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# Assessment of shallow groundwater quality in the Guelma-Bouchegouf irrigated perimeter (North-eastern Algeria)

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**Key words:** Guelma-Bouchegouf, Algeria, Irrigated perimeter, Groundwater, Water pollution

## Abstract

Extending about 80km from East to West, the irrigated Guelma-Bouchegouf perimeter is located in the North-east of Algeria. It has been promoted since 1996 as an irrigable area of 9250 hectares (ha). It spans over both banks of the Seybouse Wadi and is subdivided into five independent units. It contains a shallow water table aquifer that is vulnerable to pollution from anthropogenic sources. In order to assess groundwater quality, physicochemical and organic analyzes were carried out during the low flow period (October 2017) at fourteen shallow wells within the Guelma-Bouchegouf irrigation area. Chemical analyzes results show that the study area is dominated by chloride-calcium, sulphate-calcium and chloride-sulphate-calcium water types. The overall mineralization is controlled by several phenomena such as soil leaching and evaporation process during high and low flow periods, respectively, acid hydrolysis of underlying rocks and human activities in the area. From a quality point of view, groundwater is moderately to highly contaminated by major elements ($Mg^{2+}$, $Na^{+}$, $Ca^{2+}$, $Cl^{-}$, $SO_4^{2-}$), nitrogen compounds ($NO_3^{-}$, $NO_2^{-}$, $NH_4^{+}$) and phosphates ($PO_4^{3-}$) due mainly to the presence of salt rich evaporitic formations, on one hand, and intensive agricultural activities, on the other. It is expected that results of this work will help decision makers to take proper actions to protect soil and groundwater quality in the study area.

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## Introduction

Groundwater composition is naturally influenced by host rocks. However, human activities (population growth, urban, industrial and agricultural developments) may deteriorate the environment when the water is thoughtlessly spilled at the surface (contaminants leaching from agricultural fields, landfill sites, industrial spills, or heavy metals in acid mine drainage, etc.). Such impact is not always immediately evident and issues related to water quality have been and continue to challenge hydrologists and environmentalists worldwide.

In the Guelma-Bouchegouf irrigated perimeter, little has been published on the subject and most of recent work, mainly academic research, focused on surface waters (Kebieche 2007; Laraba *et al.*, 2013; Kachi, 2015;. Aissaoui and Benhamza; 2017 and 2018). The purpose of the present study is to explore the processes controlling the chemical composition of the underlying water table aquifer, the water quality, which influences the use of this resource and to identify groundwater pollution hazard to overcome the water quality challenges in this irrigable area. It is also a question of supplementing and bringing new elements to previous works on the subject based on different interpretation techniques of the physicochemical and organic analyzes results in order to assess the type of water pollution in the study area. In short, it is also a question of identifying the areas and mechanisms by which contaminants enter the groundwater system and to develop reliable actions to protect the public and the environment in the long run. As analysis of all contaminants is not economically feasible and since the Guelma-Bouchegouf irrigated perimeter contains a shallow water table aquifer, the presence and concentration of major elements and selected specific contaminants that have ecological consequences are targeted in this study. Relevant results will help decision makers to protect the environment and preserve soil and water resources quality through appropriate management practices.

## Materials and methods

*Study area*

The Guelma Wilaya is located in the North-east of the country. It is limited by the wilayates of Annaba to the North, El Tarf to the North-east, Skikda to the North-west, Souk Ahras and Oum El-Bouaghi to the South-east and Constantine to the West (Fig. 1). The study area is characterized by a Mediterranean type climate defined by two, dry and wet, seasons. The mean annual rainfall is about 615mm.

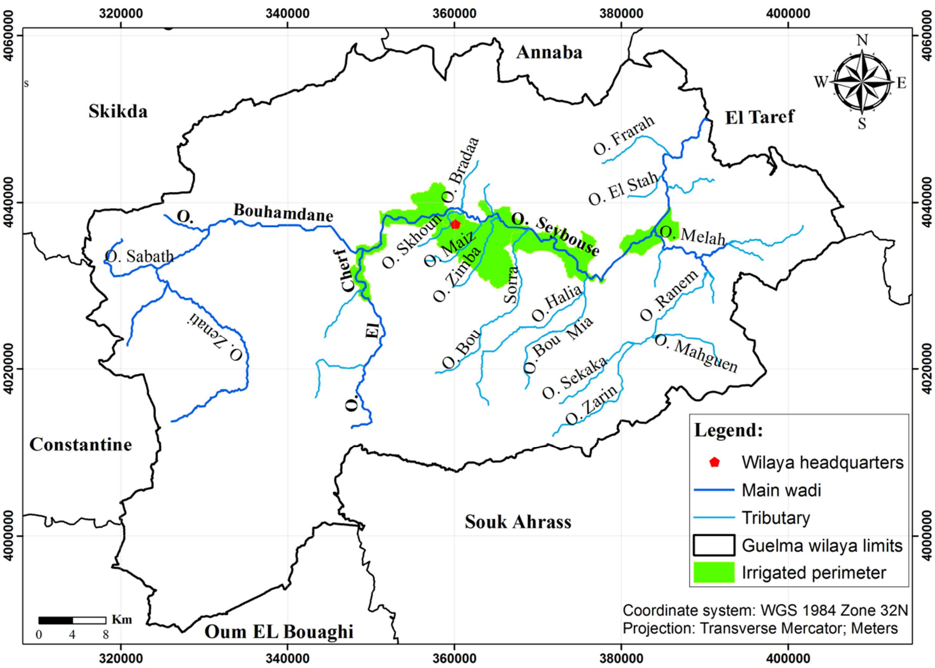


**Fig. 1.** Study area location map.

The rains fall mostly in the form of showers that vary in time and space. Average temperature ranges from 10°C in January to 28°C in August. From a geological point of view, the Guelma basin is particularly characterized by the importance of salt deposits formations that alternate with gypsum, clay and limestone layers (Boukhrouf, 2010).

The Guelma-Bouchegouf irrigated area that extends from the Bouhamdane and Cherf wadis confluence at Medjez Amar is 80 Km long. It is divided into five units, with independent development and water supply plans (Fig. 1). Spread on both banks of the Seybouse wadi, the Guelma-Bouchegouf irrigated district covers a 9250Ha irrigable soils out of a 9940. Ha total area (Kebieche, 2007). It is fed by the Hammam Debagh Dam and direct water intakes from the Seybouse wadi. The latter drains, via a relatively dense hydrographic network, all the wastewater from Guelma City, suburban and rural communities causing an increase in pollutant load in the wadi. Furthermore, the Guelma region is experiencing intensive agriculture activities with excessive use of pesticides causing some deterioration in water and soil quality.

*Sampling Points and analytical techniques*

Groundwater monitoring programs must include sampling and analytical techniques that are appropriate for groundwater sampling and that accurately measure hazardous constituents and other monitoring parameters in groundwater samples. To investigate water quality, a survey was made to appraise probable current man-made contamination of shallow groundwater in the study area. Fifteen sampling points, as close as possible to the Seybouse water course and its tributaries (14 shallow wells and 1 from the Cherf wadi) were chosen as to cover the entire irrigated area. Water sampling is conducted according to standard recommendations (Nielsen, 2006). Sampling points were located on the field using a Stc62Garmin GPS unit (Table 1 and Fig. 2).

**Table 1.** Location of water sampling points.

| Observation point | Latitude (deg. N) | Longitude (deg. E) | Elevation (m) | Observation |
|---|---|---|---|---|
| P1 | 36°28'49.8" | 7°20'40.4" | 240 | Poultryhouses |
| P2 | 36°39'17.2" | 7°42'55.2" | 222 | Irrigation |
| P3 | 36°30'45.7" | 7°26'1.8" | 287 | Drinking water, irrigation |
| P4 | 36°28'28.4" | 7°25'25.8" | 218 | Drinking water |
| P5 | 36°28'31.1" | 7°27'12.2" | 229 | Drinking water, irrigation |
| P6 | 36°28'18.7" | 7°27'41.1" | 205 | Drinking water, irrigation |
| P7 | 36°29'22.1" | 7°29'48.5" | 193 | Drinking water, irrigation |
| P8 | 36°23'56.3" | 7°30'3.4" | 339 | Drinking water, irrigation |
| P9 | 36°28'25.1" | 7°34'5.3" | 193 | Drinking water, irrigation |
| P10 | 36°26'29.6" | 7°36'52.3" | 132 | Drinking water, irrigation |
| P11 | 36°25'3.1" | 7°38'1.4" | 119 | Drinking water |
| P12 | 36°27'59.2" | 7°43'34.4" | 154 | Drinking water |
| P13 | 36°29'35.8" | 7°43'22.6" | 96 | Drinking water |
| P14 | 36°31'26.1" | 7°42'23.5" | 90 | Drinking water |
| S15 | 36°24'57.6" | 7°18'31.5" | 321 | Irrigation |

Water analyzes were carried out at the *Annaba Horizon Laboratory* in October 2017. Physicochemical parameters such as pH, temperature, electrical conductivity and dissolved oxygen were measured in situ using a HORIBA multi-parameter. Major elements (cations and anions) were analyzed by NFT 90-005 Titration whereas nitrates, nitrites, ammonium, and phosphate concentrations were evaluated by Spectrophotometry DIN 38405-D92. The sampling points are distributed as follows: El Fedjoudj sector (P1, P2, P3), Central Guelma sector (P4, P5, P6, P7, P8), Boumahra Ahmed sector (P9, P10, P11), Bouchegouf sector (P12, P13, P14) and Cherf sector (S15).

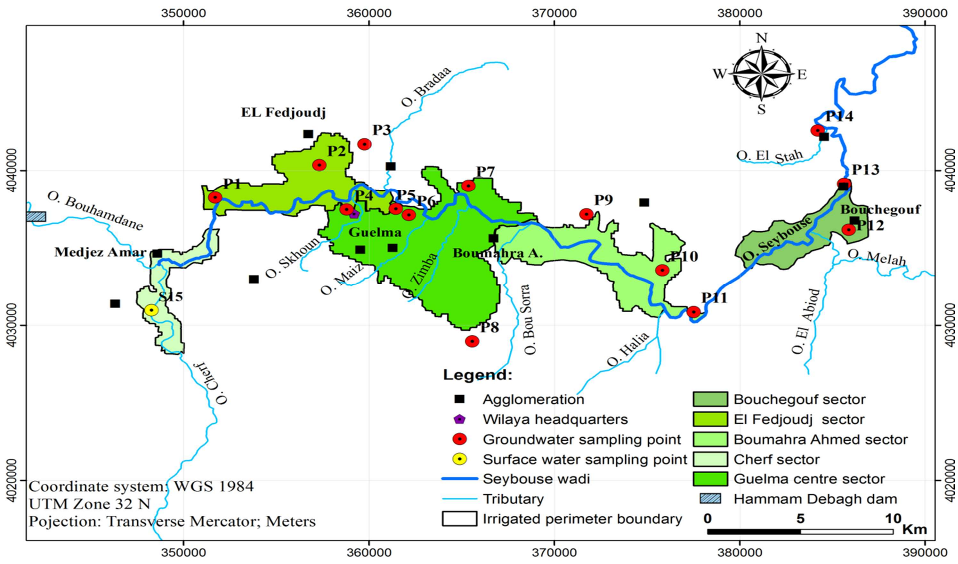


**Fig. 2.** Sampling sites location map.

**Results and discussion**

In addition to the physical parameters (temperature *T*, hydrogen potential pH, electrical conductivity *CE* and dissolved oxygen *DO*, major water chemical constituents such as calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), sodium ($Na^+$), potassium ($K^+$), bicarbonate ($HCO_3^-$), sulphate ($SO_4^{2-}$) and chlorides ($Cl^-$) were targeted in order to identify water types and global salinity in the study area. The physicochemical analyses results are reported on Table 2.

**Table 2.** Physicochemical analyses results (sampling date: 10/24/2017).

| Site | T (°c) | pH | EC (µs/cm) | $Ca^{2+}$ (mg/l) | $Mg^{2+}$ (mg/l) | $Na^+$ (mg/l) | $K^+$ (mg/l) | $SO_4^{2-}$ (mg/l) | $HCO_3^-$ (mg/l) | $Cl^-$ (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 25.0 | 7.8 | 3430 | 320.8 | 116.7 | 265.0 | 5.6 | 556.2 | 494.1 | 539.6 |
| P2 | 20.2 | 7.9 | 1478 | 142.6 | 51.9 | 105.0 | 0.9 | 37.1 | 481.9 | 255.6 |
| P3 | 23.3 | 8.0 | 1360 | 213.9 | 78. | 78.0 | 6.9 | 490.6 | 359.9 | 85.2 |
| P4 | 22.0 | 8.1 | 1460 | 178.2 | 64.9 | 124.0 | 16.7 | 438.6 | 231.4 | 184.6 |
| P5 | 21.6 | 7.7 | 1909 | 213.8 | 77.9 | 122.0 | 9.2 | 338.0 | 341.6 | 312.4 |
| P6 | 20.4 | 7.3 | 2230 | 285.1 | 103.7 | 137.0 | 2.3 | 567.3 | 372.1 | 298.2 |
| P7 | 24.5 | 8.2 | 3030 | 392.0 | 142.6 | 173.0 | 5.2 | 753.3 | 488.0 | 426.0 |
| P8 | 23.6 | 8.4 | 1517 | 142.5 | 51.9 | 125.0 | 1.7 | 128.0 | 213.6 | 397.6 |
| P9 | 19.8 | 8.2 | 2320 | 213.8 | 77.8 | 214.0 | 1.4 | 378.4 | 372.1 | 383.4 |
| P10 | 21.1 | 8.2 | 4610 | 392.4 | 142.5 | 366.0 | 24.5 | 548.6 | 250.0 | 1065.0 |
| P11 | 20.8 | 8.5 | 2000 | 179.4 | 64.6 | 166.0 | 9.3 | 236.5 | 451.4 | 298.2 |
| P12 | 22.6 | 8.4 | 1834 | 249.5 | 90.8 | 156.0 | 1.4 | 400.0 | 433.1 | 340.8 |
| P13 | 21.1 | 8.5 | 2690 | 212.3 | 78.2 | 287.0 | 19.6 | 505.0 | 469.7 | 539.6 |
| P14 | 21.8 | 8.3 | 2450 | 250.3 | 90.6 | 338.0 | 48.9 | 677.6 | 488.0 | 383.4 |
| S15 | 21.5 | 7.8 | 1823 | 142.6 | 51.9 | 224.0 | 35.1 | 279.2 | 378.2 | 312.4 |
| minimum | 19.8 | 7.3 | 1360.0 | 142.5 | 51.9 | 78.0 | 0.9 | 37.13 | 213.6 | 85.2 |
| average | 21.9 | 8.1 | 2276.1 | 235.3 | 85.6 | 192.0 | 12.6 | 422.29 | 388.3 | 388.1 |
| maximum | 25.0 | 8.5 | 4610.0 | 392.4 | 142.6 | 366.0 | 48.9 | 753.29 | 494.1 | 1065.0 |
| Cv (%) | 7.1 | 4.1 | 38.7 | 34.7 | 34.7 | 45.6 | 112.5 | 46.54 | 24.8 | 57.0 |

Cv: coefficient of variation.

*Physicochemical indices*

In the Guelma-Bouchegouf irrigated perimeter, shallow groundwater temperature and pH vary slightly from one point to another; the coefficient of variation (Cv) being less than 10%. The average values are of the order of 22°C and 8, respectively and remain within the World Health Organization (WHO) drinking threshold. However, the water salinity, expressed in terms of electrical conductivity, is excessively high (1360≤CE≤4610 µS/cmat 25°C) due to high dissolved salts contents. These values largely deviate from the WHO recommended drinking water limit set to 1000 µS/cm (WHO, 2011).

Indeed, the trilinear or Piper diagram (Fig. 3) shows the dominance of three major salt categories: chloride-calcium, sulphate-calcium and chloride-sulphate-calcium. The predominance of sulphate and chloride salts in groundwater is geologically attributed to the presence of evaporitic deposits of the Trias which is mainly represented by sodium chloride and gypsum rocks (Boukhrouf, 2010), on one hand, and water leaching of fertilizers in the Guelma-Bouchegouf perimeter, on the other hand.

Similar conclusions were pointed out by Debieche (2002) and Guettaf (2015).

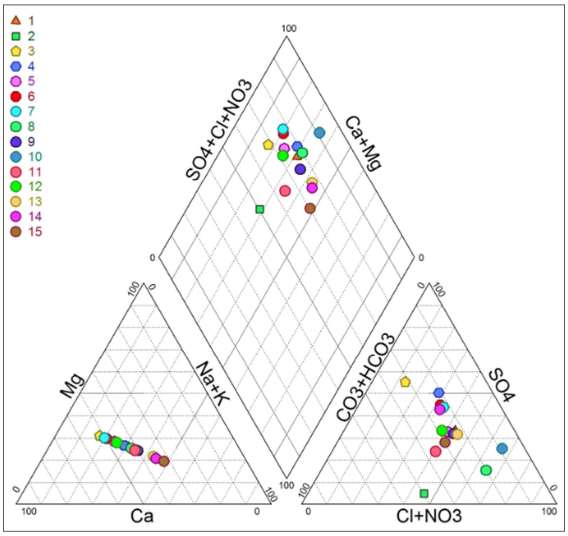


**Fig. 3.** Trilinear diagram of water chemistry in study region.

- *Pollution indices*

Evaluation of water pollution status and pollution levels can be appreciated by several indicators. In addition to the physical and chemical indicators, organic pollution and nutrients indicators are often used. Manures, fertilizers, and feeds applied to enhance production can be partially converted into animal biomass. These inputs may exceed the assimilative capacity of the ecosystem and lead to deteriorating water quality, increase stress, poor growth, and incidence of diseases, increase mortality and low production. The targeted pollution indices used to evaluate water impairment in the Guelma-Bouchegouf irrigated perimeter are dissolved oxygen (*DO*), nitrates ($NO_3^-$), nitites ($NO_2^-$), ammonium ($NH_4^+$) and phosphate ($PO_4^{3-}$) contents. Analytical results are reported on the table below.

**Table 3.** Pollution indices in the Guelma-Bouchegouf irrigated area (Sampling date: 10/24/2017).

| Site | DO (mg/l) | $NO_3^-$ (mg/l) | $NO_2^-$ (mg/l) | $NH_4^+$ (mg/l) | $PO_4^{3-}$ (mg/l) |
|---|---|---|---|---|---|
| P1 | 7,6 | 46 | 0,07 | 0,73 | 15,6 |
| P2 | 8,2 | 45 | 0,05 | 0,31 | 11 |
| P3 | 8,0 | 25 | 0,10 | 0,30 | 10,1 |
| P4 | 8,0 | 50 | 0,02 | 0,25 | 8,3 |
| P5 | 6,0 | 32 | 0,90 | 4,38 | 10,1 |
| P6 | 7,4 | 56 | 0,05 | 0,52 | 12,2 |
| P7 | 7,3 | 35 | 0,04 | 0,34 | 10,1 |
| P8 | 8,3 | 47 | 0,04 | 0,37 | 7,9 |
| P9 | 8,5 | 47 | 0,07 | 0,29 | 13,8 |
| P10 | 8,5 | 30 | 0,04 | 0,36 | 15,3 |
| P11 | 7,9 | 47 | 0,02 | 0,26 | 15,9 |
| P12 | 8,2 | 106 | 0,02 | 0,97 | 15,2 |
| P13 | 8,1 | 84 | 0,05 | 0,31 | 10,7 |
| P14 | 9,1 | 147 | 0,04 | 0,29 | 19,3 |
| S15 | 8,4 | 35 | 1,44 | 3,90 | 12,9 |
| Minimum | 6,0 | 25 | 0,02 | 0,25 | 7,9 |
| Average | 8,0 | 55,5 | 0,20 | 0,91 | 12,6 |
| Maximum | 9,1 | 147 | 1,44 | 4,38 | 19,3 |
| Cv (%) | 8,8 | 59,3 | 207,8 | 147,0 | 25,7 |

▪ *Dissolved oxygen*

Dissolved oxygen, a parameter that provides information on the water state and promotes micro-organisms growth and pathogenic germs development, occurs in small quantities in groundwater in the study area (6 to 9mg/l). These values, included within the 4-18mg/l threshold, indicate the absence of significant pathogenic contamination (WHO, 2011).

▪ *Nitrogen compounds*

Nitrogen exists in the environment in many forms and changes forms as it moves through the nitrogen cycle. However, excessive concentrations of nitrate-nitrogen or nitrite-nitrogen in drinking water can be hazardous to health. The adverse health effects of high nitrate/nitrite levels in drinking water are well documented (Madison and Brunett, 1985; Avery, 1999; Gatseva and Argirova, 2008; Bryan and Loscalzo, 2011). Nitrates ($NO_3^-$) represent the most oxygenated and soluble forms of nitrogen. In natural ground waters, the presence of nitrates is linked to intensive use of chemical fertilizers. In the Guelma-Bouchegouf irrigation area, nitrates concentrations range from 25mg/l at El Fedjoudj (P3 well) to 147mg/l at Bouchegouf (P14 well). The overall nitrates content mean is 55 mg/l (Table 3).

High nitrate values that exceed the allowable WHO standards (50mg/l) are located in the Guelma center (P4, P6) and the Bouchegouf wells(P12, P13, and P14). In order to improve crops production, farmers use fertilizers, pesticides and sprinkler irrigation during low-flow periods. This is a part of the explanation of high nitrates level in the shallow water table aquifer.

In the nitrogen cycle, nitrites are a lesser oxygenated and stable form of nitrogen. It is a transitional toxic form between nitrate and ammonium that originates from agricultural activities and/or urban and industrial wastes. In the Guelma-Bouchegouf irrigated perimeter, the nitrite values are randomly space distributed and vary considerably between 0.02 and 0.9mg/l in the shallow water table aquifer (Cv> 200%) ; the average value being 0,2mg/l. In the Cherf wadi, the nitrite content is 1.14mg/l at the S15 sampling point. Among the 15 monitored points, only the P5 and S15 wells show some contamination as the values are greater than the WHO drinking water standard (0.1mg/l). Ammonium is the most toxic form of nitrogen. In the irrigated area, the extreme values are 0.25mg/l at the P4 well and 4.38mg/l at the P5 one in the Guelma center sector. Roughly, the average ammonium content in the area (0.91mg/l) exceeds the WHO acceptable drinking water standard for groundwater (0.5mg/l). Indeed, one out of three wells is contaminated by ammonium due to intense agricultural activities and urban wastes (farms, livestock, and scattered agglomerations wastewater, etc.).

▪ *Phosphates*

The phosphates origin in water is generally linked to urban wastes or to *nitrogen-phosphorus- potassium* (NPK) fertilizers dissolution. In the study area, Table 3 points out that the phosphate levels are higher than the maximum allowable WHO value (0.5mg/l). Phosphates concentrations range between 7.9mg/l on the left bank of Oued Bou Sorra (P8) and 19.3mg/l in the Bouchegouf irrigated sector (P14). Such contents are good indicators of groundwater pollution due to agricultural practices in the irrigated area (excessive use of phosphates in the form of chemical fertilizers or pesticides).

*- Water quality classification and interpretation*

The overall water quality is evaluated according to four classes determined by a double-entry table: quality class and measured parameter (Nisbet and Verneau, 1970). The assessment of the water mineral quality is defined according to the values of each of the parameters considered and the required drinking water standards (Table 4).

- Class I: good quality water may be used without special requirements.
- Class II: medium quality water may be used after a simple treatment.
- Class III: poor quality water may be used only after more advanced treatment.
- Class IV: Excessively polluted water, may be used after specific and very expensive treatments.

**Table 4.** Groundwater quality assessment indices (ANRH[1], 2012; unpublished).

| Quality index | Water quality class<br>Class I : normal Situation | Class II : moderate pollution | Class III: significant pollution | Class IV: important pollution |
|---|---|---|---|---|
| Major chemical indices (mg/l)[2] | | | | |
| $Ca^{2+}$ (mg/l) | 40 – 100 | 100 – 200 | 200 – 300 | > 300 |
| | None | P2, P4, P8, P11, S15 | P3, P5, P6, P9, P12, P13, P14 | P1, P7, P10 |
| $Mg^{2+}$ (mg/l) | < 30 | 30 – 100 | 100 – 150 | > 150 |
| | None | P2, P3, P4, P5, P8, P9,P11, P12, P13, P14, S15 | P1, P6, P7, P10 | None |
| $Na^{+}$ (mg/l) | 10 – 100 | 100 – 200 | 200 – 500 | > 500 |
| | P3 | P2, P4, P5, P6, P7, P8, P11, P12 | P1, P9, P10, P13, P14, S15 | None |
| $Cl^{-}$ (mg/l) | 10 – 150 | 150 – 300 | 300 – 500 | > 500 |
| | P3 | P2, P4, P6, P11 | P5, P7, P8, P9, P12, P14, S15 | P1, P10, P13 |
| $SO_4^{2-}$ (mg/l) | 50 – 200 | 200 – 300 | 300 – 400 | > 400 |
| | P8 | None | P5, P12 | P1, P2, P3, P4, P6, P7, P9, P10, P11, P3, P14, S15 |
| Nitrogen compounds and phosphates indices (mg/l) | | | | |

| Quality index | Water quality class Class I : normal Situation | Class II : moderate pollution | Class III: significant pollution | Class IV: important pollution |
|---|---|---|---|---|
| $NH_4^+$ (mg/l) | ≤ 0.01 | 0.01 - 0.1 | 0.1 – 3 | > 3 |
| | None | None | P1, P2, P3, P4, P6, P7, P8, P9, P10, P11, P12, P13, P14 | P5, S15 |
| $NO_2^-$ (mg/l) | ≤ 0.01 | 0.01 - 0.1 | 0.1– 3 | > 3 |
| | None | P1, P2, P4, P6, P7, P8, P9, P10, P11, P12, P13, P14, | P5, P3, S15 | None |
| $NO_3^-$ (mg/l) | ≤ 10 | 10 – 20 | 20 – 40 | > 40 |
| | None | None | P3, P5, P7, P10, S15 | P1, P2, P4, P6, P8, P9, P11, P12, P13, P14 |
| $PO4_4^{-3}$ (mg/l) | ≤ 0.01 | 0.01 - 0.1 | 0.1 – 3 | > 3 |
| | None | None | None | P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, S15 |

[1]ANRH : Agence Nationale des Ressources Hydrauliques.

[2] Numbers in boldface are class limits.

According to the above classification, groundwater in the study area is moderately to highly polluted by major chemicals namely, $Na^+$, $Mg^{2+}$, $Ca^{2+}$, $Cl^-$, $SO_4^{2-}$. These results are closely correlated to dominant dissolved salts and the excessive mineralization that characterize groundwater in the irrigated area.

Furthermore, the comparison of analytical results (Table 3) and the quality assessment restrictions (Table 4) points out that the shallow water table aquifer in the Guelma-Bouchegouf irrigated perimeter is markedly polluted by excessive nitrogen compounds and phosphates. Most of the sampling points fall within the moderate to important pollution classes. These indicators confirm the pollution hypothesis by agriculture practices in the area.

## Conclusion

Located in the Guelma wilaya and extending over an 80km long East-West axis, the irrigated Guelma-Bouchegouf perimeter is subject to a Mediterranean-type climate with some continental features characterized by mild, rainy winters and hot, dry summers. Most of the annual 615 mm of precipitation falls in the wet season (winter) as short duration heavy showers that promote erosion and soil leaching processes. The shallow groundwater excessively high mineralization is largely attributable to evaporation process during low flow and to the interaction of water with the evaporitic formations (host rocks) that are well described in the Guelma Basin. Sodium and magnesium chloride, calcium and magnesium sulphate and, to a lesser extent, calcium bicarbonate are major dissolved salts. The drinking water quality indices show that the groundwater in the so called perimeter is heavily contaminated by nutriments like nitrogen compounds (nitrates, nitrites and ammonium), sulphates and phosphates as a result of the excessive use of fertilizers and pesticides. Such pollution constitutes a health risk for the scattered rural populations in this area.

Due to rural development and increasing water demand for irrigation in this area, effective pollution control and sustainable water resources management are necessary to overcome the water quality challenges. That is, it is imperative to equip the laboratories responsible for environmental protection with suitable equipment in order to carry out regular monitoring to better understand the origin of the phenomena and to protect these suburban and rural settlements which, in most cases, continue to use water from shallow wells without care.

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