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HYDROCHEMICAL AND ISOTOPIC METHODS OF IDENTIFYING THE IMPACT OF IRRIGATION ON THE QUALITY OF GROUNDWATER: A CASE STUDY FROM THE GUELMA-BOUCHEGOUF REGION, NE ALGERIA

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Summary

The Guelma-Bouchegouf irrigated perimeter uses water from the Bouhamdane dam between May and the end of October. It should be noted that the water is channelled to the perimeter via Seybouse Wadi, which serves as a water collector. The water is supplied during the dry season, which causes water pollution due to strong evaporation and industrial discharges. Moreover, during the summer period irrigation increases since the crops grown are industrial tomatoes, melon, watermelon and beans, requiring intense and sustained watering. The measurement of the conductivity of the water flow shows a clear increase from 3000 µs/cm to 6000 µs/cm. This increase is connected to interactions between water and rock, compounded by the adverse impact of climate change. It should be noted that during this period the average temperature is 26°C and sometimes temperature values exceeding 40°C are recorded. In addition, industrial discharges into the Seybouse Wadi occur without pre-treatment, leading to water pollution by heavy metals. The results of the analyzes of the Seybouse Wadi waters show the presence of pollutants such as iron, manganese, zinc, copper and nutrients in the upstream zone (Guelma region). In the downstream area (Annaba) we notice the presence of pollutants such as chromium, lithium, iron, manganese and nutrients.

Keywords

irrigated perimeter • pollution • heavy metals • isotopes • Seybouse Wadi

1. Introduction

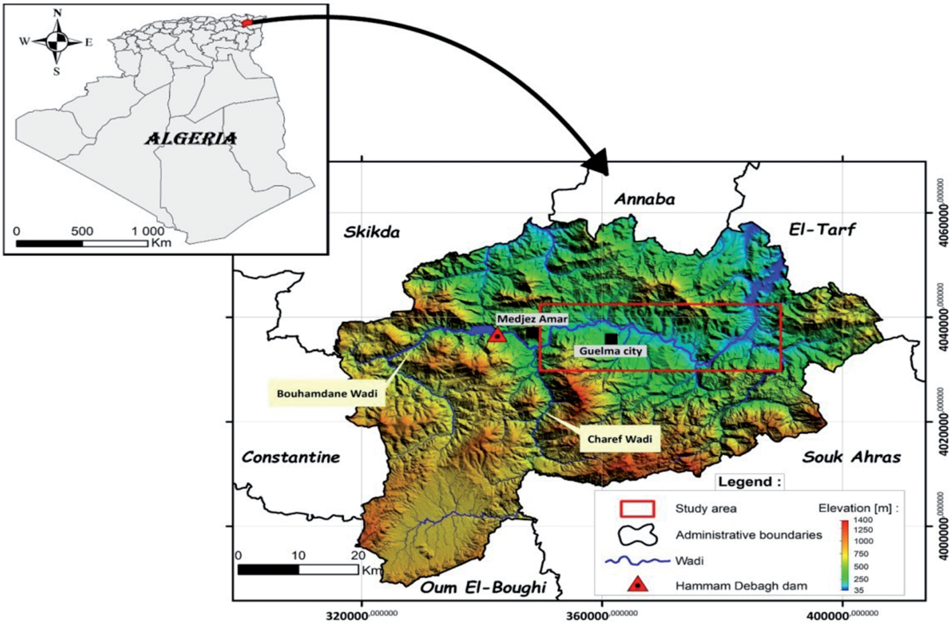
In recent decades, many countries choose irrigation as means to increase agricultural production in order to meet growing domestic demand for food. General agricultural practices include the use of fertilizers and pesticides for higher crop yields, sometimes neglecting current soil characteristics. This also causes a degradation of the quality of groundwater. Furthermore, indiscriminate disposal of domestic waste onto the ground and the seepage of sewage due to defective structures are frequently observed.

The chemical composition of groundwater that is intended for the irrigation presents one of the major problems in the Mediterranean zones, when considering its potential impact on the deterioration of water quality and the reduction of the agricultural output. This problem is often related to the nature of geological formations and climatic factors. Several studies were carried out on this topic [Djabri et al. 2007, Bouchaou et al. 2008, Fehdi 2014]. They showed the influence of these last factors on the increase in the salinity of water.

To guarantee its food self-sufficiency, Algeria has decided on creating irrigated areas. This policy began in the late 1970. In 2020, the irrigated area was around 300,000 hectares large, and it is planned to expanded it to 1,000,000 hectares by 2050. This increase has encouraged researchers from all fields to work on the quantitative and qualitative aspects of soils and waters [Ghachi 1986]. One of their aims was to report on the quantities of water passing through Wadi Seybouse. Djabri [1996] after the commissioning of the Debagh dam and the decrease of water amount in the Wadi (the waters of Wadi Bouhamdane located upstream flow into the dam) highlighted the origins of water pollution in the Wadi Seybouse. The water contamination is caused mainly by the geology of the Wadi (TRIAS) and industrial discharges to the Wadi without any pre-treatment. Urban discharges also contribute to the deterioration of water quality. It is only since 2009 that the quality of the irrigated perimeter of Guelma-Bouchegouf received some attention. The starting point was the study carried out by Mouchara [2008], who addressed the impact of the Hammam Debagh dam releases on the water quality of the Seybouse valley in its upstream part. In Tunisia many researchers have worked on similar subjects. For example, Rim Missaoui et al. 2022 presents an evaluation of a mathematical model of the influence of nitrates on water (in the Regueb basin, in the center of Tunisia). On the other hand, in the United States Guy Fipps [2003] has worked on the development of irrigation water quality standards and salinity management strategies. Iraq Hussein B. Ghalib in 2017 published a paper on groundwater chemistry evaluation for drinking and irrigation utilities in east Wasit province, Central Iraq. Also, between 2015 and 2019, three researchers from Badji Mokhtar Annaba University worked on the qualitative aspects of water and soil in the Guelma-Bouchegouf irrigated perimeter. Kachi 2015] demonstrated that the waters of the irrigated perimeter are polluted by pesticides and fertilizers. Aissaoui [2018] demonstrated that the waters of Seybouse Wadi (main water collector) are contaminated by nutrients, particularly nitrates, ammonium and phosphates. The results obtained by Mr. Touati confirm this analysis of water pollution and present results similar to those of Aisssaoui. Works carried out in Tunisia and Morocco are corresponding due to the implementation of similar policies on irrigated perimeters, such as the region of Beja in Tunisia and the region of Tadla in Morocco.

This study demonstrates that the irrigated perimeters are highly stressed during summer low water period, resulting in increased pollutants concentrations. It should be noted that these areas experience significant loss of water at the beginning and end of crop cycles.

Studies indicate a growing interest in water conservation in irrigation, however, the establishment and operation of the irrigated perimeter took place before climate change became such an urgent matter. At present, in addition to the releases from the dam, we note that the industrial and domestic discharges are carried out directly without prior treatment, leading to a degradation of the water quality that could have repercussions on the waterway's soils and crops.



Source: Soltani et al. [2023]

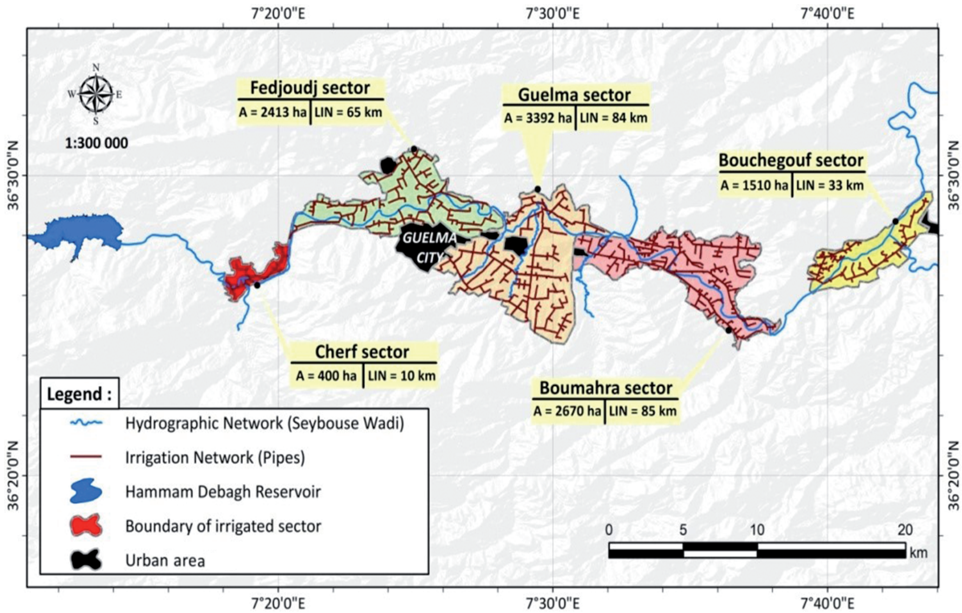
Fig. 1. Geographical location of the irrigated perimeter

2. Historical

In order to achieve food self-sufficiency, the Algerian state has established a number of irrigated perimeters, including the Guelma-Bouchegouf perimeter.

2.1. Before the construction of the Debagh dam

The flows passing through the Seybouse Wadi and measured at Mirbek were 13.2 m^3/s with a reception area of 6 071 km². The flows of the Charef and Bouhamdane wadis are, respectively, 2.27 m^3/s (17% of the total flow) for a partial basin of 1,104 km² and 3.79 m^3/s or 28.6% for a drained surface of 1,194 km². The Wadi Mellah in Bouchegouf is a small mountain basin (542 km²) with a flow of 3.41 m^3/s or 25.7% of the global flow. The Mellah Wadi had the second largest average annual contribution after Wadi Charef, even though the drainage area of the latter is two times bigger than the former.



Source: Soltani et al. [2023]

Fig. 2. The five sectors of the perimeter

2.2. After the construction of the Debagh dam

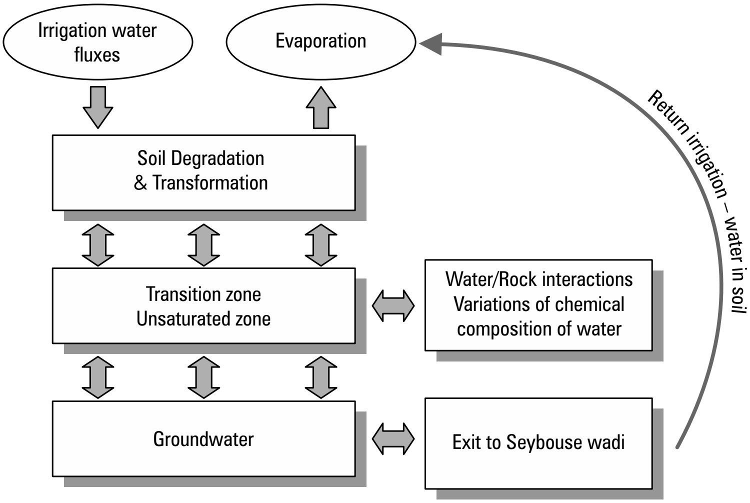
The construction of the dam led to a loss of water as the Bouhamdane wadi no longer feeds the Seybouse. In addition, the reduction in rainfall observed in recent years has caused a decrease in the flow of the wadi, which itself has contributed to the deterioration of the quality of the water in the watercourse. In fact, the Oued also receives wastewater from neighboring towns and villages (Guelma, Bouchegouf, etc.) and industrial waste. The polluted water can seep into the aquifer contaminating the groundwater. In order to highlight this phenomenon, water samples were collected from the study area and then analyzed.

3. Methods

The irrigated perimeter has its water supply from the Hammam Debagh dam. This water flows in the open air and is sometimes mixed with the water from the outlets of the treatment and purification station of Guelma. However, the quantity and the quality of water vary by season. In winter, the irrigation is carried out without the releases of the dam, while in summer, the water used comes from the Debagh dam.

3.1. The flows of irrigation water at the perimeter Guelma-Bouchegouf

The following diagram (Fig. 3) gives an overview of the passage of the irrigation water in the perimeter. It identifies three phenomena related to the water used for irrigation: first, some will evaporate; second, some will be enriched or impoverished in chemical elements and some will percolate towards the zone of instauration before it will reach the groundwater, and will eventually be reused for irrigation; third, some will flow towards the Seybouse wadi with a new chemical composition. The return of irrigation water is an aggravating factor of pollution. That is why we used the tool to study the hydrochemical properties water of the irrigated perimeter.



Source: Soltani et al. [2023]

Fig. 3. Mode of operation of the waters of the irrigated perimeter Guelma-Bouchegouf

3.2. Setting of the study area

Geographic location of the perimeter

The irrigation perimeter of Guelma-Bouchegouf is situated the plain of Guelma and is a part of the Seybouse basin (Fig. 1). It covers an area of around 122 km² and extends over a length of 25 km from east to west and over a width from 3 to 10 km along the middle Seybouse in the center of the plain. The altitude of the plain varies between 220 m in Medjez Amar (West) and 120 m in Nador (East).

Geological characteristics

The work carried out by J.M. Villa in 1980 showed that the study area belongs to the external domain of the eastern Algerian alpine chain that is composed of formations dating from the Triassic to the Quaternary. The latter have a very varied lithology study area belongs to the external domain of the alpine chain of eastern Algeria characterized by formations dating from the Triassic to the Quaternary. The latter have a very varied lithology, which includes the Cretaceous neritic formations of thick and massive limestone. Cretaceous limestones and marls form the Tellian aquifer. The Mauritanian flyschs are present in Ain Berda (north of Guelma), dating from the Cenomanian to the Oligocene, made up of marls, breccias, and limestone. The Kabyle ridge dates from the Neocomian to the Eocene. Next are the Massylian flyschs and the Numindian lyschs of Oligo-Miocene age. It should be noted that most of the sedimentary rocks are covered by Miocene and Pliocene formations, and by a Quaternary cover of sand, gravel and alluvium. The Triassic formations were found a few kilometers south of the town of Bouchegouf.

Description and mode of operation of the irrigated perimeter. From the dam to the plot, there is a mixed system (installed and managed by ONID): gravity supply and the pressurized distribution network; the dominant watering method is sprinkling. The perimeter has five sectors organized from upstream to downstream according to the diagram in Figure 2.

3.3. Geology-hydrogeology relations

The piezometric map

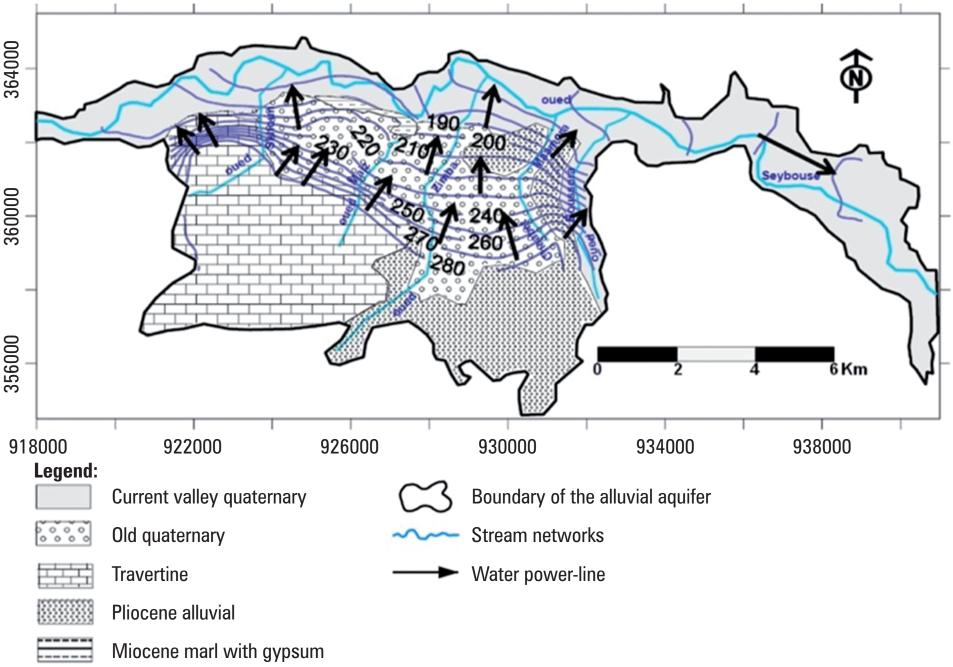
The piezometric map prepared by Moussa [2017] shows that the aquifer is situated in alluvial formations of the Quaternary age, limestone in its southeastern part and alluvial formations in the southwestern part (Fig. 4). The flows are directed towards Wadi Seybouse, where the flow velocity decreases due to an increase in permeability the favors water pollution.

3.4. Irrigation mechanism

The irrigation system at the entrance to the perimeter is, by using gravity, supplied by the waters of the Oued for each sector with the size as follows: Cherf: 400 ha, El Fedjoudj 2413 ha, Guelma center 3392 ha, Boumahra Ahmed: 2670 ha, Bouchegouf 1510 ha. These sectors receive the water pumped from the Seybouse wadi. Thresholds located in the bed of the Oued make it possible to raise the level of the water by a few meters, thus facilitating pumping. At the plot level, irrigation is provided by a system of sprinklers and mobile ramps operating at peak periods in 2 positions for 8 hours per day (spacing: 12 × 12 m and 18 × 18 m). Localized irrigation by the drip system is used for the best orchards. The third part will go to Seybouse wadi with a new chemical composition.

3.5. Field and laboratory work

The total of 80 water samples were taken during the months of March 2018 and January 2019. The samples come from the dam located upstream of the perimeter. We also took samples from the Oued and at the various thresholds. We also sampled domestic wells located within the irrigated perimeter. This approach allows us to know the chemical composition of the water at different levels and horizons and to deduce the interactions that occur there. The collected water was partially analyzed at the Water Resources Management and Sustainable Development Laboratory (Badji Mokhtar University) and at the Algiers Water Laboratory. The physico-chemical parameters (pH, T°C, Eh, dissolved oxygen and conductivity) are measured in situ using a WTW multiparameter device (Multiline P3 PH/LF-SET) and a SEBA KLL device for measuring the piezometric level. The analysis of chemical elements was carried out by flame atomic absorption (Perkin-Elmer 11005) for cations and trace elements. Anions and trace elements were measured by the WTW photo lab spectral spectrophotometer. Isotopic analyses were performed in Annaba labs by a Finnigan-Matt 251 ratio mass spectrometer. For hydrogen, samples were reacted with Cr metal at 750° C using a Finnigan H/device coupled to the mass spectrometer. For oxygen, samples were equilibrated with CO_2 gas at approximately 15°C in an automated equilibration device coupled to the mass spectrometer. Standardization is based on international reference materials VSMOW (Vienna standard mean ocean water).



Source: Mouassa [2017]

Fig. 4. Piezomtric map of the plain of Guelma

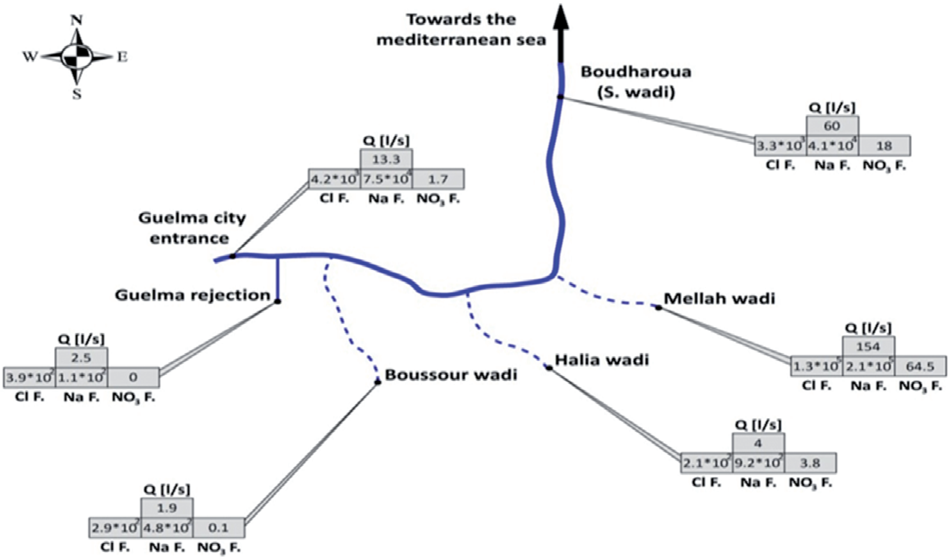
4. Results and discussion

The analyzes of water carried out before the construction of the dam showed a salinity and pollution of the water by nitrates caused by fertilizers. (Considering that the concentration of nitrates in the normal state is around 20 mg/l, the 60 mg/l in the discussed case highlights an excessive water pollution.). The salinity of the waters observed (the conductivity oscillates between 2500 and 5500 µS/cm is the another factor indicating water pollution. In order to represent the variations in the salinity of different waters, we chose six (6) sampling points (from Seybouse and its tributaries) distributed between Guelma and Bouchegouf. The following parameters measured were CI, Na, NO3, water flow, T, pH, conductivity.

Table 1. Values of flows calculated at different control points

Stations/ parameters	Wadi Seybouse Guelma	Reject Guelma	Wadi Boussoura	Wadi Halia	Wadi Mellah	Wadi Seybouse (Boudaroua)
Water flow (l/s)	13.3	2.5	1.91	4	154	60
Cl (g/l)	4222.7	390.5	296.7	213	131208	3315
Na (g/l)	75835.2	115	480.7	920	212520	41400
NO_3 (g/l)	1.7	0	0.13	3.8	64.5	18
pH	5.5	5.8	6.2	7.1	6.4	6.4
T (°C)	10	21	18	18	21	22
Conductivity (µc/cm)	1000	760	6400	5800	10000	8400

It can be seen (Fig. 5) that the contributions of the tributaries of the Wadi Seybouse are generally low, but this is compensated by the Wadi Mellah, which carries enormous quantities of chlorides (131 g/l) and sodium (212 g/l). The flows observed at the level of the Wadi Mellah are the most important. In this case, the losses to the aquifer are significant, 123 g/l for chlorides, 202 g/l for sodium and 64 g/l for nitrates, indicating excessive pollution. The water coming from the dam is used by farmers upstream and downstream of the town of Guelma. The lack of pollution in the upstream part is linked to the fact that there are no urban and industrial discharges, whereas the downstream part suffers from the presence of polluting industries such as bicycle factories, ceramics, tiling, sugar, etc. In addition, Guelma discharges its waste water into the wadi, thus affecting the quality of the water of the dam. The analyzes carried out after the releases of the dam allowed us to generate seven instantaneous profiles of the water quality. These profiles (Fig. 7) show, in general, a sensitivity of the water quality of Wadi Seybouse to any water input, whether it comes from a discharge, tributary or dam. We take the case of July 1998 as an example, because during this period there was no rainfall and the observed concentrations were generated either by the releases from the dam or by the tributaries.



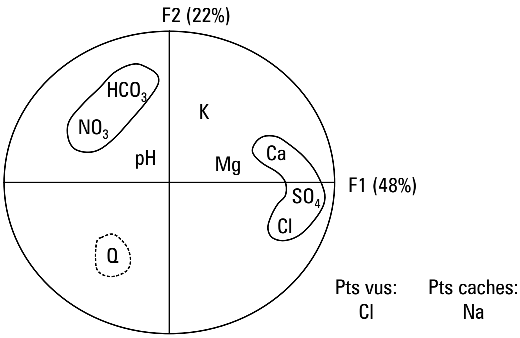
Source: Soltani et al. [2023]

Fig. 5. Calculated flux card

4.1. After the commissioning of the dam

Contributions of the main component analysis

The principal component analysis was performed on the three axes F1, F2 and F3, for our interpretation. We were interested in the circle formed by the axes F1F2, as it provided us over 70% of the information. Along the F1 axis (47.94%) (Fig. 6), there is an opposition between highly mineralized water, particularly rich in Ca, Na, Cl and SO4, which would be the cause of the observed salinity. These same waters are opposed to those coming from limestone formations accompanied by nitrates.

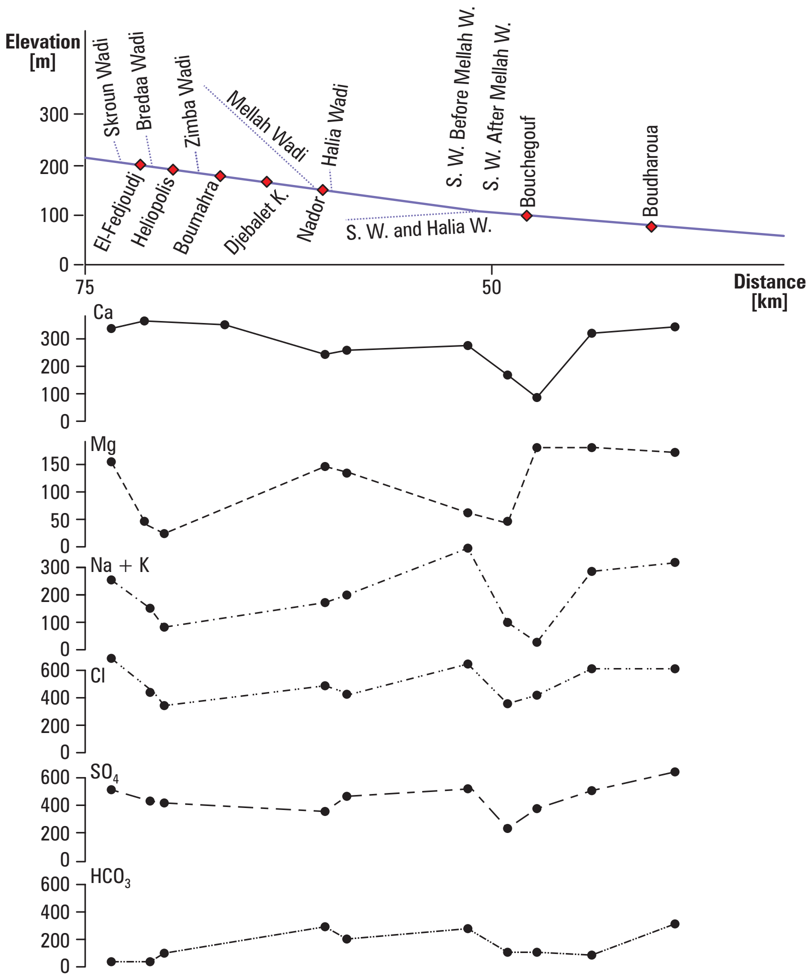


Source: Soltani et al. [2023]

Fig. 6. Global PCA circle

The F2 axis contains 22.05% of information and indicates a concurrence of bicarbonates (positive part of the axis) and chlorides and sulfates (negative part of the axis). This concurrence indicates two families of waters:

- the first linked to geology (limestone), resulting from the leaching of geological formations (see piezometric map),
- the second characterizing the waters of the dam. The nitrates come from the flows which are made through the irrigated perimeter.



Source: Soltani et al. [2023]

Fig. 7. Profile of the variation of the elements recorded along the Wadi

The profile produced (Fig. 7) shows an inverse evolution between sulphates, chlorides and sodium with respect to calcium, in the upstream part. Beyond Bouchegouf the concentrations evolve identically. The effect of purification processes becomes perceptible from Bouchegouf. The performed measurements showed the presence of iron, zinc, manganese and nutrients in the waters of the Wadi. The area under study was agricultural, and thus the construction of the dam supported agricultural practices by creating irrigated perimeters. The dam contains 200 million cubic meters.

Origin of water used in irrigation

Isotope analyzes have been carried out at a few water points in the study region. The results obtained are summarized in the following Table 2.

Table 2. Results of isotope analyzed

Sampling points and water types	Aquifers	Conductivity	$\delta^{18}O$ (‰) Smo W	$\delta^{2}H$ (‰) Smo W	Tritium UT	Region
1. Discharge Guelma RU	Ar	1315	−5.88	−58.7	4.1±0.5	Guelma
2. Byez wadi	Cal	783	−6.04	−44.5	20.7±2.7	Guelma
3. Wells Héliopolis	Cal (As)	1172	−5.54	−26.6	21.0±2.7	Guelma
4. Dam Exit	Cal	2020	−5.36	−29.6	23.1±3	Guelma
5. Belkheir	Cal	884	−5.8	−33.2	11.7±1.5	Guelma
6. Discharge from the sugar refinery	Ar	1177	−6.10	−41.3	9.7±1.7	Guelma
7. Seybouse to Bouhamra	Ar	2910	−4.9	−36.5	7.4±1.6	Guelma
8. Sidi Smair	Cal (P)	852	−6.24	−38.5	15.0±1.9	Guelma
9. Djeballah	Cal (P)	1273	−5.24	−37.7	12.4±1.4	Guelma
10. Boussoura Wadi	AR	1381	−5.47	−33.8	11.2±1.7	Guelma
11. Seybouse wadi	Ar	2160	−4.96	−34.7	14.8±1.9	Guelma
12. Ain sofra	GN	1466	−5.62	−38.1	4.7±1.4	Guelma
13. Haliawadi	Cal	1090	−5.32	−27.7	13.8±1.9	Guelma
14. Seybouse Before Halia	Ar	2030	−5.08	−39.28	10.8±2.11	Guelma
15. Seybouse beyond Halia	Cal	2020	−5.17	−38.99	2.3±2.4	Guelma
16. Source Nador	T	865	−4.74	−31.3	14.4±2.8	Guelma
17. Nador	T (P)	2440	−5.30	−40.6	17.6±3.4	Guelma
18. Charef	Cal (P)	685	−4.81	−30.1	20.6±4	Bouchegouf

Table 2. cont.

Sampling points and water types	Aquifers	Conductivity	δ ¹⁸ O (‰) Smo W	δ ² H (‰) Smo W	Tritium UT	Region
19. Wells Charef	Cal (As)	1780	–6.00	–35.8	10.7±2.1	Bouchegouf
20. Seybouse before Mellah	Ar	1864	–5.1	–37.6	13.0±2.6	Bouchegouf
21. Seybouse beyond Mellah	Ar	1870	–5.35	–32.9	13.1±2.6	Bouchegouf

Classification of water using tritium units

In the case of this study, 22 samples of surface water and groundwater were taken and analyzed. It appears that their content varies between 4.1 and 24.5 TU. We distinguished three groups:

- 1st group are very recent waters: the contents are greater than 15 TU; sampled from water points: 1, 2, 4–, 8, 17, 18.
- 2nd group are recent waters: the contents are between 6 and 5 TU; sampled from water points: 5°, 6+, 9*, 10–, 11–, 13–, 14–, 15–, 16°, 19*, 20–, 21–, 22–.
- 3rd group are old waters: the contents are less than 6 TU; sampled from water points: 3+ and 12°.

The waters in the 1st group, which have high tritium contents, are considered to have the same value as current precipitation. This is based on the comparison with the results of the Tunis-Carthage station. These are recent waters from the last rains that flow towards the wadis, infiltrate directly into the subsoil and towards the aquifer.

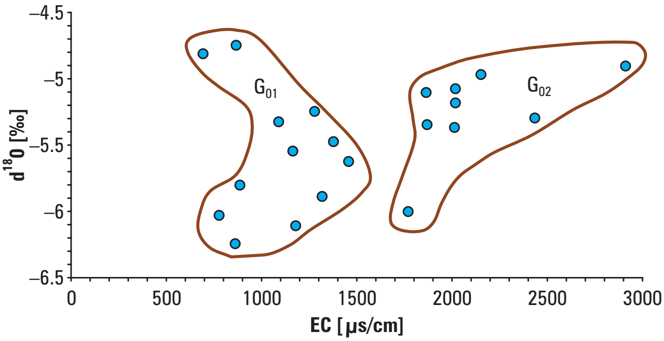
In the 2nd group (5, 6, 9, 10, 11, 13, 14, 15, 16, 19, 20, 21, 22) the water samples have intermediate values ranging from 6 to 15 TU and correspond to relatively recent waters, compared to those of the 3rd group and older ones of the 1st group. In this intermediate group, the lower is the TU content the older are the waters, with the existence of all possibilities of mixing. This category of intermediate values indicates a relatively short residence time of water.

The 3rd group, points 3 and 12, suggests deep waters, therefore old waters. Demonstrating that most of the waters analyzed are surface waters and so recent.

4.2. Relation oxygen 18 (O18) – Electrical Conductivity (EC)

The establishment of the diagram of the variation of the values of δ O18 and those of TDS shows the existence of two types of waters (Fig. 8):

- First type is characterized by a relatively low conductivity ranging between 1000 and 2000 μs/cm. Oxygen-18 has values between –6.5‰ and –4.5‰. These waters are found in wells and wadis, indicating an influence of evaporation on conductivity.
- Second type of waters with the conductivity reaching 3000 μs/cm and the oxygen-18 values varying from –2‰ to + ‰, indicating recent warmed waters.



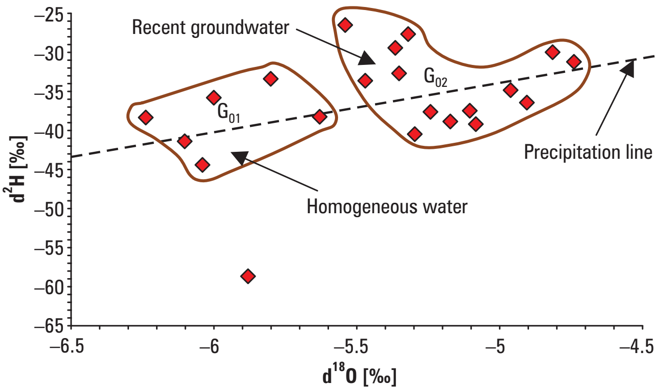
Source: Soltani et al. [2023]

Fig. 8. Relationship between oxygen 18 (O18) and conductivity

4.3. Deuterium – Oxygen 18 relationship

The oxygen-18 and deuterium contents for all the studied samples are plotted in the classic O^{18} – H^2 diagram (Fig. 9), together with the so-called global meteoric water line (d H^2 = 8 ¥ d O^{18} + 10), defined by Craig (1961) and the local meteoric water. The plot of data points in such diagram provides some indication upon the origin and the recharge processes of waters. Figure 8. presents the evaporated waters on the straight line of a low slope. The homogeneous waters warmed thus constitute a point cloud. Oxygen-18 is stable.

The isotopic tool reveals a neo-salinity, the origin of which remains poorly known. In this case we need the results of chemical analyzes.



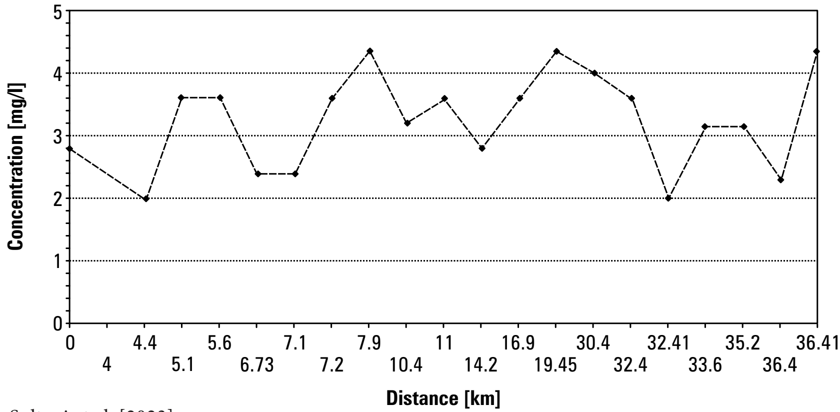
Source: Soltani et al. [2023]

Fig. 9. Deuterium vs Oxygen 18

4.4. Water pollution of the Wadi Seybouse

Several heavy metals were measured during the campaigns. The profiles (Fig. 10) were generated based on the results of the analyzes carried out in January 2020. The Guelma region showed high concentrations of iron – about 4 mg/l, and manganese – 0.5 mg.

These concentrations are caused by the flushing effect that takes place after water is released from the dam.

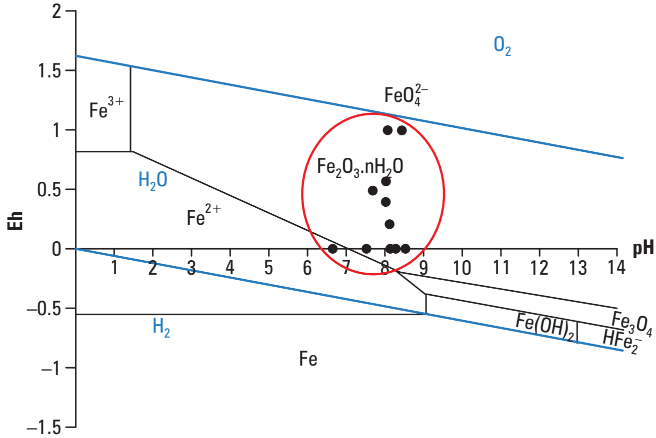


Source: Soltani et al. [2023]

Fig. 10. Water pollution by iron

4.5. Origins of water pollution by iron

Figure 10 shows the pollution of water by iron. This pollutant originates from various infrastructures found in the study area. To explain the presence of iron in water we have followed an approach that analyzes the speciation of iron and its various forms.



Source: Soltani et al. [2023]

Fig. 11. Variations in iron ion at Seybouse wadi

4.6. Contributions of speciation

The distribution of a chemical element among different physicochemical species is known as chemical speciation. In other words, to define the speciation of iron in water, it is necessary to identify the different physicochemical forms present in seawater and assess their relative importance. Currently, the speciation of iron in water is not fully understood, unlike other nutrients, such as silicon, nitrogen, phosphorus or carbon. In order to understand the speciation of this metal, different approaches are required. One approach involves chemical analysis, another – physical separation.

4.7. Chemical speciation

Two complementary approaches are possible: the redox approach and the organic/inorganic approach.

Redox speciation

This approach to speciation focuses on the degree of oxidation of iron in water by taking into consideration the two oxidation states: + (II) and + (III). In an oxic medium, iron (III) is the thermodynamically most stable oxidation state, but it has very low solubility. Iron (II) is much more soluble, but very quickly oxidizes in toxic environments. Iron (II) could be detected in surface waters, with concentrations representing up to half of the total dissolved iron. The transition between the two forms can occur through various mechanisms:

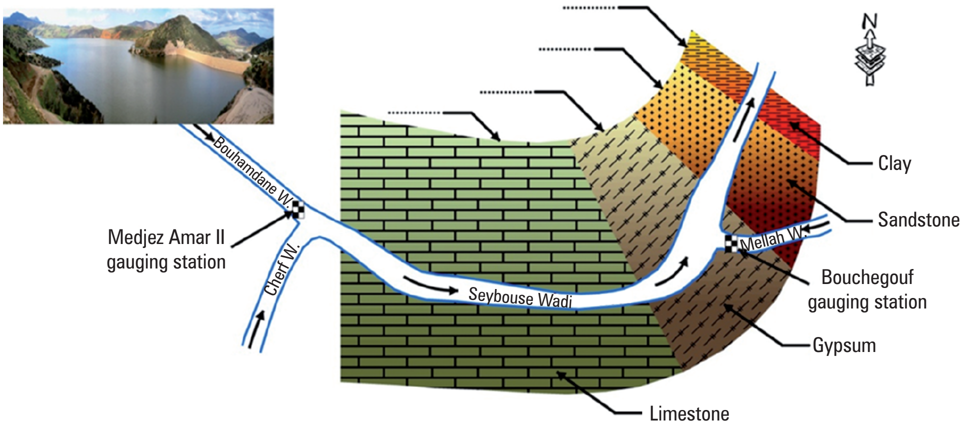
(i), iron (III) can be reduced to iron (II) by chemical reduction; (iiii) by microbial reduction in reducing environments (e.g. sediments and anoxic ponds). In return, the Fe (II) forms are rapidly oxidized by oxygen or by other oxidants naturally present in water.

Evolution of iron

Figure 12 shows a dispersion of the samples, indicating a dilution of the iron ion in contact with the waters of Wadi Seybouse. Nonetheless, it is important to note that we are talking about two distinct groups:

- the first characterized by pH stability, the values oscillate between 6.5 and 8.5, this group demonstrates an Eh zero,
- the second group has a stable pH at around 8 Eh value, it is greater than zero and reaches a value of around 1.5.

This value is close to 0.77 and indicates an oxidation of Fe^{3+} to Fe^{2+}.



Source: Soltani et al. [2023]

Fig. 12. Water chemistry acquisition in the Guelma-Bouchegouf irrigated area

5. Conclusion

The study area is designated for agro-industrial purposes and is experiencing a deterioration in water quality. Our work identified two sources of pollution:

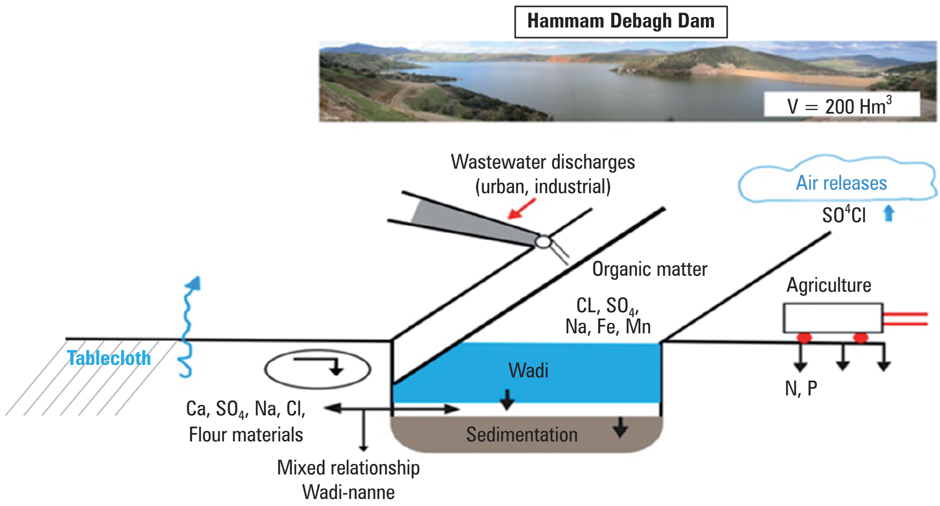
- pollution of anthropogenic origin,
- pollution of natural origin.

The first source of pollution are industrial activities (cycling, ceramics, tiling, etc.) and dumping discharges into Seybouse Wadi without pre-treatment. Water pollution caused by iron was highlighted in this study. This metal originates from the waste produced by the tile factories located on the Zimba wadi and from the marble factory, which flows directly into the Seybouse wadi near the village of Nador. Meanwhile, natural pollution is caused by the leaching of $CaSO_4$-rich Triassic formations, leading to an increase in mineralization. These same formations are also present in the village of Nador, upstream of the Seybouse wadi. The pollution by metals does not affect the variation in the chemical composition of the waters in the Seybouse wadi as the pollutants are trapped in the sediments. This is evident from the lower concentrations of heavy metals found far from sources of pollution. The disappearance of pollutants in areas far from the source of pollution explains this phenomenon. In the area of the Seybouse Wadi, we can observe a variation of the chemical facies of the waters. This variation is connected to the change in the geological nature of the bedrock through which the water flows. The following diagram (Fig. 13) shows the water courses of the area along the outlet of the dam. Water at the level of the dam and at its outlet has a bicarbonate facies due to its contact with the limestone. Arriving at the place called Nador, the water facies change and become sulphated due to the contact with the gypsum formations in this area. This contact enriches the water with $CaSO_4$, resulting in the appearance of sulphate water. Upstream of Bouchegouf, the Mellah wadi, salt water, and the Seybouse wadi converge, resulting in a change in water's chemical composition. As a result of the water and the contact between water and sandstone outcropping in this small area, water becomes enriched in chlorides. Additionally, clays were observed in the area between Guelma and Bouchegouf. Thus, the chemical facies changes, when water becomes rich in sodium due to the exchange of bases occurring between water and clay. Water releases calcium and captures sodium, resulting in a sodium facies. At the entrance to the second part of the area, and beyond, the outcrop formations are of alluvial type with varying facies. The isotopic overview, particularly the tritium units, indicates that the majority of the water is recent, which implies a relatively short residence time and highlights its exogenous origin. The contribution of isotope analyses remains undeniable, demonstrating that most of the water used for irrigation comes from dams or domestic wells.

The study focuses on the quality of the water used in an irrigated perimeter, where multiple water sources intersect. The Guelma-Bouchegouf zone utilizes water from various source, such as the Debagh dam, rainwater, water treated by the Guelma plant and water from domestic wells. This mixture of water sources makes it difficult to identify the specific types of waters flowing through the perimeter. For this reason, we used the hydrochemical and isotopic tools in eleven samples. The analyses carried out in this study indicate that the waters of the irrigated region are mineralized to various degrees, ranging from 1700 to 10 000 μs/cm. This wide variation in conductivity supports the hypothesis that the water originates from different sources. This variation may also be linked to the fact that the water flows on the surface, which is susceptible to the influence of climatic factors, particularly the increase in temperature during the summer season when irrigation is intense. This results in strong evaporation, which in turn leads to increased salinity of the water. In order to explain the observed variations, we analysed the principal components. The results indicate a competition or rather an opposition between the waters rich in bicarbonates, from the dam, and the waters from the Wadi, rich in chlorides or sulphates. This illustrates the impact of the Wadi argillaceous matrix. To track the variation of chemical elements in space, we created profiles that show the evolution of the measured elements. These profiles reveal the same trend as the one identified by the principal component analysis. The trend is demonstrated by an inverse evolution between the elements as well as by comparing the changes in calcium (Ca^{2+}) to those in sodium (Na^{+}). The waters at the outlet of the dam are rich in calcium, which dominates over sodium. However, in the wadi, the water becomes rich in sodium. This change in the chemical distribution is explained by the exchanges between water and clay. During these exchanges sodium is released into the water and calcium is captured, resulting in an increase of the sodium concentrations in the water. In the next step, we were interested in the variations of the chemical elements of eleven site-stations (sampling points). A domination of the chlorides on the anion side and sodium, in a discontinuous manner, on the cation side was noticed. These observed variations are caused by the contributions to the irrigated area. To determine the origins of waters, we used the results of the isotopic analysis. The tritium levels indicate that the water is generally recent, except for the water from deep boreholes, which suggests a long residence time in the water table.

The graphs for deuterium and oxygen-18 show two families of water salinity: the first being the water from the dam, and the second being the mineralized water characterizing the water from the Oued and nearby wells. Among the heavy metals present in the waters of the wadi, we registered the presence of iron and manganese. Using the Bourbaix diagram, we identified a heterogeneous distribution of iron. This tendency is associated with the dilution that occurs when the water is supplied from the dam, confirming that the water is recent.

The diagram below summarizes the various chemical processes which occur in the zone and the water exchanges, the deuterium, the oxygen-18 and the tritium.



Source: Soltani et al. [2023]

Fig. 13. Mechanisms governing the water quality of Seybouse wadi

The authors declare that they have neither conflict nor competing of interests.

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