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Research Article

Surface water quality of the oued-charef sub-basin: threats to the foum El Khenga dam, Algeria

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Abstract:

Insufficient irrigation water supply created an alarming situation for the authorities. A policy of constructing large dams was initiated and implemented. Faced with excessive water pollution and mineralization, the study of these phenomena, their origins, their assessment, and the recommended solutions became crucial, hence this study originated. This study investigates the contamination and pollution of surface waters in the Oued Charef upstream sub-watershed (northeastern Algeria), located in a semi-arid environment. Runoff from carbonate formations and from Triassic, Mio-Pliocene, and Quaternary evaporitic deposits drains toward the Foum El Khenga Dam reservoir.Monthly water sampling campaigns from the dam reservoir, the Sedrata wastewater treatment plant (WWTP) and some tributaries (representative) were carried out on a hydrological cycle for physical (T, EC, TDS), and chemical (major elements and pollution indicators) analyses. In a qualitative context, the origin and mineralization of the waters were determined using diagrams (binary and chemical facies distinction), ionic ratios, and the spatiotemporal evolution of physicochemical parameters. This was supported by a multivariate descriptive statistical analysis, including principal component analysis (PCA), hierarchical ascending classification (HAC), and box plots. All the methods used revealed practically similar results.The compared data revealed three origins or groups of waters: - evaporitic (G2), - carbonate (G1) and - mixture (G3). For a more precise determination of the mixing proportions between fresh and salt water, future research studies will focus on the use of stable isotopes ($\delta^{18}O$ and δ^2H). The Sedrata WWTP effectively reduces polluting organic loads by decreasing BOD_5 and COD by more than 95%. Modernizing the existing treatment plant to include a tertiary dephosphorization stage to prevent long-term eutrophication is a crucial task that cannot be overlooked.

1. Introduction

Surface water represents a major component of Algeria's water resources, supporting domestic use, agriculture, economic activities, and local ecosystems [1]. Although it is an essential element, indispensable for all life, water remains a double-edged substance due to its harmful role in transporting pollutants, which are the main cause of impaired water quality for drinking water supply, irrigation, and waterborne diseases and epidemics [2]. Few studies in the region have been carried out on the physicochemical quality and pollution of surface water in the Oued Charef-amont sub-watershed, including, among others, physicochemical characterization, geochemical analysis [3,4] as well as some biological studies on biodiversity and aquatic ecosystems [5]. Other studies on water quality in Northern Algeria have addressed this theme, including the work on surface water assessment and groundwater quality [6–17]. Pressure on water resources has increased due to population growth [18], higher water demand associated with improved living standards, and recent climatic changes [19,20]. The combination of the geographical (semi-arid environment) and geological (evaporitic and saliferous formations) situation makes the overall situation alarming. Apart from this pollution, contamination by dissolved salts, naturally coming from evaporitic (Triassic) and saliferous (mp, Q) formations in turn plays another harmful effect, especially in the modification of the physicochemical properties of the soils and reduction of permeability by accumulated salts. This phenomenon is accentuated in recent decades, particularly in semi-arid areas and during the summer period [7,21]. According to FAO [21], salinization reduces the area of irrigated land by 1 to 2% per year and according to Shen et al. [22], (5%) of cultivated land is affected by excessive salt content (salinization, sodification). Finally, to summarize, our study aims to address the issues of contamination and pollution and their origins. To this end, given the current scientific gaps in the research, our research focuses on examining innovative processes and methods such as:

- The impact of geological formations, particularly Triassic, saline, and carbonate formations.
- The contribution of hydrogeochemistry (using water from the dam and representative wadis) and, potentially, their spatiotemporal evolution.
- The use of statistical methods to identify the different types and probable origins of the water.
- Evaluation of the effectiveness of the wastewater treatment plant located downstream of the city of Sedrata and upstream of the dam.

2. Material and Methods

2.1 Geographical location of the study area

The sub basin (Agence des Bassins Hydrographiques (ABH) code 14 01) is located upstream of the Seybouse watershed [23]. It is characterized by a Mediterranean semi-arid climate featuring hot summers, cold winters, a mean annual temperature of 15–16 °C, and annual rainfall of 350–400 mm. According to the administrative division, the study region is located at the intersection of three wilayas in North-Eastern Algeria: Guelma in the North-West, Souk-Ahras in the East and North-East and Oum El Bouaghi in the South-West (Figure 1A). The sub-watershed of the upper Oued Charef covers an area of 1735 km^2, with a minimum altitude of 739 m at the Foum El Khenga dam reservoir (outlet) and a maximum altitude of 1559 m at its mountainous border. The sub-watershed has an elongated triangular shape, and the Lambert coordinates of the dam reservoir, according to the Sédrata topographic map, are as follows: X = 921.400, Y = 322.770, and Z = 739 m (Figure 1A). The dam's reservoir is located at the confluence of the Oued Charef (the main wadi), which drains the Eastern and Southern parts of the land, and the Oued Settara, which drains the Western part. Together with their tributaries, they form a dense hydrographic drainage network. (Figure 1A)

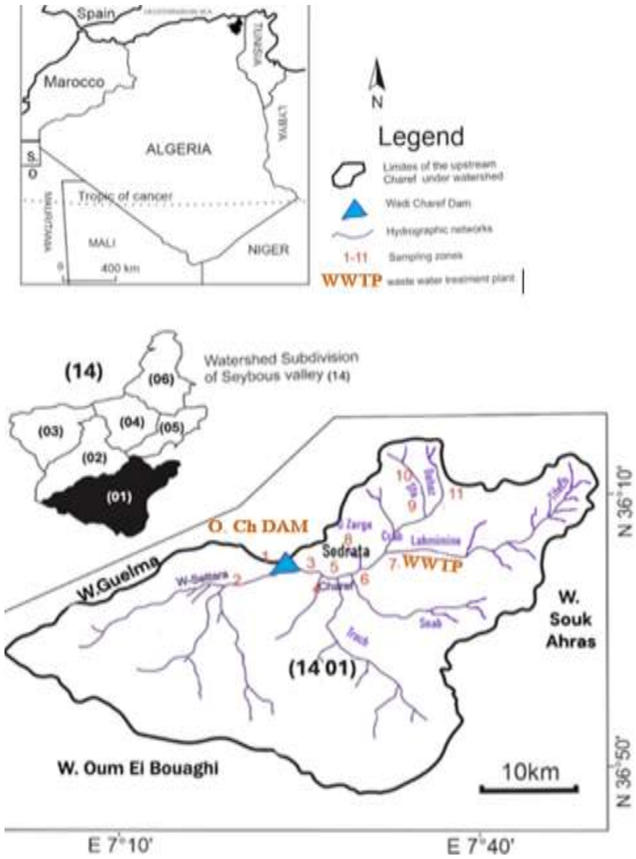

Figure 1A: *Geographical location of the study area*

2.2 Geological context

The study area spans three major structural units: (1) the Constantinois and Tellian nappes in the north, (2) the South-Constantinois allochthonous unit, and (3) the Nord-Aurés autochthonous domain [24] (Figure 1C, based on the 1/500,000 map, modified). The allochthonous terrain in the north of the study area is essentially composed of marl, clay and sandstone (Numidian sandstone), as well as marl-limestone interspersed with limestone beds. This includes sandstone limestone or limestone-cemented sandstone, giving the series a predominantly detrital and carbonate facies [25] (Figure 1C). The Neogene continental Miocene formations consist of gypsum clays dating from the end of the Miocene, underlain by gypsiferous marls, lacustrine limestones, and sands, giving the series a predominantly detrital facies containing, primarily, gypsum, rock, salt and dolomite. The Quaternary formations, which cover most of the central and southern parts of the study area, comprise alluvium, silt, limestone crusts, and alterations of the pre-existing layers, giving a highly varied detrital facies containing gypsum, rock salt, and other less soluble salts such as calcium and magnesium carbonates. To the south of the study area, the southern geological strata belonging to the autochthonous Nord-Aurésien edifice outcrop. The Triassic formations, containing evaporites, dolomitic limestones or sandstone limestones, generally mark the major anomalous contacts (Figures 1B and 1C).

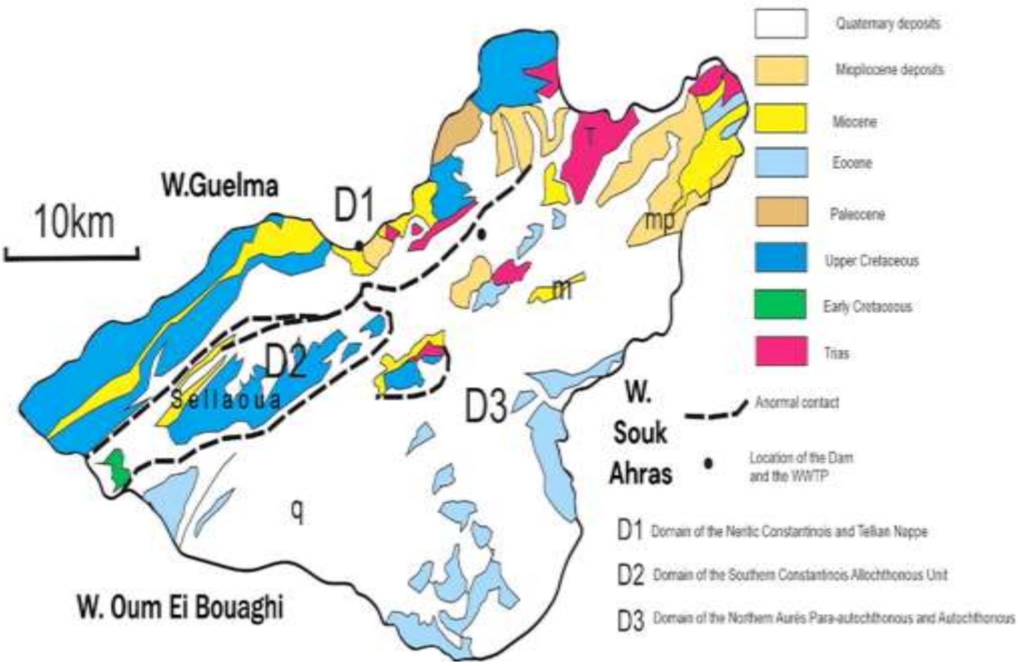

Figure 1B: *Geological map of the study area after J M Vila et al. 1978, (1/500 000) modified*

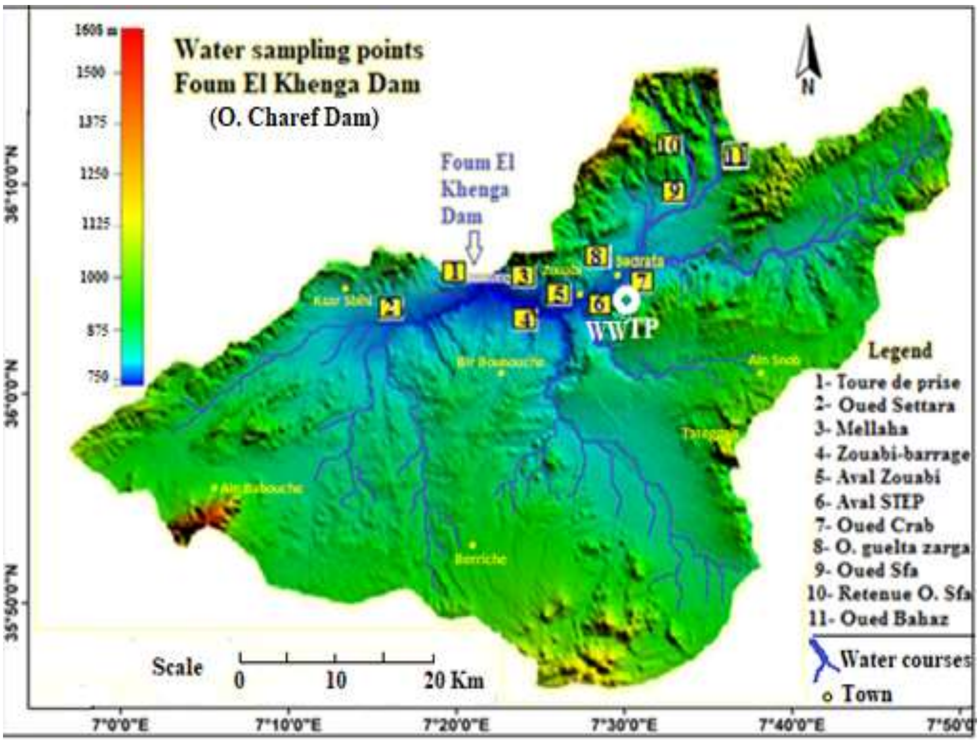

Figure 1C: *Hypsometry, hydrographic network and water sampling points.*

2.3 Methodology

Eleven representative surface-water samples were collected monthly during 2020 for in-situ measurements and laboratory analysis of physical, chemical, and pollution parameters. The sampling points were carefully chosen in the dam reservoir and in the wadis (considering location, a depth of 50 cm below the water surface, and a distance of approximately 1.5 m from the wadi banks). A precise protocol was adopted to guarantee the preservation of the samples (including conservation and transport in accordance with standards and directives). Additional measures were taken, such as using plastic bottles stored in a cool box at 4°C and transported in less than eight hours. Analyses were performed following the standard methods established by Rodier et al. [26] and according to the instrument manuals.

2.3.1 Materials (equipment) used in situ and in the laboratory

The various parameters measured in situ and in the laboratory were determined using the following methods and equipment: electrical conductivity (EC, in µS/cm), Total Dissolved Solids (TDS), salinity (mg/L) and temperature (T, in °C) were measured using a portable multi-meter of the HANNA HI 9835 type. Calcium, magnesium, bicarbonates, chlorides, and total hardness were analysed using the volumetric method [26]. Sulfates were determined by the colorimetric method with a JENWAY 6060 colorimeter, while Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS) (SS or MES) were measured by an OXITOP IS6 type BOD-meter, the volumetric method using potassium dichromate, and by filtration, respectively [26].

2.3.2 Contribution of statistics

To provide additional support and a more comprehensive explanation for the analytical results, the use of statistical analysis was deemed appropriate. The statistical software used in this study is XLSTAT 2014.

<u>2.3.2.1 Principal component analysis (PCA):</u> The PCA is a primarily descriptive statistical method, its aim is to present, in graphical form, the maximum amount of information contained in a dataset. The table comprises rows of individuals representing quantitative variables [27]. In order to establish relationships between the data measured in situ (T, pH, EC, TDS) and those analysed in the laboratory (Ca, Mg, Na, K, Cl, SO_4, HCO_3), a principal component analysis was carried out on eleven variables representing eleven sampling points (wadis and the dams). The use of additional statistical methods was employed to reinforce the results obtained.

<u>2.3.2.2 Hierarchical Ascending Classification (HAC):</u> This study adopted Ward's aggregation method, which allows two classes in a partition to be grouped together to obtain a more aggregated partition. HAC aggregates individuals iteratively to produce a dendrogram or classification tree.

<u>2.3.2.3 Descriptive statistics: box plot (whiskers diagram):</u> This diagram is a useful tool because it provides a visual summary of the data, enabling the identification element dispersion and potential symmetry.

2.3.3 Origin of high mineralisation (excess salts)

The combination of geological, geophysical, statistical, and chemical tools in the study of water chemistry enables the determination of the origin of mineralisation and its spatial evolution [28].

<u>2.3.3.1 Geological criteria (lithology):</u> Surface and groundwater acquire their primary mineralization from the rocks they pass through and leach, or from the surrounding geological formations during water-rock interaction [26].

<u>2.3.3.2 Hydrogeochemical criteria (origin of water chemistry):</u> According to our analysis, the mineral content of the water exceeded 1600 mg/L (TDS) and the electrical conductivity surpassed 3200 µS/cm in several locations. Chemical elements such as sulfates (450 mg/L), chlorine (over 330 mg/L) and sodium (220 mg/L) were well in excess of the tolerated limits [29,30].

2.3.4 Role of the WWTP in preserving, depolluting and lowering the levels of salts and organic matter

The interpretation of the diagrams representing the various organic pollution parameters in surface waters provides insights into their contamination levels[31]. Apart from the settling tank in the village of Zouabi and the lagooning system in the town of Bir Bouhouch, the studied sub-basin only includes the Sedrata WWTP (Wastewater Treatment Plant). In order to monitor the performance and efficiency of the WWTP and the preservation of the water quality in the dam, two sets of measurements for the parameters controlling pollution were carried out simultaneously on a monthly basis and analyzed.

3. Results and discussions

As shown in Table 1, the majority of significant positive correlations were observed along the F1 axis, which is associated with the evaporite pole; these correlations are represented in the correlation matrix. The two negative correlations, associated with the carbonate pole, are represented in the matrix within the gray boxes. Sodium shows a moderately significant correlation, while potassium (K) shows no significant correlation with the two axes F1 and F2 (Table 1, Figure 2c).

The factor planes F1 and F2 represent 55.51% (evaporitic pole) and 23.13% (carbonate pole) of the total variance, respectively, accounting for a cumulative total of 78.64% (Table 1).

Correlation Coefficient Analysis: it is essential to specify the degree of correlation between the different parameters (variables). The correlation results are presented in the following matrix (Table 2).

Table 1. *Summary statistics, factor and variable correlations*

Variables	Minimum	Maximum	Mean	Std. deviation	Factors and variables			Variables vs Factors	
					F1	F2	F3	F1	F2
T °C	16,40	21,5	18,95	01,42	0,0007	**0,7583**	0,0629	-0,03	**0,87**
Ph	07,70	08,6	08,14	0,36	**0,5454**	0,4080	0,0021	**0,74**	**0,64**
C.E µs/cm	624	2750	1699	711,09	**0,9793**	0,0014	0,0010	**0,99**	0,04
TDS mg/l	309	1407	848,09	353,93	**0,9732**	0,0006	0,0053	**0,99**	0,03
Ca mg/l	58,30	184,37	123,24	35,00	**0,8179**	0,0574	0,0280	**0,90**	-0,24
Mg mg/l	03,16	81,37	36,91	21,94	**0,7687**	0,0070	0,1315	**0,88**	0,08
Na mg/l	34,23	205	136,78	47,74	0,2750	**0,5624**	0,0974	**0,52**	**-0,75**
K mg/l	02,71	08,62	05,08	01,66	0,0841	0,0424	**0,6559**	0,29	0,21
Cl mg/l	33,91	328,43	202,65	95,37	**0,6947**	0,1362	0,0283	**0,83**	-0,37
SO4 mg/l	130,80	450	249,77	109,5	**0,9034**	0,0077	0,0144	**0,95**	0,09
HCO3 mg/l	141,52	389,18	265,75	91,69	0,0639	**0,5631**	0,1849	-0,25	**-0,75**
					Evaporate pole	**Carbonate pole**			

Table 2. *Matrix of correlations (T in °C, EC in µs/cm, and other parameters in mg/l)*

Variables	T°C	Ph	C.E	TDS	Ca	Mg	Na	K	CI	SO4	HCO3
T °C	**1**										
Ph	0,4571	**1**									
C.E µs/cm	-0,0028	**0,7555**	**1**								
TDS mg/l	-0,0099	**0,7533**	**0,9965**	**1**							
Ca mg/l	-0,1555	0,4737	**0,8999**	**0,9009**	**1**						
Mg mg/l	0,1574	**0,6917**	**0,8511**	**0,8663**	**0,7936**	**1**					
Na mg/l	**-0,7046**	-0,0788	0,4761	0,4707	**0,5538**	0,2815	**1**				
K mg/l	0,0175	0,3576	0,2427	0,2113	0,1614	0,0392	0,1658	**1**			
Cl mg/l	-0,2758	0,3499	**0,7982**	**0,7842**	**0,769**	**0,6525**	**0,8456**	0,2254	**1**		
SO4 mg/l	0,0178	**0,7635**	**0,9403**	**0,9417**	**0,8783**	**0,8782**	0,3561	0,2296	**0,6646**	**1**	
HCO3 mg/l	-0,4898	**-0,7012**	-0,288	-0,251	0,0952	-0,072	0,2242	-0,376	-0,074	-0,232	**1**

The projection of the variables on the F1-F2 factorial plane (correlation circle) shows that the parameters: pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, amd SO_4^{2-}, are strongly positively correlated with the F1 axis. The parameters T, HCO_3^{-}, and Na^{+}, are correlated with the F2 axis; temperature is positively correlated, whereas bicarbonates and sodium are negatively correlated. We also note that the potassium (K^{+}) variable (which is generally associated with sodium) is located near the centre of the circle, indicating that it is not optimally represented by the two main axes F1 and F2 (Figure 2a). To determine whether the water groups evolved sequentially or independently of each other, the projection of the individuals (wadis or sampling sites) revealed three distinct water groups and their positions on the F1 and F2 axes. The watercourses belonging to the evaporite pole are positioned in the upper-right quadrant and exhibit a significant positive correlation. The water points belonging to the carbonate pole are positioned in the two left-hand quadrants and show a significant negative correlation with respect to the F1 axis (Figure 2b). The last group of wadis represents a mixture of mineralized waters, diluted by the less mineralized waters of the carbonate pole, which aligns with the results found using the lithological and hydrochemical criteria (Figure 2b). Superimposing the individuals and variables (water sampling points and physicochemical parameters) onto the factorial plane comprising the F1 and F2 axes yields the same results as described above (Figure 2c).

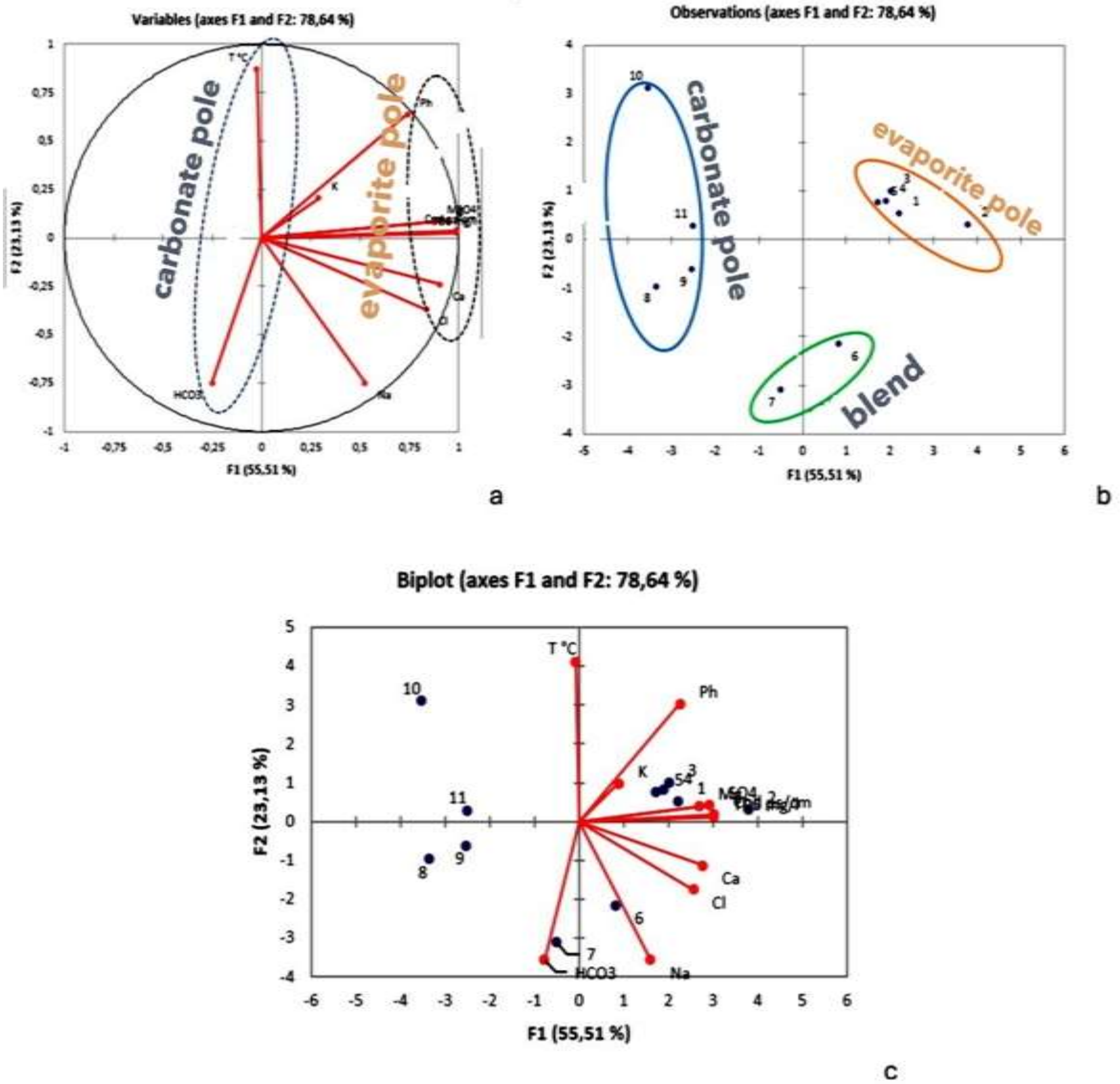

Figure 2a, b, c: *Projection of variables and/or individuals onto the factorial plane containing the F1 and F2 axes*

Geogenic mineralization and anthropogenic pollution can be distinguished thanks to the analyses conducted at eleven sampling sites (Figure 2) and multivariate statistical techniques (correlation analysis and PCA) [32,33]. Specifically, trends in pollution-indicator parameters point to a significant decrease in organic loads downstream of the Sedrata WWTP (see Figure 12A–C); these findings are examined below in relation to treatment efficiency and seasonal variability. Based on the interpretation of analytical data from eleven samples (Figure 2), our study answers questions about the origin of excess salts and pollution indicator materials by studying the evolution and evaluation of various water quality parameters [32]. As a result, it participates in and contributes to slowing down , or even stopping, this phenomenon [34] (Figure 12A, B) and highlights the very positive effect and benefit of the WWTP in protecting the dam waters and the wadis downstream (Figure 12A). The statistical approach (correlation analysis, PCA, etc.) also helped strengthen the interpretation of the analytical data [33].The application of Hierarchical Cluster Analysis (HCA) to our analytical data yielded consistent results, thereby confirming the PCA findings (Table 3, Figure 3).

***Table 3.** Central objects*

Classe	Ca	Mg	Na	K	Cl	SO4	HCO3
1 (Obs1) G1	124.0000	46.0000	240.0000	4.0000	360.0000	238.0000	366.0000
2 (Obs4) G3	130.0000	59.0000	250.0000	3.0000	420.0000	356.0000	171.0000
3 (Obs6) G2	134.0000	42.0000	325.0000	5.0000	490.0000	362.0000	153.0000

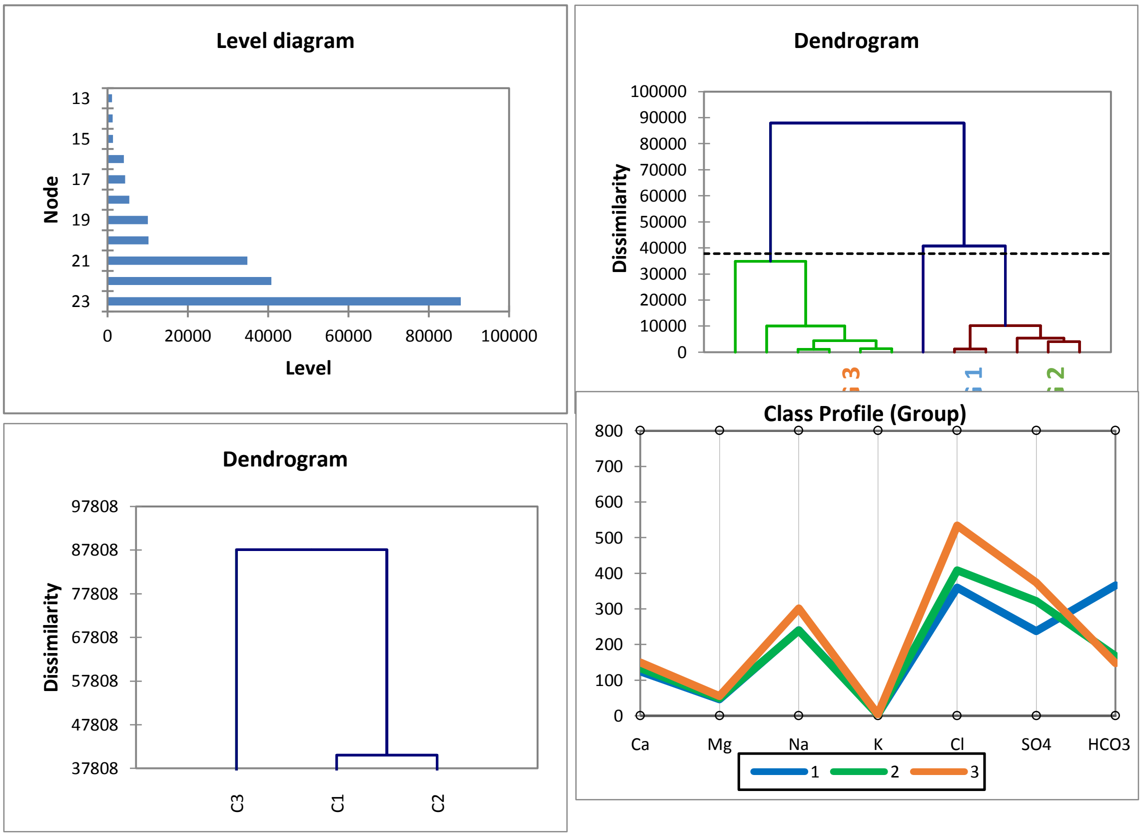

***Figure 3:** Level diagram, Dendrogram and Class Profile (group).*

In our study, observation of the diagrams shows that the overall range and length of the boxes representing the water group from evaporitic and saliferous formations are greater, resulting in a wider dispersion of the elements Mg^{2+}, Na^{+}, SO_4^{2-}, and Cl^{-}. Conversely, the narrower boxes associated with the water group from carbonate formations indicate the elements Ca^{2+} and HCO_3^{-} are less dispersed. Comparing the symmetry of the medians reveals positive or negative asymmetry for the first group, whereas the second group exhibits higher symmetry. These observations further confirm the previous results.

***Table 4:** Descriptive statistics (Quantitative data) All parameters in mg/l*

Statistic	Nb of observation	Minimum	Maximum	1st Quartile	Median	3rd Quartile	Mean	Variance (n-1)	Standard deviation (n-1)
Ca	12	98.00	192.00	128.50	139.00	151.00	140.67	579.88	24.08
Mg	12	32.00	76.00	42.75	48.00	61.75	52.00	174.73	13.22
Na	12	210.00	330.00	240.00	267.50	292.25	270.33	1401.33	37.43
K	12	03.00	05.00	03.00	04.00	04.00	03.83	0.52	0.72
Cl	12	360.00	690.00	395.00	467.50	486.25	467.08	8838.45	94.01
SO4	12	238.00	400.00	300.00	353.00	393.00	341.17	3078.88	55.49
HCO3	12	114.00	366.00	143.00	159.00	172.50	174.25	4229.66	65.04

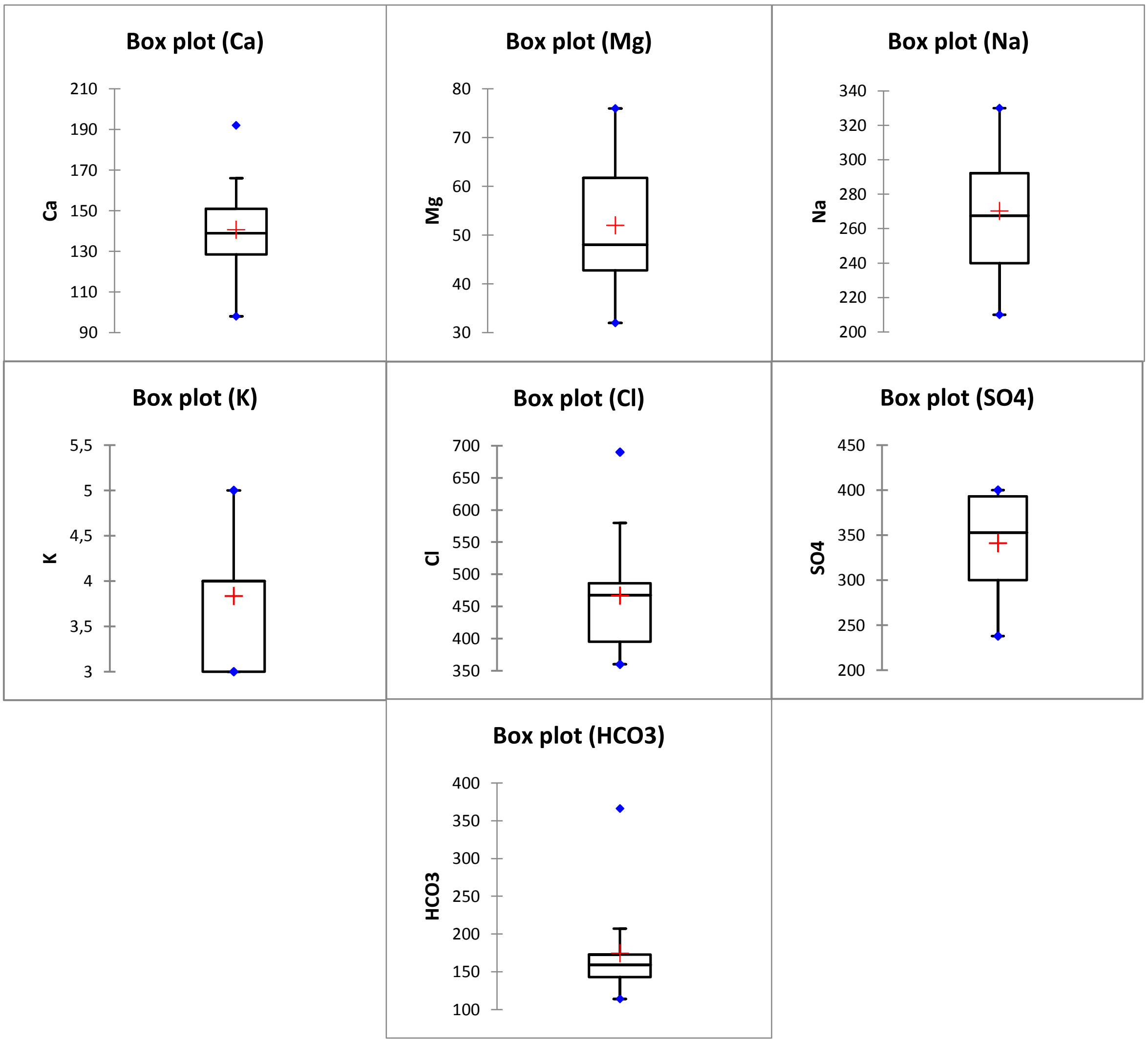

Figure 4: Whisker chart of water groups

3.1 Origin of high mineralization (excess salts)

The excessive salt concentrations in the waters of the Foum El Khenga dam and at specific sampling points can be attributed to the lithological characteristics and hydrogeochemical processes (water chemistry).

3.1.1 Geological criteria (lithology)

The lithology of the various geological formations indicates that:

- The waters within the Neogene formations (Mio-Pliocene and Quaternary) exhibit higher mineral salts loads compared to other zones. This is attributed to the long flow paths and extensive leaching processes as the water travels toward the dam (increasing salinity with residence time and travel distance). Furthermore, Triassic outcrops located near the watercourses and lining several tributaries of the Oued Charef to the northeast of the site contribute to this mineralization (Figure 1B, 1C).Water from allochthonous terrains is characterized by a carbonate and detrital facies (Numidian sandstone). It follows a relatively short flow path, distant from Triassic outcrops, resulting in lower mineral contamination. This is particularly evident where the water originates from or is channeled through springs emerging from carbonate formations (Figure 1B, 1C).- Water from the Foum El Khenga Dam shows elevated dissolved salt concentrations, with certain parameters exceeding national and WHO guideline values. This degradation in water quality affects both irrigation suitability and agricultural soil health. Over time, this can lead to reduced crop yields, soil loss through salinization, and the clogging of agricultural land [35].

3.1.2 Hydrogeochemical criteria (origin of water chemistry)

In several locations, the mineral content of the water exceeds 1600 mg/L (TDS) and the electrical conductivity surpasses 3200 µS/cm. Chemical elements such as sulfates (450 mg/L), chlorides (over 330 mg/L) and sodium (220 mg/L) are well in excess of the tolerated limits [29,30] which accounts for the excess salinity. The high levels of sulfate, chloride and sodium often result from the dissolution of evaporitic and saliferous formations (Triassic), in addition to pollution from the various wastewater discharges into the hydrographic network feeding the dam basin. This is consistent with our fieldwork, as all towns and villages in the study area (e.g., Zouabi, located a few kilometers from the dam, Bir Bouhouch, and Oum Ladaim, etc.) discharge into the network, with the exception of the town of Sedrata, which is served by the only WWTP in the entire sub-watershed [36]. Based on the chemical analyses, it is essential to establish the existing relationships between the elements using binary or scatter diagrams and characteristic ratios.

3.1.3 Na^+ - Cl^- relationship

The water sampling points (wadis, reservoirs, and springs) are subdivided into two very distinct groups. The first group comprises waters from the northeastern (NE) limits of the study area, which are less mineralized (Na^+, Cl^-). These points are located far from Triassic evaporitic outcrops, and a portion of this water originates from springs. The second group consists of water with a longer flow trajectory, resulting in increased residence time and higher concentrations of dissolved salts from extensively leached formations. These waters cross Mio-Pliocene and Quaternary formations and are situated close to the Triassic evaporitic outcrops. Consequently, one group exhibits significantly higher chloride and sodium contents than the other (Figure 5). This indicates that the Na^+ and Cl^- ions in each group have distinct origins, leading to the dominance of different hydrochemical facies.

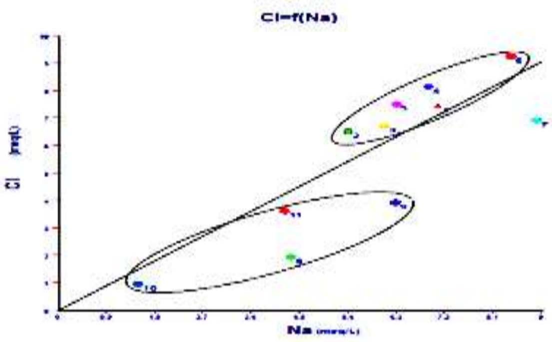

Figure 5: *Na+ - Cl- relationship*

3.1.4 The couple SO_4^{2-} - Ca^{2+} relationship

This relationship provides additional detail concerning the origin of evaporitic minerals within water samples. The analysis reveals a new subdivision into three distinct groups of water: low mineralization (Gr1), moderate mineralization (Gr3), and high mineralization (Gr2). The graph exhibits a good correlation between the two elements (SO_4^{2-} -, Ca^{2+}) in the most highly mineralized waters (Gr2). Due to their extended flow paths through saliferous and evaporitic formations, their evolution is proportional and follows a centered linear trend, which confirms a common evaporitic origin. In contrast, for the remaining waters, the two chemical elements (SO_4^{2-} -, Ca^{2+}) are less correlated, showing non-proportional and off-centre evolution, indicating a different origin (Figure 6a, 6b). Furthermore, the Gr3 group represents the mixture of Gr1 and Gr2. These waters acquired their intermediate mineralization through the dilution of Gr2 waters by the less mineralized Gr1 waters, which originate from the carbonate and sandstone formations. (Figure 6b).

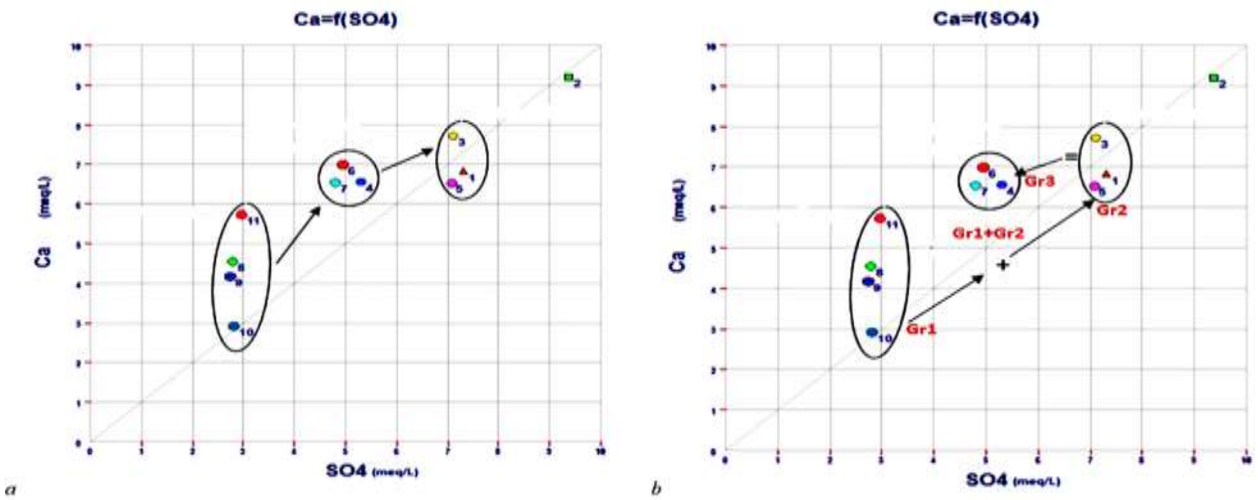

Figure 6a, b: *SO_4^{2-} - Ca^{2+} relationship*

3.1.5 Calcium vs. Bicarbonates relationship

The graph exhibits a strong correlation and a clear linear alignment of the water points, associated with carbonate pole. In contrast, the second group, situated at the evaporite pole, shows a poor correlation between these two parameters (Figure 7a). Analyzing the evolutionary trends of the water chemistry reveals distinct pathways for each group, confirming their unique geochemical origins (Figure 7b). The group on the left, characterized by simultaneous ion evolution, indicates the dissolution of carbonates, whereas the other groups follow a different hydrochemical trajectory (Figure 7b)

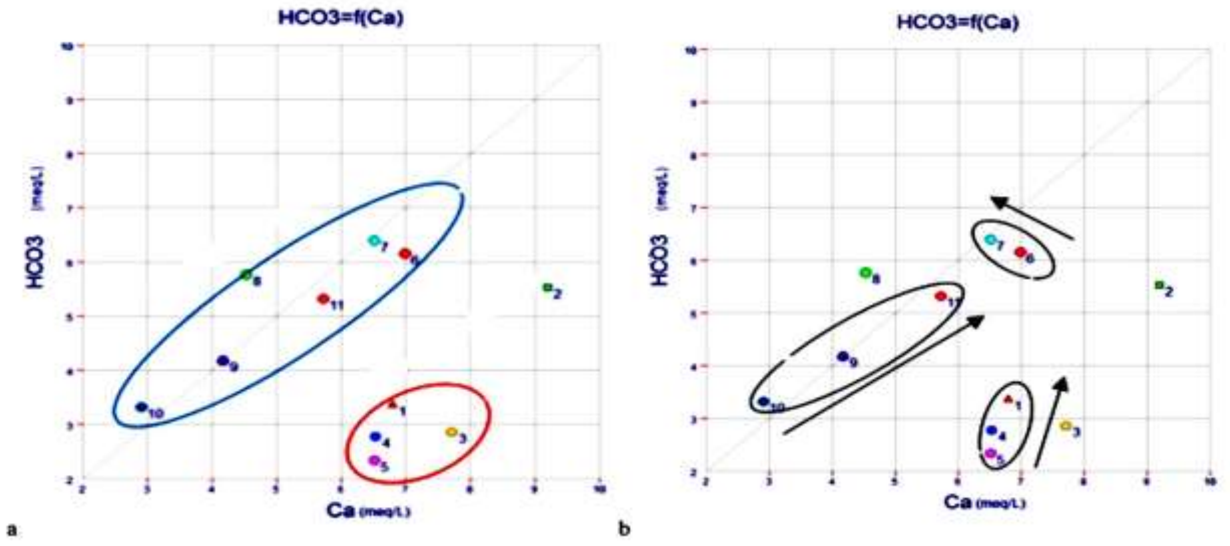

Figure 7a, b: *The couple Ca2+ - HCO3-*

3.1.6 The HCO_3^- - SO_4^{2-} relationship

The HCO_3^- - SO_4^{2-} relationship reflects the distinct evolutionary pathways of each group, confirming their different geochemical origins (Figure 8a) This graph also distinguishes groups characterized by an excess of either sulfates or bicarbonates (Figure 8a, 8b). In the subsequent plot (Figure 8b), the positioning of the three water groups reveals varying concentrations of SO_4^{2-} and Na^+. This distribution highlights the high sulfate concentration of Gr2, which is directly linked to the evaporitic pole. In contrast, Gr1 shows a different chemical signature associated with the carbonate pole. Gr3 exhibits intermediate concentrations, further supporting the conclusion that it represents a mixture of the two other water groups (Figure 8b).

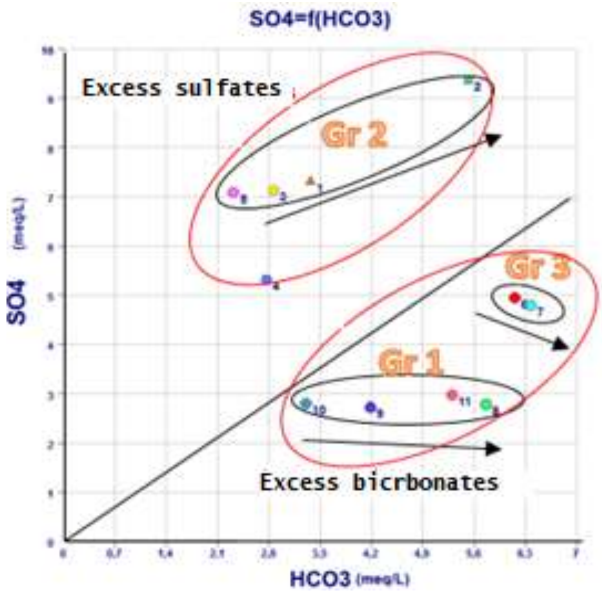

Figure 8a: *Couplage HCO_3^- - SO_4^{2-}*

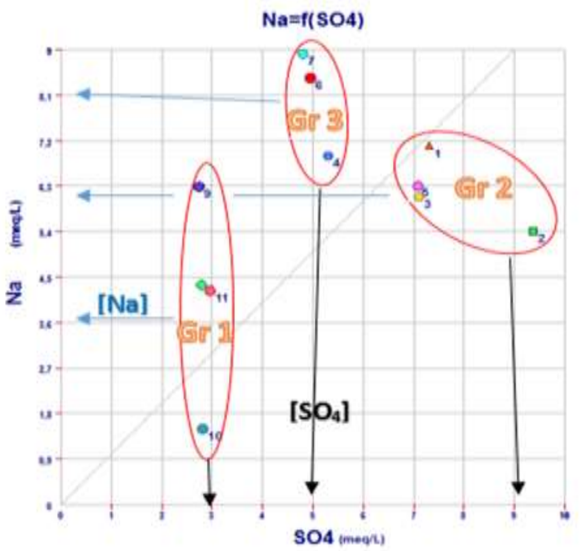

Figure 8b: *Couplage SO_4^{2-}- Na^+*

The graphs representing the various ion pairs reveal that the waters are categorized into three distinct groups. One group corresponds to a carbonate pole, characterized by high concentrations of calcium and bicarbonate ions. Another group aligns with an evaporitic pole, defined by elevated levels of sodium, sulfate, and chloride. Consequently, sodium chloride and sodium sulfate ions predominate over calcium bicarbonate and sodium bicarbonate ions, precisely confirming the water facies identified in the Schoeller Berkaloff and Piper diagrams.

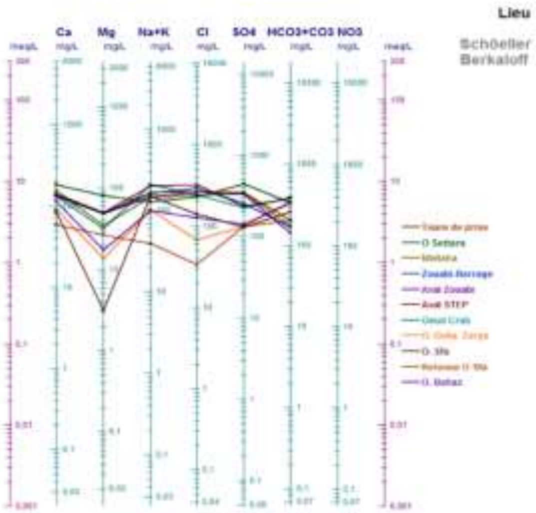

Figure 9: *Schoeller Berkaloff diagram for sampled water*

Figure 10: *Piper diagram for sampled water*

The use of TDS and EC once again confirms the existence of two primary poles: an evaporitic pole characterized by high TDS and electrical conductivity, a carbonate pole with low TDS and electrical conductivity, and a third group representing their mixture (Figure 11a, b)

3.2 Role of the WWTP in preserving, depolluting and lowering the levels of salts and organic matter.

Located downstream of the town of Sedrata, the WWTP plays a key role in treating the raw water collected (domestic, industrial and stormwater), reducing the very high levels of organic matter, suspended solids and pollutants before they reach the dam. Once the effluent has been treated, the purified water is discharged, without any problems, into the Oued Charef, which then feeds the dam. Analyses carried out using pollution indicator parameters clearly show the very positive effect of the WWTP on the water in the wadis located downstream and in the dam. Six selected graphs, among others, reflect this influence: Figure 12 (A, B and C), Figure 12 (D, E and F)The first three graphs show the evolution, over the course of a year, of BOD_5, COD, and SS (MES) for the water

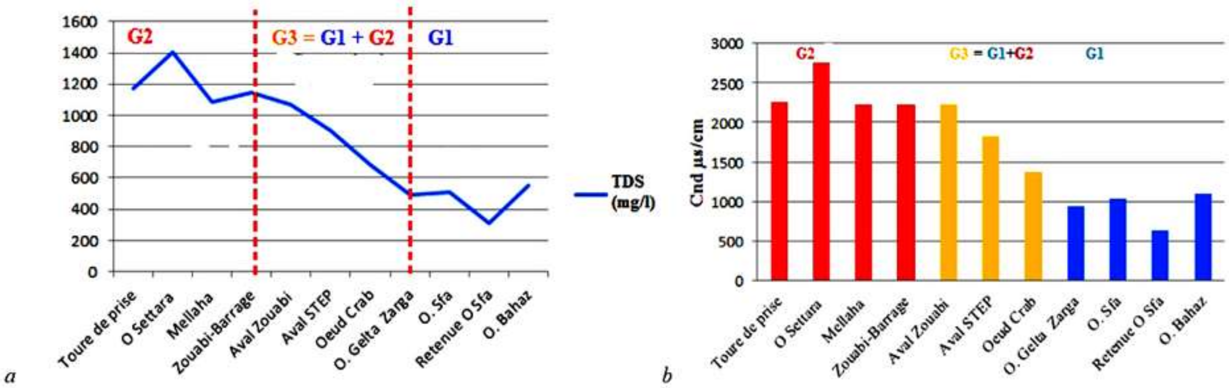

Figure 11a, b: *Water poles and mixtures based on TDS and electrical conductivity (Cnd or EC).*

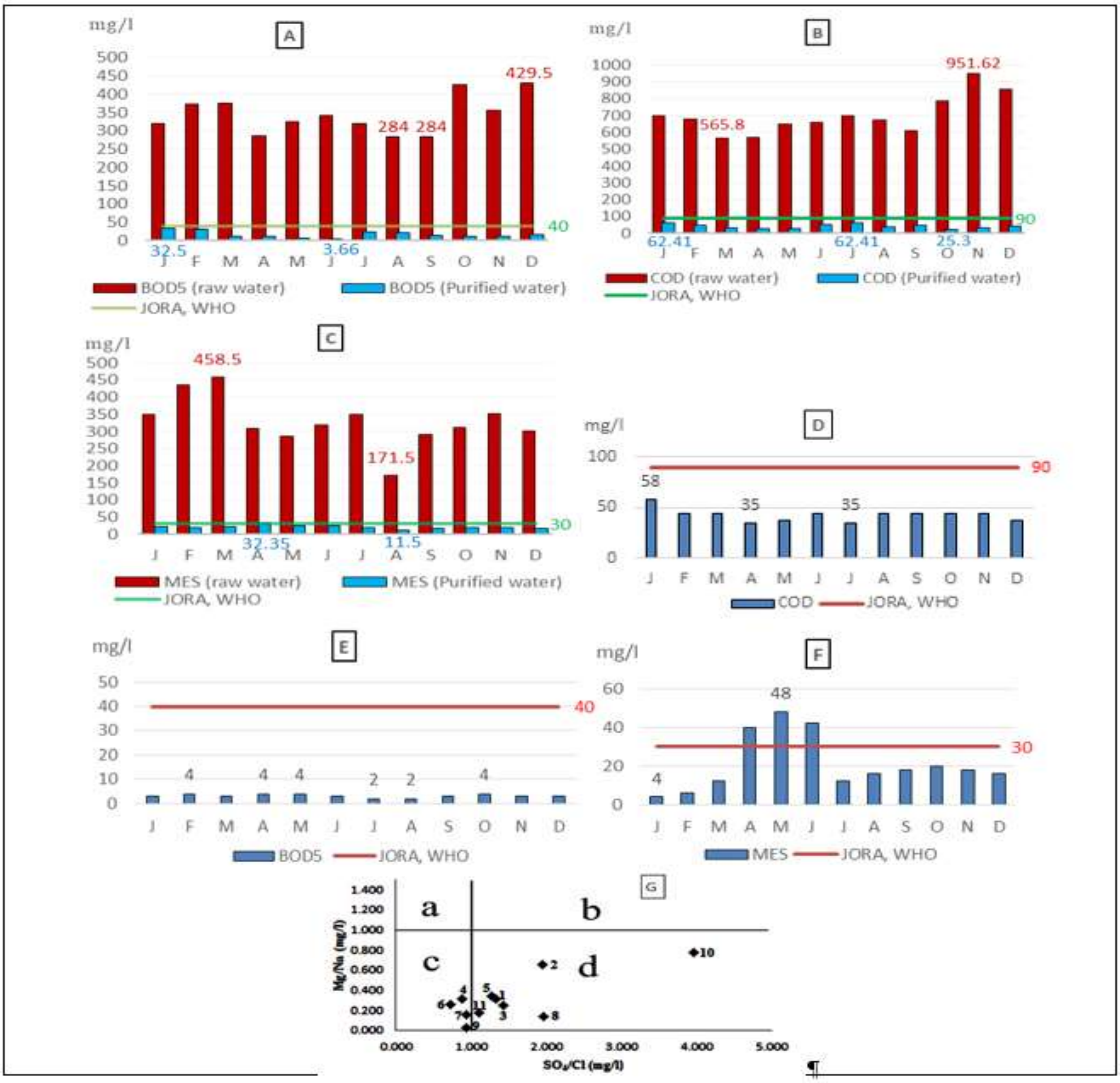

Figure 12: (A, B and C): *Monthly evolution and comparison with the JORA and WHO standards of BOD5, COD, and TSS (MES) of raw and treated water of the Sedrata WWTP, year 2020;* **(D, E and F):** *Monthly trends and comparison with the JORA and WHO standards for BOD5, COD and TSS (MES) in dam water, year 2020 at the ANRH laboratory, Constantine*[37] *;* **(G):** *SO_4^{2-}/Cl^- vs Mg^{2+}/Na^+ ratio method: determination of geochemical facies (high salinity waters)*

entering and leaving the WWTP, as well as their comparison with the Algerian standard for irrigation. The water discharged into the Oued Charef, during this year, all presented values below the standard. The water discharged into Wadi Charef during this year all had values below the standard (Figure 12: A, B and C). The other three graphs show the evolution, during the same year, of the BOD_5, COD and SS for the water from the dam and their comparison with the Algerian standard. Apart from the months of April, May and June, for TSS (MES) (probably due to sampling during the arrival of agitated water, because of the rainfall), the water from the dam is preserved and does not present any anomaly affecting the Algerian standard for irrigation (Figure 12: D, E and F).As an indication, the biodegradability coefficient K, according to the COD/BOD_5 ratio [26], after calculations carried out over a hydrological cycle, gives the following results: raw wastewater in February, March, May, June and October is easily biodegradable ($COD/BOD_5 < 2$). In contrast, raw wastewater from January, April, July, August, September, November and December is moderately biodegradable ($2 < COD/BOD_5 < 5$). Finally, the SO_4^{2-}/Cl^- vs Mg^{2+}/Na^+ ratio method is used to determine the geochemical facies of waters with high salinity. The sodium chloride (c) and sodium sulfate (d) facies, determined by Figure 12 G, are typical of alkaline and alkaline-earth evaporite environments, which confirms the results of the lithological and physico-chemical criteria used.

Conclusions

This study demonstrates that surface-water quality in the Oued Charef upstream basin is strongly controlled by the dissolution of Triassic evaporitic formations and Mio-Pliocene/Quaternary saliferous deposits, which significantly increase mineralization and salinity. Multivariate statistical analyses (PCA, HAC, and boxplots) consistently identify three hydrochemical groups: (1) carbonate-dominated low-salinity waters, (2) highly mineralized evaporitic waters, and (3) mixed waters influenced by both sources.

The Sedrata wastewater treatment plant significantly reduces organic pollution (BOD_5 , COD, and TSS), contributing to the protection of downstream wadis and the Foum El Khenga reservoir. However, existing treatment facilities in the basin remain insufficient, as several upstream villages discharge untreated wastewater into the tributaries.To mitigate salinization and organic contamination, it is necessary to build additional wastewater treatment plants and, urgently, a protection perimeter, including canals and dikes (seawalls) to divert saltwater, around the reservoir. Improving sanitation coverage and better managing runoff from evaporite formations are also crucial. To ensure long-term environmental resilience, it is advised that decision-makers incorporate circular economy principles and sustainable waste management solutions. Using such tried-and-true, situation-specific approaches is crucial to resolving the pollution issues found in this sub-basin. The results show that the Na-Cl and SO_4 facies are determined by the geogenic dissolution of halite and Triassic gypsum. The findings highlight the urgent need for integrated water-quality management in this semi-arid region, especially under increasing climatic and anthropogenic pressures.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.

- **Author contributions:** The authors declare that they have equal right on this paper.

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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4. Abbreviations:

ABH: Agence des Bassins Hydrographiques

BOD: Biochemical Oxygen Demand

COD: Chemical Oxygen Demand

EC: Electrical Conductivity

G or Gr: Group (for ex: G1= Gr1 = Group of water 1)

HAC: Hierarchical Ascending Classification

JORA: Journal Officiel de la République Algérienne

PCA: Principal Component Analysis

TDS: Total Dissolved Solids

TSS (MES): Total Suspended Solids

WWTP: Wastewater Treatment Plan