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Origin of mineralization and impact of anthropogenic pollution on water quality in *Boussellam wadi* and its environment, Wilaya of Sétif (North-East Algeria)

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Abstract

The *Boussellam wadi* crosses the quaternary formations that dominate the expanse of the plain of the same name in the region of Sétif in the North-East of Algeria. It represents one of the main water resources intended mainly for irrigation and drinking water supply. The shallow water table in the geological formations containing this aquifer is very heterogeneous in texture and varies considerably from upstream to downstream in the watershed. As a result, the northern and eastern zones are marked by a chloride-calcium facies, the central part by a bicarbonate-calcium facies, while the western zone is characterized by a sulphate-magnesium facies. This situation remains unchanged for the four periods considered: April 2014, October 2014, April 2016 and October 2016. However, small variations in the contents of the major elements are essentially due to dilution by rainwater or the impact of wadi water on the nearest wells on the plain. For the same periods, the study of the evolution of pollution in the Boussellam wadi into organic elements including nitrites, nitrates, phosphates and ammonium and its impact on the quality of the water of the plain, concerned 21 wells distributed samples which show an excess of these elements with for nitrates a net increase probably due to wastewater discharges and the intensive use of fertilizers thus increasing the risk of vulnerability of the waters of the plain to pollution and degradation of surface waters and the environment in general.

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Introduction

The *Boussellam* plain which is the subject of this study covers almost the entire up stream sub-watershed of the *Bousselam wadi.* It is limited to the East and West by the natural borders of the sub-basin and to the North by the northern administrative borders of the communes of Sétif and Ain Arnat, to the South by the southern borders of the communes of Tixter, AinTaghrout and Guidjel. The upstream sub-watershed of the *Boussellam wadi* has 35% of the surface of the great *Bousselam,* it extends over the high Setifian plateaus with an area of 1785km² and is part of the territory of the wilaya of Sétif located in the North-East of Algeria, its code: 15 06 according to the Agence des Bassins Hydrographiques, the *Boussellam wadi* reaches a length of 65km.

With a total annual input of 764 Hm³/year, the upstream sub-watershed of Bousselam wadi represents an important water potential to be preserved, because after evapotranspiration only 190 Hm³/year remain. The 80% of this quantity represents mobilizable water, while the water actually mobilized represents only 60 Hm³/year intended to supply the inhabitants with drinking water with a rate of about 70%, 18% for agriculture and the remaining 12% for industry (Boulgueraguer *et al.*, 2014).

One of the major problems threatening the *Boussellam* plain is the risk of pollution and water contamination caused by the various organic and chemical materials discharged into the wadi. Thus nitrate pollution is generated by agricultural activity which is responsible for their increase in surface waters to a large extent (Thorbum *et al.*, 2003). In the *Boussellam* basin at the two upstream stations, the very low taxonomic richness and diversity (Ish < to 1) are mainly due to urban discharges from the city of Sétif (Zouggaghe *et al.*, 2014).

In this context, the objective of this study is to determine the different sources of pollution in the plain, its evolution, as well as the procedures that must be undertaken to preserve water quality in this area which has very fertile land with a vast agricultural activity and especially cereals.

Several approaches have been developed and published on similar issues and all reach the same conclusions. These studies concerned similar regions located in semi-arid and arid zones carried out by: Hassoune *et al.*, 2006; Gasmi *et al.*, 2006; Harzouli *et al*, 2007; Derwich *et al*, 2008; El Addouli *et al*, 2009; Bahroun *et al.*, 2011; Makhoukh *et al.*, 2011 and Mounjid *et al.*, 2014. These different case studies deal with water pollution situations in basins with the same socio-economic and environmental characteristics. More than one million inhabitants live in the plain territory with an important agricultural vocation and a much diversified industrial zone. This one installed near one of the main tributaries of the *Boussellam wadi*, threatens these waters and its immediate environment whose protection and preservation is today proven.

Material and methods

Geographical location and presentation of the study area (Fig. 1)

The *Boussellam wadi* is the main tributary of Soummam with a length of 150Km and an area of 5010Km², their basin is subdivided into four sub-basins: *Boussellam* upstream (C : 15 06, S = 1785Km²), *Boussellam* medium (C : 15 07, S = 1234Km²), El Main (C : 15 08, S = 930Km²) and *Boussellam* downstream (C : 15 09 S = 1061Km²).

The average altitude of the *Bousselam* sub-basin is about 1000m. The altitude sector exceeding 1300 m is very small in the basin (0.57%); it corresponds to the mountain located in the North of the basin: Djebel Megris (1737m). The altitude zones between 1200 and 1600 m cover 151.32km² or about 8.47% of the total area and correspond to the southern fronts of the Megris, Medjounes, Matrona, Tarmount, Mnaguer and Aissel mountains. The altitude zones ranging from 1000 to 1200m cover an area of 557.15km², or 31.21% of the total area, and concern the high Setifian plains in the North and South. Finally, the altitude range between 800 and 1000m is spread over an area of 1066.28 km² or 59.73% and concerns the vast plains up to the Ain Zada dam.

Table 1. The sampling stations in the *Boussellam wadi.*

Station	X (m)	Y (m)	Z (m)
Pd1 (Witness)	715418,96	4011060,87	1022
Pd2	710267,13	3999748,09	987
Pd3	700760,14	3992949,79	924
Pd4	698243,63	3995992,42	866
Pd5	694659,35	3999842,17	856
Pd6 (Dam Ain Zada)	694659,91	4002883,61	847

Geographic coordinate system: WGS 1984

Coordinate projection system: WGS 1984_UTM_31 N_ Unit Meter

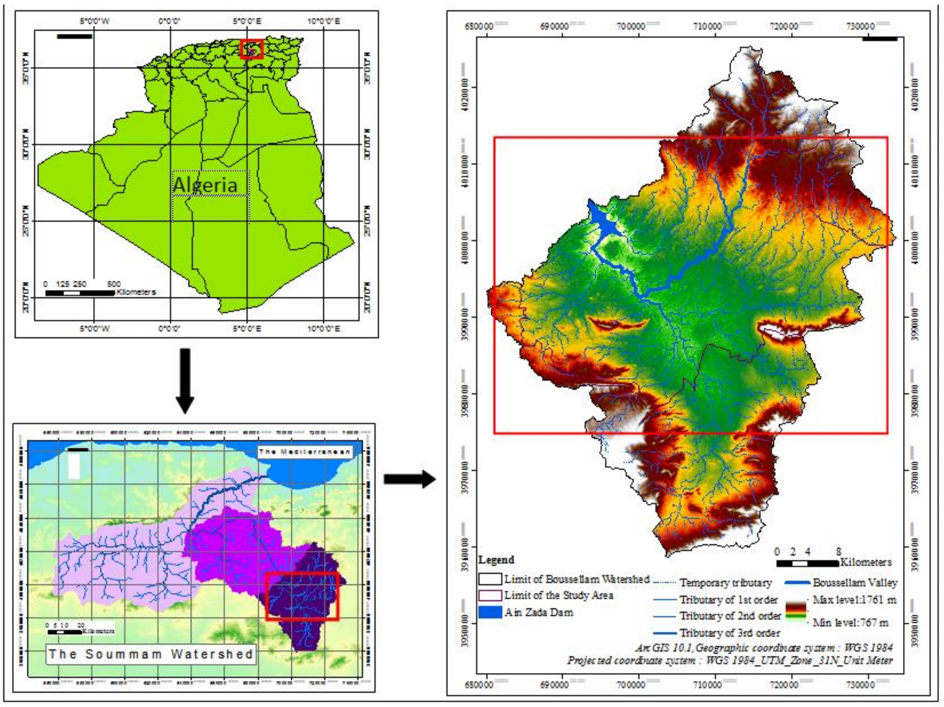

Fig. 1. Geographical situation of the *Bousselam wadi* sub-watershed.

Morpho-metric analysis makes it possible to evaluate a number of important parameters that must be closely linked to the lithological nature of the terrain and the topography of the basin. The *Bousselam wadi* sub-basin is characterized by an elongated shape allowing precipitated waters to take longer to reach the outlet. The results of the concentration time are of the order 27.19 hours, important duration for the evaluation of floods. The average altitude is 1000m, which gives the sub-basin the appearance of a fairly strong morphometry. The drainage density is 3.03km/km² which leads to a somewhat rapid runoff especially as the basin is characterized by a strong relief: 250m < Ds < 500m. The climate of the *Bousselam* sub-basin is characterized by average interannual precipitation heights which vary from one station to another; they are more important at altitude and decrease from North to South. Mean interannual temperatures differ slightly between the centre of the study area and its northern and southern boundaries, decreasing as one moves further away from the centre. The study of climatic indices confirms that the study area belongs to the semi-arid climate influenced by the humid Mediterranean currents in winter and the warm Sahara currents in summer. The water balance is often in deficit for all the stations studied.

The hydrogeology of the *Boussellam* plain shows that this zone contains good exploitable aquifers:

- The lower Cretaceous formations seem to be the only ones where limestones can be exploited because they are free of Triassic rocks or because the latter is relatively deep.

- The formations of the Middle and Upper Cretaceous also offer aquiferous possibilities especially in the southern zone where these horizons are sometimes thick and present a sufficient feeding surface.

Situation of samples and samples taken (Fig. 2)

The sampling of this study was carried out in the wells of the *Boussellam* plain and wadi. There are four sampling periods to get an idea of the annual and seasonal evolution of the different parameters analysed between 2014 and 2016. The analyses were carried out by the ion chromatographic assay method (METROHM 850 IC ion chromatography chain) for the major elements and spectrometry (Spectrophotometer UV-Visible SHIMADZU E17) for organic pollutants at the laboratory of the Institute of Water Sciences and Technology of Gabès (ISSTEG) and at the laboratory of the Faculty of Sciences of Gabès in Tunisia for the period of October 2014, and to the Algerian water laboratories (ADE), Skikda and Sétif for the periods April 2014, April 2016 and October 2016. Physico-chemical parameters (pH and T) were measured on site. Sampling in the plain concerned 15 wells (Table 1) and 6 stations along the Boussellam wadi talweg in order to assess the influence that may exist between the wadi and the plain and to study the evolution of domestic and agricultural elements and their impact on water quality in the region (Table 1).

Table 2. The sampling points in the *Boussellam* plain.

Water point (wells)	X (m)	Y (m)	Z (m)
P1 (Witness)	722771,57	3993150,06	951
P2	717816,53	4000502,71	969
P3	714619,72	4007295,92	1065
P4	711902,44	3992750,46	918
P5	710463,68	4004658,56	981
P6	707586,76	3996505,79	938
P7	705908,43	3990752,46	869
P8	703290,35	3994748,46	911
P9	702232,11	3988434,78	910
P10	701752,59	4002181,03	944
P11	700713,63	3995148,07	902
P12	697676,67	3998504,71	870
P13	696397,94	3993869,34	890
P14	694559,78	3987955,26	938
P15	691922,42	3996107,11	906

Geographic coordinate system: WGS 1984

Coordinate projection system: WGS 1984_UTM_31 N_ Unit Meter

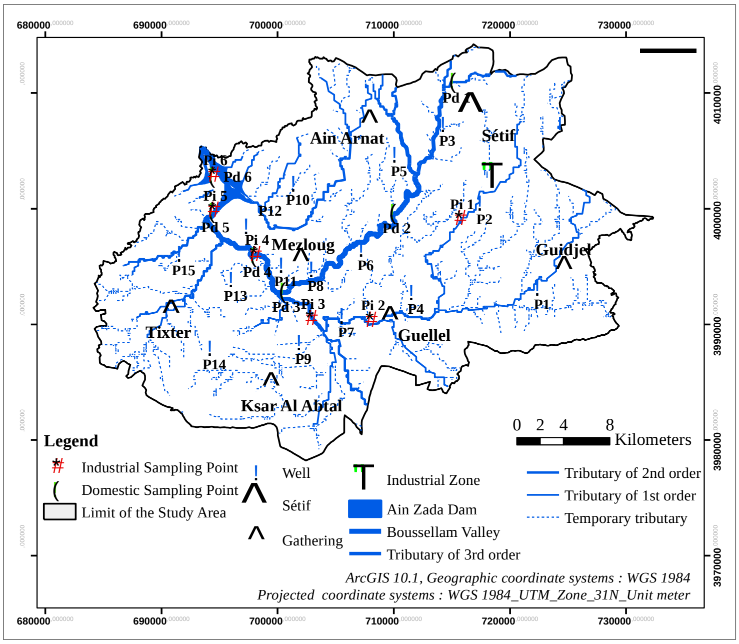

Fig. 2. Map of sampling points.

The maps were produced at the geology laboratory of the Faculty of Tunis in 2015 and at the Water Resources and Sustainable Development (REDD) laboratory of the geology department in Annaba in 2017 on the basis of digital satellite images (DTM) and GDM format processed in ArcGis.

Results and discussion

Physico-chemical characteristics Temperature and pH

The water temperatures recorded in the majority of the wells are between 17 C° and 24 C° and this differs according to the period whose lowest values were recorded in the low water period (October 2014 and 2016) thus the pH values fluctuating between 6.8 and 7.5 with a slight variation from one point to another and from one period to another.

Salinity

The salinity of water between 600mg/l and 1200mg/l for all points and over the four periods and always remains within the drinking water standards (< 3000mg/l) and the hardness reach 35 F° in October 2014 for well P1 to 73 F° in April 2016 for well P8 what gives the appearance of hard water (from 30 to 40mg/l) to very hard water (+ 40mg/l) as well as the calculated conductivity is between 900µs/cm and 1600 µs/cm which allows us to classify plain water in the good class for irrigation according to Wilcox classification (Fig. 3).

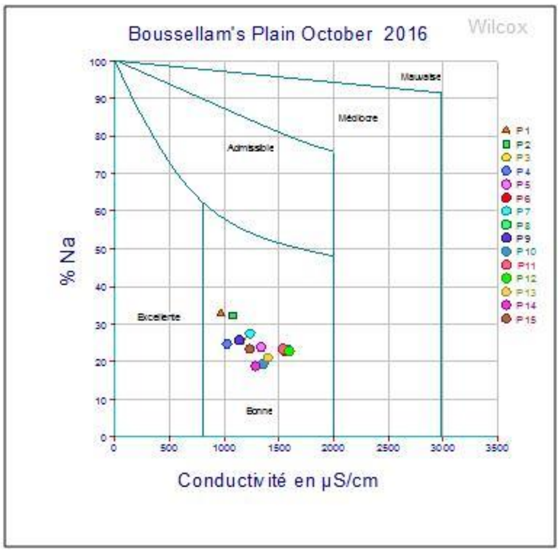

Fig. 3. Wilcoxdiagram, *Boussellam* Plain (October 2016).

Chemical facies

The analysis of the composition of major ions and their distributions in the Piper diagram makes it possible to distinguish three main chemical facies Chloride-calcium and Bicarbonate-calcium and Sulfated-magnesian and with the exception of the point P9 which is Sulfated-calcium (Fig. 4).

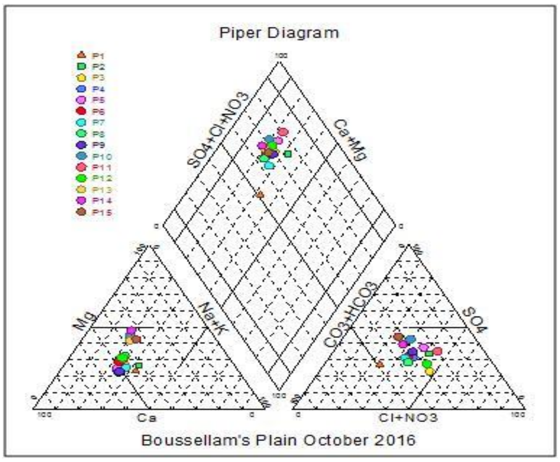

Fig. 4. Piper Diagram, *Boussellam* Plain (October 2016).

The Chloride-calcium facies is found in wells P2, P3, P4, P5, P11 and P12 these wells are located in the northern and eastern part of the study area. This mineralization can be explained by the presence of the mio-plio-quaternary saline alluvial formations which are the gypsum marls, the Triassic dolomites and the Cenomanian, as well as the contamination of these waters by those of *Boussellam wadi* which has higher chloride contents, while the bicarbonate-calcium facies marks wells P1, P6, P7 and P8 which are located in the centre of the plain. Their mineralisation is certainly due to the carbonate formations bordering the chalk slick and the Cretaceous limestones. The third facies is the sulphate-magnesian facies characterizing wells P10, P13, P14 and P15 which cover the western part of the plain. The high sulphate and magnesium contents can be explained by the cation exchange between the gypsum and dolomite formations as well as by the dissolution of fertilizers containing these two elements such as Epsom salt which constitutes a source of Mg^{++} and SO_4^{-2}. Only one well (P9) is marked by the sulphate-calcium facies and this is probably due to the dissolution of gypsum present locally in the region.

This situation of the low water period of October 2016 does not differ much from the other periods of April 2014, October 2014 and April 2016 with however slight variations that can be explained by the dilution of the waters of the plain by the rains and the dissolution of the Quaternary formations like chlorinated evaporites, gypsum and contamination by the waters of the *Boussellam wadi* which represents a real source of pollution especially for the wells closest to its bed.

Evolution of organic pollutants

Nitrites (NO_2^-)

The high nitrite levels in the waters of the *Boussellam wadi* valley mark a change between the periods of high and low water, including an increase in this element in 2016 compared to 2014 (Table 3).

The large increases move from upstream to downstream of the wadi, which is a receptacle for all domestic waste. The disposal of untreated waste water from the agglomerations of the wilaya of Setif in the wadi and its tributaries and the use of fertilizers contribute to the increase in NO_2^- during the period of wadi water exhaustion (Fig. 5). The results indicate very high levels compared to the Pd1 control (0.1 to 0.2mg/l) and exceed algerian surface water standards (< .1mg/l). The evolution of nitrite levels in the plain shows values approximately related to the impact of wadi waters on the surrounding water points (Fig. 6).

Table 3. Evolution of Nitrite levels in the plain in mg/l.

NO_2^-	Water point	Apr 2014	Oct 2014	Apr 2016	Oct 2016
	Witness (Pd1)	0.01	-	0.02	-
Boussellam	Min	Pd2 (1.02)	Pd2 (1.11)	Pd2 (1.05)	Pd2 (1.21)
Wadi	Max	Pd6 (1.52)	Pd6 (1.82)	Pd6 (1.64)	Pd6 (2.51)
	Medium	1.20	1.44	1.25	1.70
	Witness (P1)	0.31	0.38	0.38	0.41
Plain of	Min	P14 (0.11)	P14 (0.11)	P14 (0.11)	P14 (0.12)
Boussellam	Max	P8 (0.77)	P8 (0.96)	P8 (0.96)	P8 (1.01)
	Medium	0.48	0.58	0.54	0.60

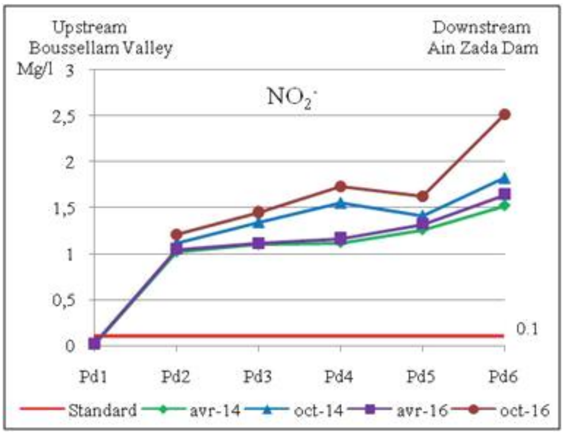

Fig. 5. Evolution of NO_2^- in *Boussellam wadi.*

Nitrates (NO_3^-)

Nitrate levels always remain below the standards (< mg/l) for the four sampling periods (Table 4). They are slightly higher compared to the Pd1 control (18.5 to 22.3mg/l). The maximum is observed at Ain Zada dam with 36.45mg/l in October 2016 with a slight increase from upstream to downstream of the wadi (Fig. 7). This change is present in periods of low water compared to high water and can be explained by the drop in surface and groundwater levels suggesting an increase in NO_3^- concentrations (Fig. 8)

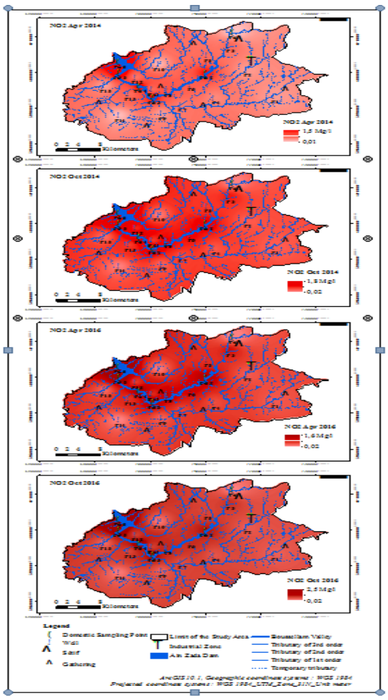

Fig. 6. Evolution of NO_2^- in the Boussellam plain.

Table 4. Evolution of Nitrate levels in the plain in mg/l.

NO_3^-	Point d'eau	Apr 2014	Oct 2014	Apr 2016	Oct 2016
Boussellam Wadi	Witness (Pd1)	18.52	-	19.55	-
	Min	Pd2 (27.13)	Pd2 (31.24)	Pd2 (24.65)	Pd2 (32.42)
	Max	Pd6 (29.73)	Pd6 (35.82)	Pd6 (35.82)	Pd6 (36.45)
	Medium	28.06	33.45	29.14	34.44
Plain of *Boussellam*	Witness (P1)	22.24	23.14	24.65	26.22
	Min	P14 (17.35)	P14 (17.24)	P14 (17.48)	P14 (17.69)
	Max	P6 (25.72)	P6 (25.72)	P6 (28.18)	P8 (30.85)
	Medium	22.88	24.20	24.31	25.63

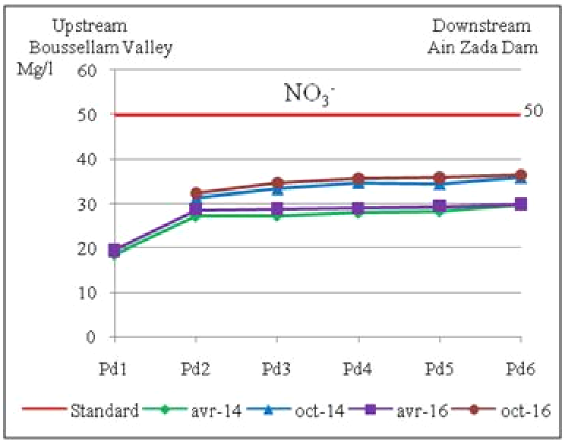

Fig. 7. Evolution of NO_3^- in *Boussellam wadi*.

Phosphates (PO_4^{-3})

Phosphate levels in the waters of the *Boussellam wadi* valley exceed the standards (2 mg/l) and keep the same evolution as the other parameters (Table 5). This increase increases when moving downstream with a decrease in this element during the low water period (Fig. 9). Fertilizers are used during the high water period to meet the needs of an agricultural activity based in particular on cereal crops. Soil fertilization increases phosphate concentrations in the plain and are higher than in the wadi (Fig. 10). This agricultural activity is recorded at the Pd1 control level with levels ranging from 2.4mg/l to 3.2mg/l.

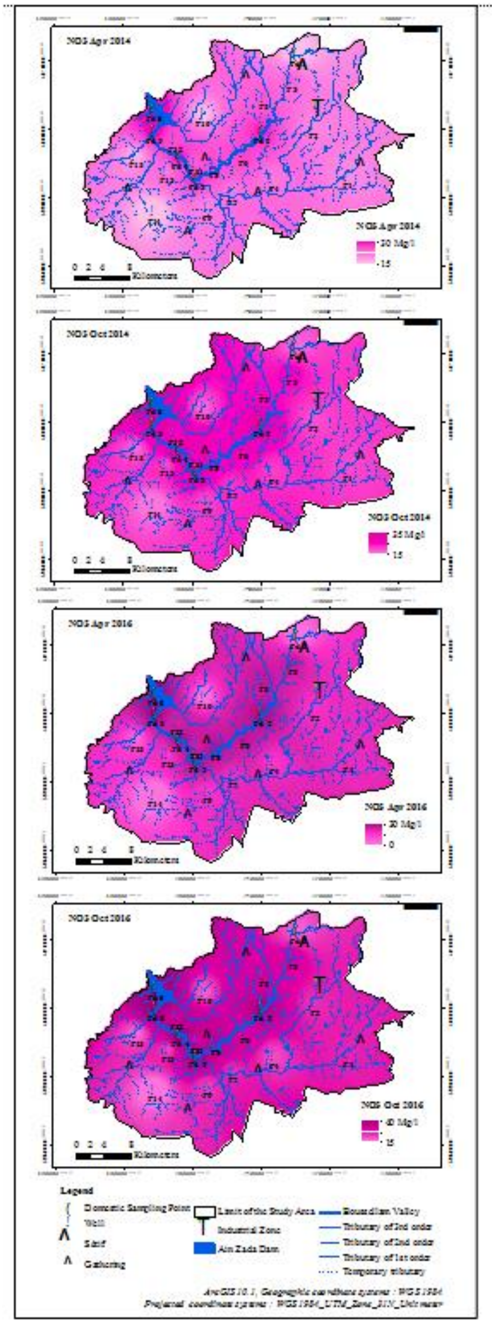

Fig. 8. Evolution of NO_3^- in the *Boussellam* plain.

Table 5. Evolution of phosphate levels in the plain in mg/l.

PO_4^{-3}	Point d'eau	Apr 2014	Oct 2014	Apr 2016	Oct 2016
Boussellam Wadi	Witness (Pd1)	1.91	-	2.65	-
	Min	Pd2 (2.82)	Pd2 (1.16)	Pd2 (3.22)	Pd2 (3.01)
	Max	Pd6 (8.26)	Pd6 (6.03)	Pd6 (7.13)	Pd6 (6.74)
	Medium	5.67	4.34	5.82	5.53
Plain of *Boussellam*	Witness (P1)	9.88	9.35	10.65	9.78
	Min	P2 (10.66)	P2 (10.02)	P2 (10.98)	P2 (10.45)
	Max	P13 (16.05)	P11 (15.24)	P13 (16.46)	P11 (15.38)
	Medium	14.28	13.04	14.79	13.67

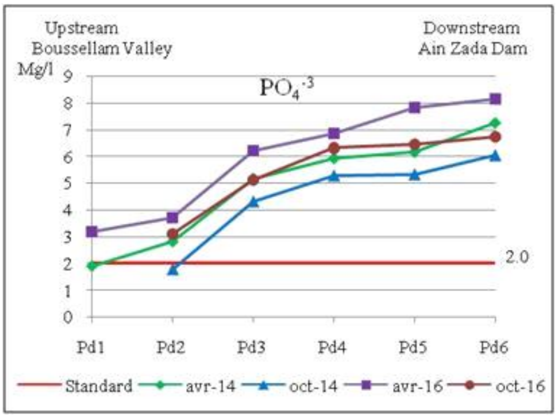

Fig. 9. Evolution of PO_4^{-3} in *Boussellam wadi.*

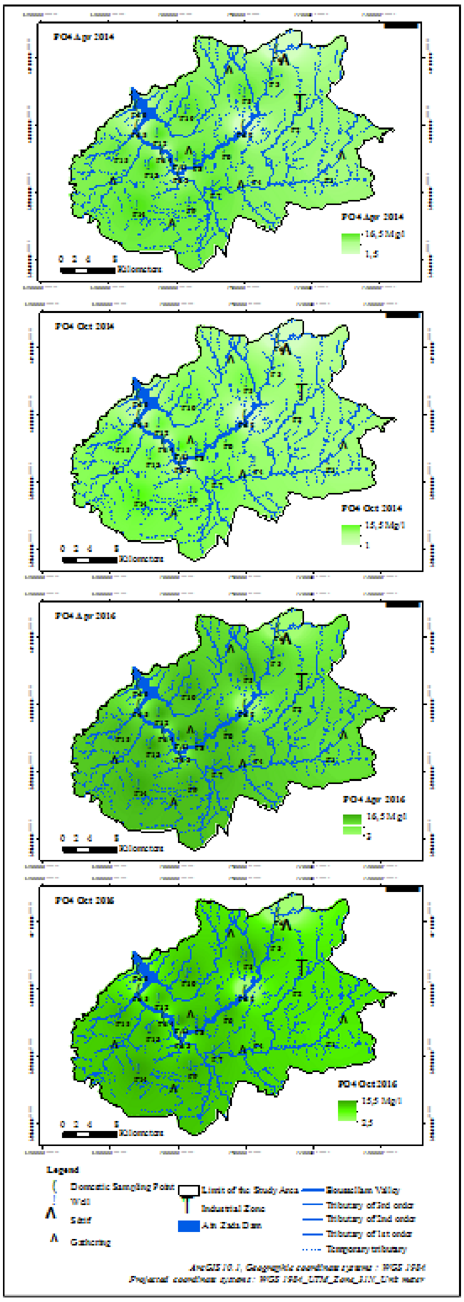

Fig. 10. Evolution of PO_4^{-3} in the *Boussellam plain.*

Ammonium (NH_4^+)

The analyses show a very clear evolution of ammonium in the different periods with higher levels in 2016 compared to 2014 (Table 6). The increase is always from upstream to downstream, but the levels decrease during the low water period (Fig. 11).

The intense use of fertilizers increases the levels that exceed the standards (0.5mg/l) even at the Pd1 control station with 0.5mg/l and 0.7mg/l in 2016.

The levels recorded in the plain waters are higher than those of the wadi favoured by the dissolution of fertilizers during intensive agricultural activity before the low water period (Fig. 12).

Table 6. Evolution of Ammonium levels in the plain in mg/l.

NH_4^+	Point d'eau	Apr 2014	Oct 2014	Apr 2016	Oct 2016
Boussellam Wadi	Witness (Pd1)	0.42	-	0.72	-
	Min	Pd2 (1.00)	Pd2 (0.98)	Pd2 (1.10)	Pd2 (1.06)
	Max	Pd6 (2.16)	Pd6 (2.05)	Pd6 (2.29)	Pd6 (2.22)
	Medium	1.56	1.46	1.71	1.55
Plain of *Boussellam*	Witness (P1)	2.78	2.45	2.99	2.56
	Min	P2 (2.33)	P2 (1.92)	P2 (2.86)	P2 (2.15)
	Max	P10 (5,44)	P10 (4.78)	P13 (5.89)	P15 (5.23)
	Medium	4.18	3.66	4.60	3.96

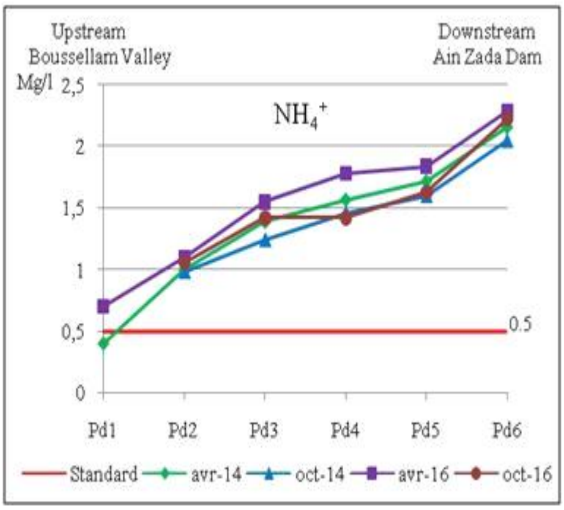

Fig. 11. Evolution of NH_4^+ in *Boussellam wadi.*

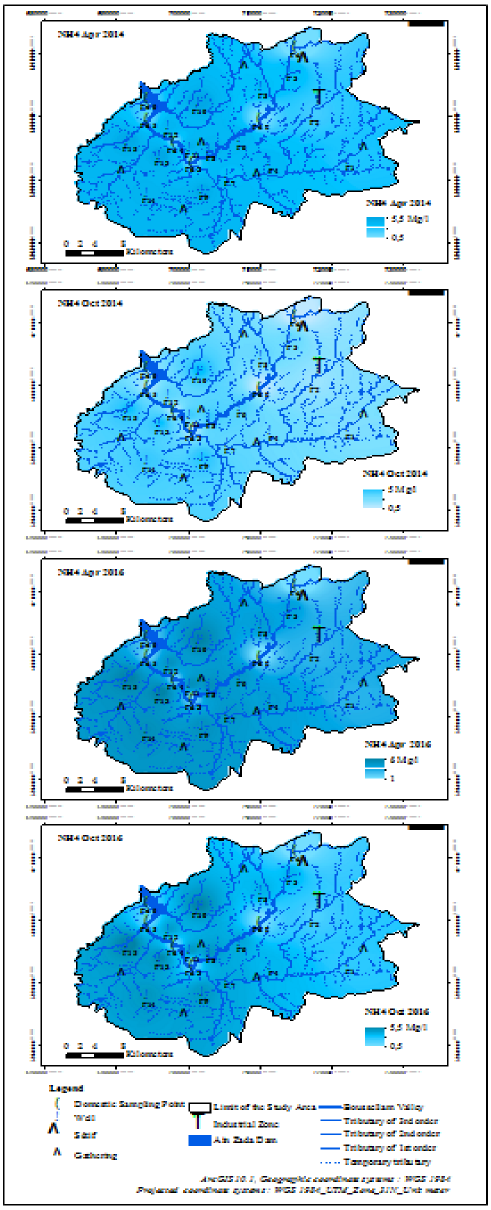

Fig. 12. Evolution of NH_4^+ in the *Boussellam* plain.

Conclusion

The waters of the *Boussellam* Valley sub-watershed are chemically characterized by the following facies: Chloride-calcium, Sulfate-magnesium and Bicarbonate-calcium with small variations in Ca^{+2}, Mg^{+2}, (Na^{+}+ K^{+}), Cl^{-}, SO_4^{-2}, and HCO_3^{-}. This variation is due to various factors such as the dilution of well water by rain, the dissolution of quaternary formations containing chlorinated evaporites and gypsum and also the relationships that may exist between the water table and the wadi depending on the period considered. Salinity remains acceptable for all water points that remain usable for irrigation.

The contamination of the *Boussellam wadi* waters with nitrites is increasing and continuous (≥ 0.1mg/l) which suggests a risk of pollution of the waters of the *Boussellam* valley plain whose wells closest to the wadi is the most threatened and contaminated. The Ain Zada dam, which represents a lake for the accumulation of water from the wadi, suffers from pollution carried by the wadi and records fairly high levels of almost all the elements.

The risk of nitrate pollution (close to 50mg/l) is imminent; this element is continuously increasing since the 2014 sampling period. The contamination of the wells of the plain in phosphates (≥ 2mg/l) and ammonium (≥ 0.5mg/l) with a rapid increase in these elements due to the intensive use of fertilizers and its impact on the water quality of the *Boussellam wadi* which is closely related to the water table, the Ain Zada dam and the environment in general.

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