI values remained relatively consistent throughout the study period at each sampling site. Among the investigated locations, the Jamanke site exhibited the lowest average WQI value (38.08), indicating the best overall water quality. This was followed by the Shkafty, Spendre, and Sedara sites, with average WQI values of 50.73, 55.29, and 59.58, respectively. In contrast, the highest average WQI values were recorded at the Siare, Barsh, and Kanimaze sites, with values of 211.6, 225.3, and 326.3, respectively, reflecting poorer water quality conditions.

Table 3. WQI value for all water samples

Months / Sites	08.2022	09.2022	10.2022	11.2022	12.2022	01.2023	02.2023	03.2023	Average
S1-Barash	225.3	225.3	225.3	225.3	225.3	225.3	225.3	225.3	225.3
S2-Spendre	55.26	55.30	55.30	55.31	55.28	55.29	55.29	55.30	55.29
S3-Siare	211.6	211.6	211.6	211.6	211.6	211.6	211.6	211.6	211.6
S4-Jmanke	38.07	38.07	38.07	38.08	38.08	38.08	38.09	38.09	38.08
S5-Kanimaze	326.3	326.3	326.3	326.3	326.3	326.3	326.3	326.3	326.3
S6-Kavarky	96.39	96.40	96.40	96.40	96.40	96.41	96.41	96.41	96.40
S7-Shkafty	50.72	50.73	50.73	50.73	50.75	50.73	50.74	50.74	50.73
S8-Swratok	87.33	87.34	87.34	87.34	87.34	87.36	87.34	87.35	87.34
S9-Baramenk	147.0	147.0	147.0	147.0	147.0	146.9	147.0	147.0	147.0
S10-Sedara	59.57	59.58	59.58	59.55	59.59	59.60	59.60	59.60	59.58

The elevated WQI values at these locations were primarily influenced by parameters that approached or exceeded the permissible limits, including Ca^{2+}, Mg^{2+}, TA, TH, and certain heavy metals, particularly Zn and Pb. These parameters contributed most significantly to the deterioration of overall water quality and consequently had the greatest impact on the WQI calculations.
Based on the classification criteria provided in Table 1, the investigated sites were categorized according to the values of Water Quality Index WQI from best (Lowest value / S4-Jmanke) to worse (Highest Value / S5-Kanimaze), and the results are summarized in Table 4.

Table 4. Categorization of the tested samples based on the WQI of each sample

Site	WQI	Water Quality Status
S4-Jmanke	38.08	< 50 Excellent
S7-Shkafty	50.73	50 - 100 Good
S2-Spendre	55.29	50 - 100 Good
S10-Sedara	59.58	50 - 100 Good
S8-Swratok	87.34	50 - 100 Good
S6-Kavarky	96.40	50 - 100 Good
S9-Baramenk	147.0	100 - 200 Poor
S3-Siare	211.6	200 - 300 Very poor
S1-Barash	225.3	200 - 300 Very poor
S5-Kanimaze	326.3	> 300 Unsuitable

CONCLUSIONS

In the present study, the physical-chemical characteristics of spring water, including DO, temperature, pH, TDS, TH, EC, Cl^-, Ca^{2+}, SO_4^{2-}, Mg^{2+}, and selected heavy metals, were evaluated and compared with the WHO guidelines for drinking water quality.

The results indicated that the pH of most water samples was slightly alkaline and remained within the acceptable range for drinking water. Dissolved oxygen, electrical conductivity, total dissolved solids, chloride, sulfate, and Zn, Fe, Cu concentrations generally complied with the recommended WHO limits.

However, the concentrations of total hardness, calcium, and magnesium exceeded the recommended limits at several sampling sites, indicating that the water may require treatment prior to consumption. In all sites, Pb values were higher than maximum admmissible of 0.01 mg/L. TA was also found to be slightly higher than the desirable level in some locations. These parameters were identified as the major contributors to the deterioration of water quality and had a significant influence on the WQI values.

The WQI assessment revealed spatial variations in water quality among the investigated springs. Site S4 (Jmanke) was classified as having *excellent* water quality, while Sites S2, S6÷S8, S10 were categorized as *good*. Site S9 fell within the *poor* water quality category, sites S1 and S3 were included in very poor quality, whereas site S5 was classified as *unsuitable* for drinking purposes.

Although the concentrations of determinated heavy metals were generally below the WHO permissible limits, elevated levels of lead were observed in all locations. Therefore, appropriate treatment measures should be implemented to reduce the concentrations of this metal and ensure a safe and reliable water supply for communities relying on these springs. Furthermore, regular monitoring of spring water quality is strongly recommended to detect potential changes in water quality parameters and to support the sustainable management of spring resources.

AI Use Statement

We used an AI assistant (ChatGPT) to support sentence structure correction, improve grammar, and enhance clarity during manuscript preparation. All AI-generated suggestions were carefully reviewed, and all final editorial decisions were made by the authors. We confirm that the content, interpretations, and any remaining errors remain solely the responsibility of the authors.

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