

## Effects of Irrigated Agriculture on Water and Soil Quality (Case Perimeter Guelma, Algeria)

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### Abstract

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In Algeria, more than 20% of irrigated soils are concerned by the problem of salinity. In the perimeter of Guelma, the results showed that the soils have low salinity despite of high electrical conductivity (1244  $\mu\text{S}/\text{cm}$ ) of irrigation water and increased organic matter, nitrogen, potassium, and phosphorus contents. It should be noted that the soils had exhibited higher salinity and low organic matter content before starting the irrigation in 1973. The reduction in the salt content is due to the leaching of salts from percolated water after the intensive irrigation; however, the increase in the content of organic matter can be explained by the accumulation of the organic matter transported by irrigation water, conditions of waterlogging, and types of crops (vegetable/cereals). As to the quality of groundwater, nitrate is the dominant nitrogen component entering groundwater and it is very alarming that by 45% of water sources (springs, wells, and boreholes) the nitrate contents are over 50 mg/l. It is a serious problem because it serves as a drinking water supply for the local population. Moreover, this water is highly mineralized (electric conductivity > 1000  $\mu\text{S}/\text{cm}$ ) because of the intensive use of artificial fertilizers and to the poor quality of water irrigation. The contamination by organochlorine pesticides is below the value admitted by the WHO for water resources. Endosulfan is the most dominant active ingredient with an average concentration of 0.066  $\mu\text{g}/\text{l}$ .

**Keywords:** agricultural intensification; contamination; fertilizers; irrigation; organochlorine pesticides

The Algerian government has made considerable investments in agricultural development and hydraulic installations in order to modernize its agriculture and consequently ensure the food self-sufficiency of the country. The development of many agricultural areas in this region has necessarily been accompanied by an intensive use of nitrogen fertilizers. The irrigated perimeter of Guelma was put into service in 1996. It is supplied from the Bouhamdane dam by the releases on the Seybouse river that drains all wastewater which increases its polluting load.

Currently, it knows an intensification of agricultural practices. Certainly, this intensification has a positive effect on the agricultural yields (SCOTT *et al.* 2000) that produce more and cheaper food, but

this increase has often made on the soil and water quality (COSTA *et al.* 2002). Also, inappropriate farming techniques and crop types (e.g. potatoes) have a significant contribution to nitrate pollution and salinization (GONZÁLEZ VÁZQUEZ *et al.* 2005). Approximately 20% of irrigated land is moderately or severely affected by salinization (DOUAOUI & HARTANI 2007).

The objective of this study was to make a general diagnosis of the quality of soil and groundwater in order to minimize the risk of contamination resulting from irrigation practices on the environment that may limit the durability of the agricultural production and cause an irreversible damage (FERNÁNDEZ-CIRELLI *et al.* 2009).

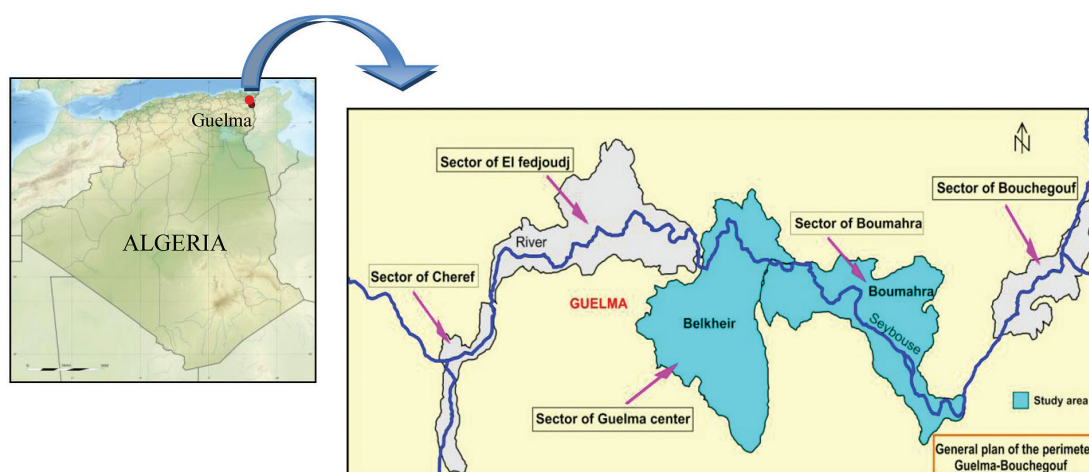


Figure 1. Situation of the study area in the perimeter of Guelma-Boucheougouf

## MATERIAL AND METHODS

**Study area.** Guelma city is located in the NE of Algeria in a large agricultural region at 290 m a.s.l. The climate is sub-humid with an average precipitation of 600 mm/year and a temperature of 18.5°C. It has a big fertility due to the Seybouse river and to a big dam ensuring irrigation of a vast perimeter of 9650 ha (Figure 1).

In the perimeter of Guelma, the irrigation method is sprinkler irrigation and the dominant cultures are tomatoes and potatoes (truck farming) and cereals (durum wheat, common wheat). Over 70% of local population (200 000 inhabitants) are supplied with drinking water from boreholes, wells, and springs located within the irrigated perimeter, so protection of these water resources quality is of major priority. The groundwater quality is generally poor and seems to be degraded (tendency to nitrification) (DEBEICHE 2002; NOUAR 2007; LARABA & HADJ ZOBIR 2009) by the intensive use of chemical fertilizers and pesticides that lead to groundwater pollution (COSTA *et al.* 2002).

An agro-pedological study was conducted at the perimeter of Guelma in April 1973 aimed to assess the soil quality (DJERABA 1973). The main types of perimeter soils are slightly evolved soils, vertisols, and calcimagnesian soils.

**Methods.** In the present research, the following methods were adopted: literature reviews, field visits, soil and groundwater sampling during the rainy period, *in situ* measurements, laboratory analyses, and data treatment.

**Soil.** Totally 17 soil samples were taken in December 2013 from the upper horizon (0–20 cm) using a hand

auger. The choice of the sampling sites was based on two main criteria: soil type and its representativeness in terms of surface (Figure 3). Samples were dried then grinded and sieved in 250µm and are the object of a series of physicochemical analyses. The analyzed parameters were: pH, electric conductivity (EC), total nitrogen (titrimetry, NF ISO 11261), organic carbon (colorimetry, ISO 12435.1998), nitrates (ion chromatography, NF IN 10304-1), total potassium and phosphorus (atomic emission – ICP, NF IN ISO 11885). The rate of organic matter (OM) in the soil was calculated from the measurement of total organic carbon of a sample multiplied by a factor of 1.724 (NELSON & SOMMERS 1982).

**Water.** The study concerned 19 water samples taken in December 2013 from boreholes, wells, and springs

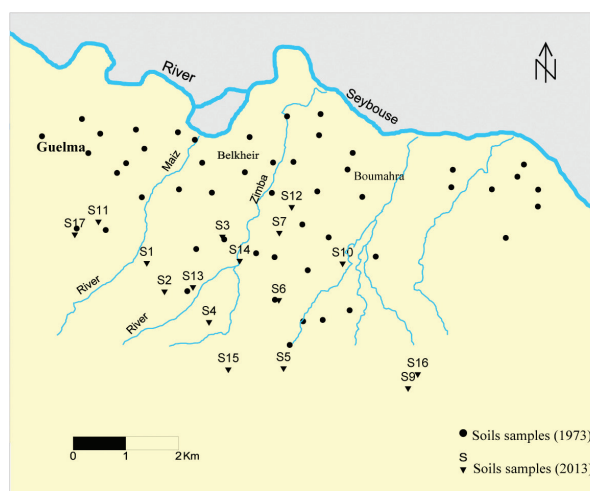


Figure 2. Soils samples from the perimeter of Guelma-Boumahra

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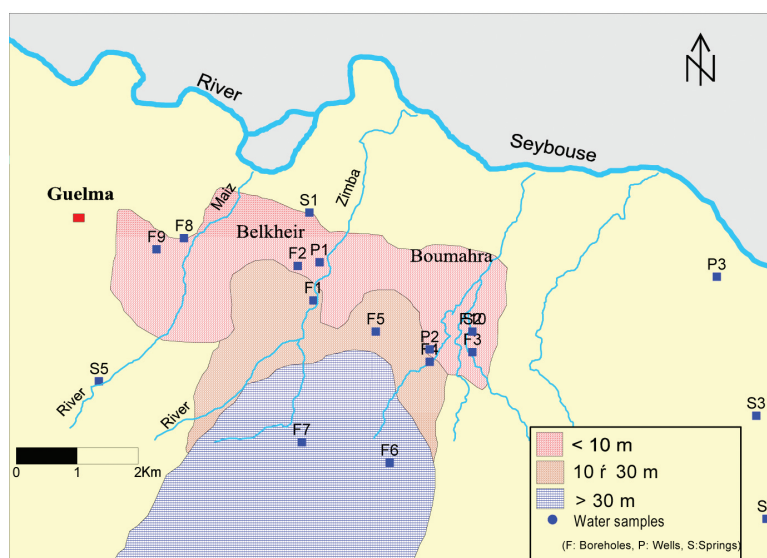


Figure 3. Water depth of the alluvial aquifer in the perimeter of Guelma-Boumahra

located within the irrigated perimeter (Figure 2). Some parameters of water quality as the pH, EC, and dissolved oxygen (DO) were measured *in situ* using a multiparameter meter (Model 9828; Hanna Instrument, Tenneries, France) and the groundwater depth by a piezometric level probe. The water samples were put in plastic bottles and stored in a cooler (4°C) for 72 h until analysis. The analysis determined the contents of potassium (atomic-ICP Emission, NF IN ISO 11885, 2007), total phosphate (colorimetry, ISO 6878, 2004), nitrates, and chlorine (ionic chromatography, NF EN 10304-1). To evaluate for the first time the contamination levels of residues of organochlorine pesticides used within the perimeter, samples of groundwater were taken from boreholes, wells, and springs in December 2014 (Figure 3). All samples were collected into high purity smoked glass bottles and refrigerated at 4°C until analysis using a gas chromatograph and mass spectrometer (PerkinElmer Clarus 680/600; PerkinElmer, Waltham, USA) according to EN ISO 6468.

To determine the quality of irrigation water, two samples were taken: the first on the principal water

supply pipe line of storage tanks, the second on the valves of irrigation. The physicochemical characteristics are listed in Table 1.

## RESULTS AND DISCUSSION

### Irrigation water quality

The analyzed irrigation water in the perimeter of Guelma has normal values of pH. On the other hand, it presents a moderate risk of toxicity regarding to bicarbonate and chloride contents for sprinkler irrigation (FAO 1985) (Table 1). The EC is about 1244  $\mu\text{S}/\text{cm}$  (0.62 g/l). The classification of irrigation water on the basis of EC according to the USDA scale shows that the water belongs to the class C3-S1 (EC 750 and 2250  $\mu\text{S}/\text{cm}$ ) and is qualified as water with high salinity, used only in well-drained soils.

It should be noted that the irrigation water is low in oxygen and becomes more mineralized after storage in tanks.

The ratio COD/BDO<sub>5</sub> (chemical oxygen demand/five-day biochemical oxygen demand) is equal to 8.03

Table 1. Physicochemical characteristics of irrigation water in the perimeter of Guelma-Boumahra (December 2013)

Samples	pH	TDS (mg/l)	EC ( $\mu\text{S}/\text{cm}$ )	DO	$\text{Cl}^-$	BDO <sub>5</sub>	COD (mg/l)	OM	$\text{HCO}_3^-$	$\text{Ca}^{2+}$
Irrigation water (Seybouse river)	8.21	621	1242	2.00	99.40	5.12	34.96	15.06	112.24	92.18
Irrigation water (valve)	7.77	622	1244	1.25	135	3.50	28.12	11.17	170.80	104.20

TDS – total dissolved solids; EC – electric conductivity; DO – dissolved oxygen; BDO<sub>5</sub> – five-day biochemical oxygen demand; COD – chemical oxygen demand; OM – organic matter

and indicates that irrigation water is containing effluents not easily biodegradable (industry origin) and is slightly low charged in OM. During the past decades, a variety of analytical and numerical models have been developed to predict water and solute transfer processes between the soil surface and the groundwater table (ŠIMŮNEK *et al.* 1999).

### Soil quality

**pH.** The soil pH defines its state of acidity or alkalinity. For the analyzed soils, the pH was fairly alkaline and no notable difference was perceived between the pH of the soils before and after starting the irrigation. At the surface horizon (0–20 cm), the average pH values before and after irrigation were between 7.53 and 7.74, respectively (Figure 4a).

**Electric conductivity.** The values of measured EC of the diluted extract from 1/5 of the soil horizon (0–20 cm) vary from 115.80 to 544  $\mu\text{S}/\text{cm}$  with an average equals to 210.41  $\mu\text{S}/\text{cm}$ .

According to the electric conductivity of different soils that carried out in 1973 on 47 samples, the values are ranged between 300 and 1370  $\mu\text{S}/\text{cm}$  with an average of 660.37  $\mu\text{S}/\text{cm}$ . The current results show a decrease in this parameter (Figure 4b).

After 17 years (1996–2013) of intensive irrigation, the sector of Guelma-Boumahra reports non-saline soils. On the other hand, the soils are more mineralized before their irrigation in 1973. From a statistical point of view, irrigation with epurated wastewater of the river Seybouse has a significant effect on reducing the salinity of irrigated soils and the EC is much lower than for non-irrigated soils (Table 2). The decrease of EC of irrigated soils is due to salt leaching by percolated waters after intensive irrigation (FAO 1985; MOREIRA BARRADAS *et al.* 2015). A similar effect was noticed by SIMONNEAU and AUBERT (1963) and NADER (2014) who testified that leaching by irrigation water reduced the soil salinity.

**Potassium.** The average value of potassium in the sampled soils was 3.79 g/kg, indicating that the soils are very rich in potassium (Figure 4c). However, there is a decrease in potassium content compared to the average value detected in the soils in 1973 (5.51 g/kg). The excess in potassium rates can be transformed into salt and pollute groundwater by percolation and infiltration.

**Total phosphorus.** The concentration of total phosphorus in the horizon (0–20 cm) of different soils varied from 0.10 to 0.90 g/kg with an average

of 0.26 g/kg, which means the soils were very rich in phosphorus (Figure 4d). The irrigation development and more intensive farming practices, notably the intensive fertilizing, have contributed to the higher concentration of phosphorus in the perimeter. The decrease of total phosphorus in comparison to the average value (0.4 g/kg) in 1973 is mainly due to intensive irrigation that generated the soil leaching.

**Organic matter.** The rate of OM recorded in 2013 within the horizon (0–20 cm) of soil perimeter varied from 1.82 to 11.85% with an average of 5.39% (Figure 4e). In contrast, the same horizon in 1973 showed a low OM rate, ranging between 0.32 and 2.84%, with a mean of 1.70%. Statistically, the evolution in soils OM rate linked with irrigation is due to waterlogging conditions retarding the mineralization of the OM carried by the irrigation water and therefore its accumulation (HERRE *et al.* 2004; GROSBELLET 2008), and due to the types of cultures (Table 2).

**C/N ratio.** The C/N ratio is an indicator of biological activity of soil. It provides information on the degree of evolution of OM, biological activity, and the potential of nitrogen supply by the soil (mineralization). In cultivated soils, the C/N ratio indicates either a good biological activity which leads to OM mineralization ( $\text{C}/\text{N} < 10$ ), or a lower biological activity leading to humification ( $\text{C}/\text{N} > 10$ ) (SOLTNER 2000). The C/N value of the soils varied between 7 and 11 in 1973, with an average of 8.90 (good decomposition of OM). At present, the agricultural intensification within the Guelma-Boumahra sector has led to a reduced C/N ratio (2.91 on average) indicating a rapid OM decomposition in soil with a major risk of leaching the nutrients released after mineralization (Figure 4f). According to the WHO (2011) report, most of the organic compounds contained in wastewater are rapidly decomposed in soils.

**Nitrate.** The nitrate content in the soils varied between 13 and 151 mg/kg with an average of 36.90 mg/kg (Figure 5). The present study was not aimed at determining the nitrogen fertilizer recommendations on cultivated soils, but at reporting on the state of OM mineralization in soils. The nitrates are not retained by the soil and their excessive amount can be washed down through an intensive irrigation and find its way into groundwater easily.

### Groundwater quality

The alluvial aquifer of the perimeter is recharged by rainfall and irrigation water that percolates and reaches

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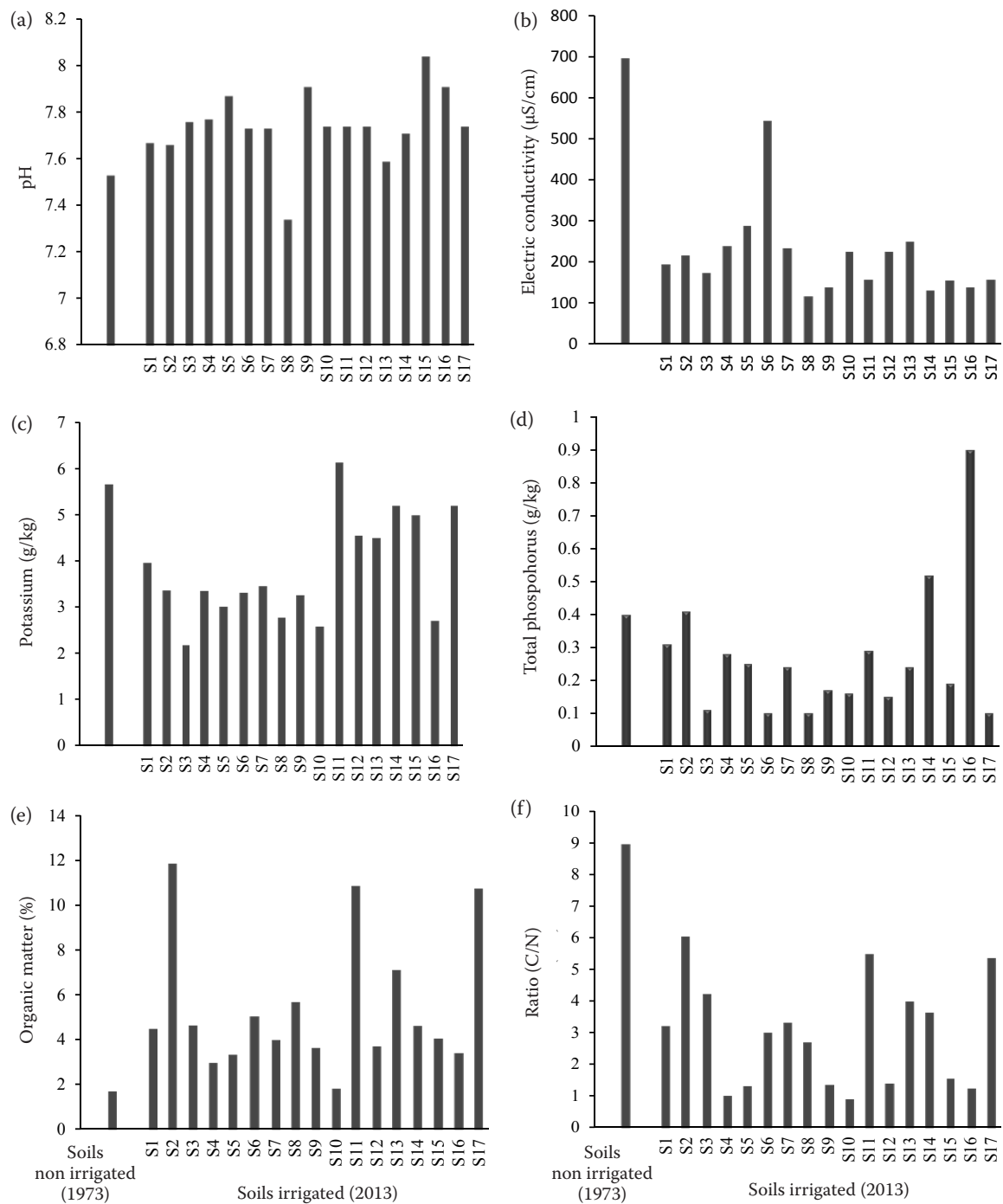


Figure 4. Soil values before and after irrigation in the perimeter of Guelma-Boumahra: pH (a), electric conductivity (b), potassium (c), total phosphorus (d), organic matter (e) and C/N ratio (f)

the groundwater whose depth varies from 4 to 46 m and with an average of 15.37 m (Figure 2). The excessive pumping has modified the groundwater flows within the aquifer by converging all water towards the borehole.

**Dissolved oxygen.** For all samples, dissolved oxygen (DO) showed significant variations from one site to another. During the study period, its values varied

from 1.29 to 6.85 mg/l with an average of 4.43 mg/l. The obtained results show that wells and springs are less oxygenated than boreholes (Figure 6a). According to the WHO (2011), the groundwater quality within the perimeter is good to poor ( $DO < 3$  mg/l). In general, low values of dissolved oxygen support the development of pathogenic germs.



Table 2. Comparison of the average electric conductivity and organic matter contents of irrigated and non-irrigated soils (Student's *t*-test, unilateral test)

Parameter	Depth (cm)	Soils non-irrigated (1973)			Soils irrigated with EWW (2013)			<i>t</i> -value	df	<i>P</i> -value
		N	average	SD	N	average	SD			
EC (μS/cm)	0–20	47	660.37	235.68	17	210.41	102.16	–7.451	66	< 10 <sup>–4</sup>
OM (%)	0–20	47	1.70	0.489	17	5.39	3.07	8.64	66	< 10 <sup>–4</sup>

EC – electric conductivity; OM – organic matter; N – number of samples; SD – standard deviation; *t*-value – value of Student's *t* test; *P*-value – significance level 0.05; df – degrees of freedom; EWW – epurated wastewater

**pH.** The groundwater pH fluctuated in an acceptable range of 7.35–8.92 with an average of 8.13 indicating fairly basic character of water (Figure 6b).

**Electric conductivity.** All the groundwater samples analyzed showed high mineralization, with EC higher than 1000 μS/cm (WHO standard) and the average of 1230 μS/cm (Figure 6c). These results could be explained either by the intensive use of artificial fertilizers (NPK) and to the amount of salt carried by irrigation water. The salts accumulated in the soil are leached into groundwater altering its physicochemical quality.

**Nitrate.** Figure 6d shows an abundance of nitrates in several water samples which make the water unsuitable for human consumption. Indeed, 45% of the analyzed samples showed higher values than the standard permitted by the WHO (50 mg/l) with a maximum of 94 mg/l; on the other hand, the nitrites content remains below the admitted limits. The nitrate content increases from the upstream towards the downstream and in the same direction of groundwater flow. This increase is mainly due to the accumulation of the solute towards the outlet of the aquifer. The high nitrate levels are

preferentially observed in the zones at shallow water depth (< 10 m) and within soils rich in OM and nitrate which confirms the agricultural pollution. Intensive agriculture causes leaching of nitrogen released from fertilizers and a rapid mineralization of organic soil horizons (FERNÁNDEZ-CIRELLI *et al.* 2009). Nitrates are highly soluble in water and are transported by runoff or irrigation water, gradually penetrating into groundwater serving as a drinking water supply.

**Potassium.** In the irrigated perimeter of Guelma-Boumahra, the potassium content in groundwater varied from 0.66 to 10.43 mg/l with an average of 3.21 mg/l (Figure 6e). A higher content of potassium (12 mg/l) was detected, too, but it was still within the limits admitted by the WHO (2011).

We can admit that the intensive use of fertilizers within the perimeter allowed the infiltration of the potassium ions in the shallow aquifer as nitrates.

**Chloride.** It is not harmful, but it is an important indicator of pollution arrival from urban effluent. Chlorides are not removed by wastewater treatment plants. The contents recorded in groundwater were 181.80–726.75 mg/l with a mean of 351.48 mg/l (Figure 6f). In general, in the majority of water samples there were high chloride concentrations exceeding the limits admitted by the WHO (250 mg/l). The percolation of irrigation water rich in chlorides increased their accumulation in groundwater.

**Pesticides.** The concentrations of organochlorine pesticides in all the studied samples were under the

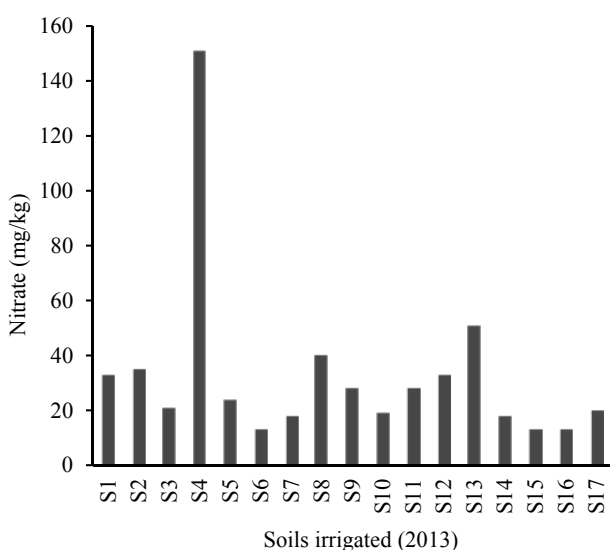


Figure 5. Nitrate values in soils after irrigation in the perimeter of Guelma-Boumahra

Table 4. Average concentrations of organochlorine pesticides detected in groundwater (December 2014)

Compounds	Average (μg/l)
α-Chlordane	0.021
β-Chlordane	0.022
Endosulfan sulfate	0.066
p,p'-DDT	0.043
Methoxychlor	0.040

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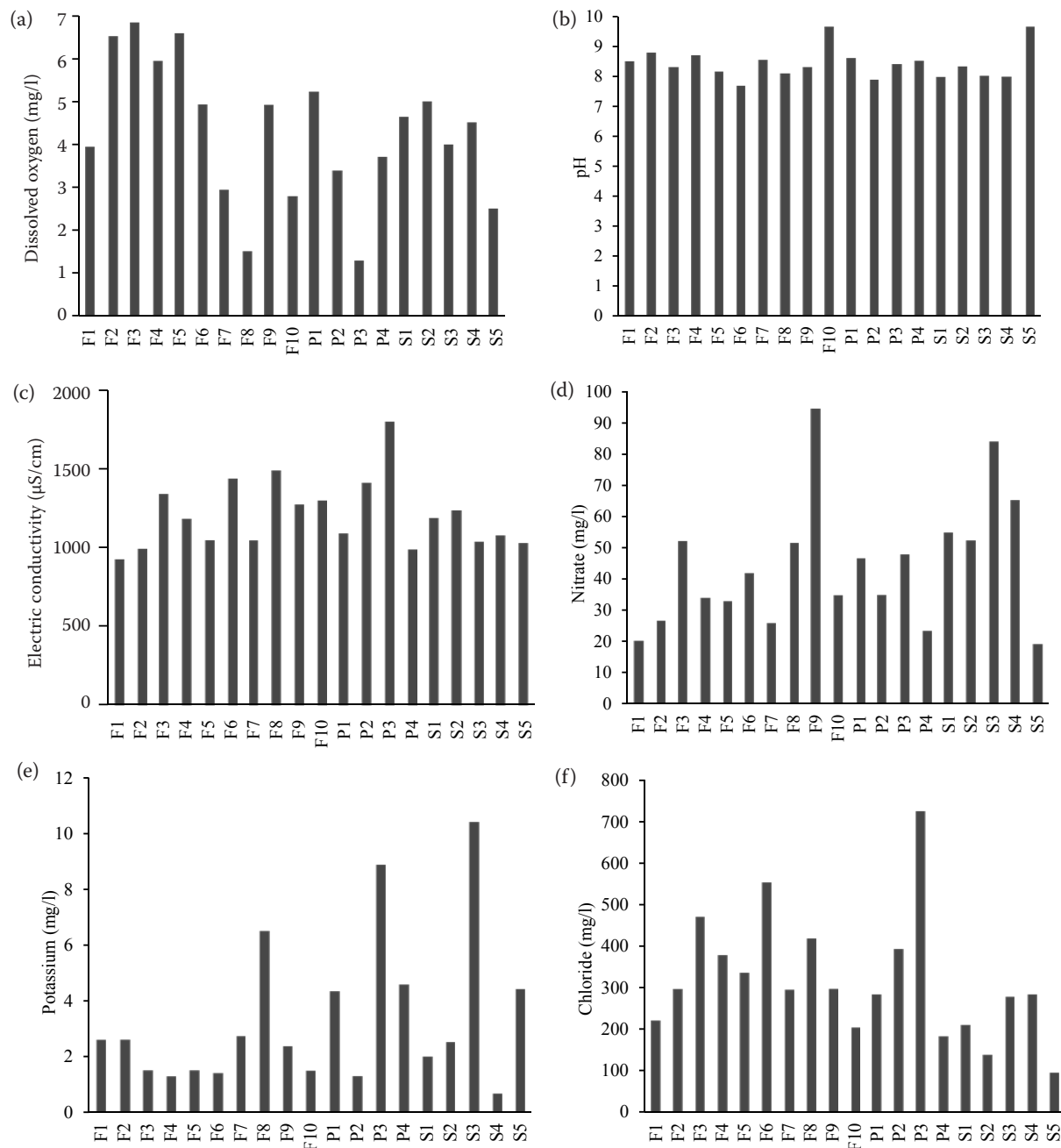


Figure 6. Water values in the alluvial aquifer of the perimeter Guelma-Boumahra: dissolved oxygen contents (a), pH (b), electric conductivity(c), nitrate contents (d), potassium contents (e) and chloride contents (f); F – boreholes; P – wells, S – springs

regulatory limit of 0.1 µg/l (WHO 2011) with a higher level of endosulfan sulfate (0.066 µg/l). However, the detection of pesticides residue in water highlighted the increase of threat by leaching (Table 4).

**Total phosphorus.** The total phosphorus content of groundwater receiving the water surplus of the irrigated perimeter was less than 0.05 mg/l even for samples that showed agricultural pollution.

## CONCLUSION

The intensive agriculture within the irrigated sector of Guelma-Boumahra has engendered an imbalance either for soil and groundwater proprieties. The soil is very rich in nitrogen, phosphorus, and potassium due to the intensive use of fertilizers. Also, there is an enrichment of the surface horizon (0–20 cm) with

OM and decreases in salinity are the most important changes that we have noticed in the perimeter.

As the quality of groundwater is concerned, the nitrate pollution is very alarming with 45% of water samples (boreholes, wells, and springs) having nitrate concentrations above the limits admitted by the WHO (50 mg/l). Furthermore, these waters are saline to highly saline within the perimeter of the study ( $EC > 1000 \mu S/cm$ ). However, for the contamination by the organochlorine pesticides, the recorded concentrations are below the value admitted by the WHO (2011) for water resources. The endosulfan is the most dominant active compound with an average concentration of  $0.066 \mu g/l$ .

Also, it should be noted that despite the positive effects of irrigation waters of Seybouse river on decreasing salinity and increasing the organic matter contents of irrigated soils, but while being percolated in-depth, they transport all accumulated elements in soils which deteriorate the groundwater quality.

So, the installation of observatories of the soil and groundwater quality within the perimeter is indispensable to ensure the durability of the production system.

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