ORIGINAL ARTICLE

Assessing the organic pollution of surface water of Medjerda watershed (NE Algeria)

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Abstract Water quality in the Northern part of Mellegue-Medjerda watershed (East Algeria) has been adversely affected by important pollutants discharged into the Medjerda wadi without, in most cases, any treatment. Chemical and physical degradation are due to agricultural and industrial practices and domestic wastewaters. Over a three-month period, a study of the low-flow water quality characteristics throughout Medjerda wadi was undertaken. Longitudinal profiles of water quality were constructed using data from fourteen sites. All sewage, agricultural, and industrial inputs were included. Analyzed properties were nutrients (NO_3^-, NO_2^-, NH_4^+, and PO_4^{3-}), Biochemical oxygen demand after five days (BOD_5), chemical oxygen demand (COD), and dissolved oxygen (DO). Along Medjerda wadi, all values change because of conditions specific to each sampling station. Nitrate was the most important form of nitrogen-element load (94%). Its concentration reached 34.3 mg L^{-1} at OM_4 point, downstream of domestic wastewater discharges. The spatial evolution of the organic pollution index (OPI) shows that the wastewater effluent constitutes the main source of pollution. Indeed, water quality goes from a moderate pollution state at some sampling stations not or slightly affected by wastewaters discharges to a very strong pollution state (OPI of about 1.75) downstream of the domestic effluents inputs of Souk-Ahras city.

Introduction

Agriculture can have a significant impact on the quality of surface water. Nitrate and phosphate pollution of surface water is of high concern as it may have negative impacts on water supply and ecosystems. High nitrate concentrations in water serving as a source for drinking water is a serious health problem, being known for many years as the cause of blue baby syndrome (Comly 1945; Gelberg et al. 1999) and related to increased levels of diarrhoea of children (Gupta 2001).

Return flows from irrigated agriculture may increase the salt, nitrate, and phosphate concentrations of the receiving water bodies, limiting their agricultural, industrial, urban, and ecological uses. Irrigated agriculture in semi-arid areas significantly contributes to crops productivity, stability, and diversification. However, the return flows from irrigated agriculture are considered a major diffuse contributor to the contamination of surface and groundwater bodies.

High nitrate and phosphate concentrations induce eutrophication of Wadis (Doussan 2002). When water is too little oxygenated, anaerobic conditions can also result in accumulation of ammonia and nitrites which intoxicate fauna and flora. High nitrite concentrations often reflect the presence of toxic materials directly from, inter alia, runoff from fertilizers and sewage (Hermon 2002; Vivier 2006).

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Urban and industrial activities can also contribute significantly to deterioration of surface water quality by direct discharge of effluents without any treatment.

The Northern part of Mellegue-Medjerda catchment (surface area 7731 km^2 in Algeria), called Medjerda catchment, which is the focus of this study, is subject to a significant sources of regional pollution with a large influence on regional water chemistry. There have been clear environmental concerns for this wadi and many of its tributaries which have a history of water quality problems and associated biological deterioration (Guasmi 2005; Derradji et al. 2007). It is important to note that this wadi feeds the Ain Dalia dam (region of Souk-Ahras) which supplies several cities, for example Souk-Ahras, Taoura, Drea, Ouled Driss and Zaarouria, with drinking water.

This study aims to characterize spatial and temporal variability of pollution and nutrients in surface waters of Medjerda wadi and to determine the influence of the discharged wastewaters.

General settings

Medjerda catchment (surface area 1411 km^2) is located in the East of Algeria (Fig. 1) and represents the fourth largest basin in the Eastern part.

Its source is on the Southern flank of the Ras El Alia Mount, around 1300 m above sea level in Algeria, and it flows into the Gulf of Tunis (Tunisia). The surface area of the Medjerda-Mellègue catchment both in Tunisia and Algeria is about 22000 km^2.

The studied area is a part of the Tell (Northern Algeria), the structure of which is mainly due to tectonic movements of the Cenozoic age (mainly Miocene). These geological systems are usually constituted by Mesozoic, Cenozoic, and Quaternary formations generally represented by clay, marl, alluvium, sandstone, and gravel (Joleaud 1911; David 1956; Vila 1980).

On average 520 mm of rain falls annually between the months of November and April at Souk-Ahras city on the western edge and 125 mm during the other months of the year. The climate in this region is of semi-arid type (Guasmi 2005), the mean temperature is between 16 and 17.5°C and the potential evapotranspiration exceeds 1100 mm/year.

Land use is dominated by mixed farming of three crops, cereal and other arable crops, permanent grass, and livestock (cattle, sheep and poultry). According to the agricultural survey, the major fertilizers used were of NPK type. Agricultural lands are located on both sides of the wadi.

Medjerda wadi, in its upstream channel, remains in permanent flow only during rainy months. The average of rate flow varies between 0.049 and 0.213 m^3 s^{-1} at the sampling sites (Table 1) during the period studied, with an average of 0.521 m^3 s^{-1}.

It has undergone, in recent years, regional deterioration because of agricultural practices, domestic effluents mainly of Souk-Ahras city, and industrial effluents from a paper factory (Celpap rosa), the ENAP plant for painting products, brick, and textile (Elatex) factories, and a poultry complex. These daily releases are not regularly controlled.

Methodology

The sampling stations were selected by considering the site localities of previous studies conducted in the area (Guasmi 2005), and by taking the contaminant sources into account.
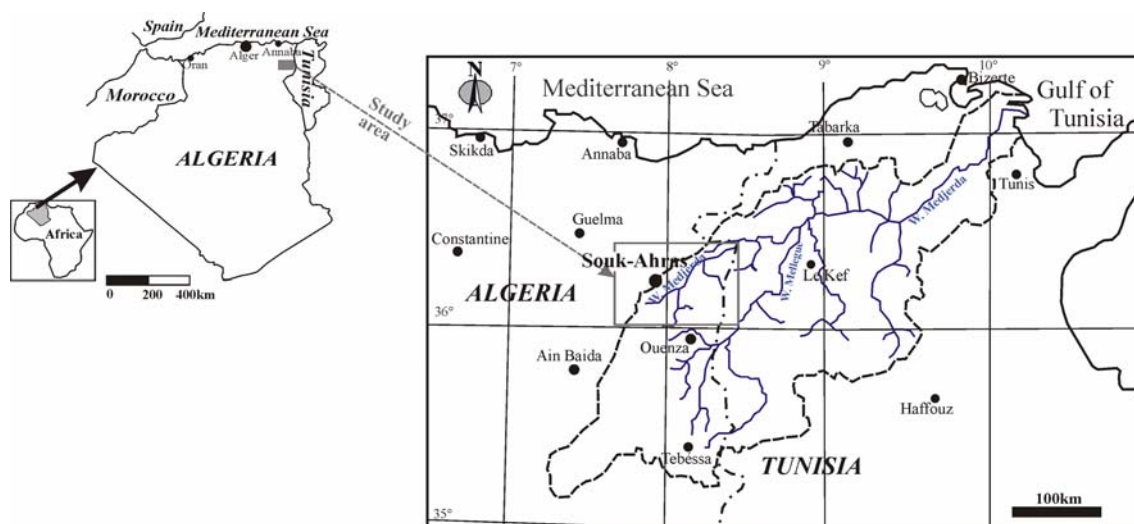

Fig. 1 Location of the study area

Table 1 Class limits of pollutants (Leclercq 2001)

Classes	BOD_5 (mg O_2 L^{-1})	Ammonium (mg N L^{-1})	Nitrites (µg N L^{-1})	Phosphates (µg P L^{-1})
5	<2	<0.1	≤5	≤15
4	2–5	0.1–0.9	6–10	16–75
3	5.1–10	1.0–2.4	11–50	76–250
2	10.1–15	2.5–6.0	51–150	251–900
1	>15	>6.0	>150	>900

For all the plants, wastewaters are discharged after the sites (Fig. 2) except for the brick factory where the discharge is between OM_6 and OM_7. Water samples were analysed for a range of physical and chemical properties including pH, dissolved oxygen, electrical conductivity, water temperature, BOD_5, COD, and nutrients (NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}). The nitrite, nitrates, and ammonium concentrations, are important properties for monitoring surface water quality (Blieffert and Perraud 2001) and are essential properties to evaluate for better water management.

Filtered and unfiltered samples were taken from 14 sites (OM_1–OM_{14}; Fig. 2), during the low-water period, along the main stream and tributary confluences. Water was sampled every two weeks from June to August (3 months) during the year 2006. Additionally representative aspects of each site in relation to the system as a whole, and the accessibility of each location were considered.

Water samples were collected at each site in polyethylene bottles and transported on ice back to the laboratory for further analyses. Water temperature, pH, electrical conductivity (EC), and dissolved oxygen (O_2) were measured in situ using a multivariable WTW (Multiliste P3 PH/LF-SET) and Oxymeter (WTW, probe Cellox 325). The nutrients (nitrates, nitrite, ammonia, and phosphates) were determined by spectrophotometry using a Photolab Spektra, WTW. Determination of the chemical oxygen demand (COD) was based on measuring the amount of potassium dichromate consumed by the dissolved solids in suspension. BOD_5 was measured by incubation of the water sample in the presence of a solution of phosphate and allyl thiourea during the daytime (in darkness and at 20°C).

To understand the nitrate behaviour in the observation sites, we established the ammonium nitrate diagram (Detay 1997). Also, to furnish evidence of the evolution of the global organic pollution of the waters, the organic pollution index (OPI) (Leclerq and Maquet 1987; Fawzi et al. 2001; Duong 2006) was calculated.

The OPI was developed by spreading the values of pollutants (BOD_5, ammonium, nitrites, and phosphates) into five classes according to Table 1. Following these analyses, we determined the class of analyzed pollutants then calculated the average of the number of classes (= OPI) of the four properties according to the grid evaluation mentioned in Table 2.

Results and interpretations

Table 3 illustrates minimum and maximum values of the properties analyzed at the monitoring stations on Medjerda wadi; Table 4 summarizes their averages at each sampling site.

The physical and chemical properties of wadi Medjerda waters show particularly elevated values of conductivity.

Fig. 2 Location of gauging and sampling stations and wastewaters inputs. *1 and 5* urban discharge, *2* poultry complex, *3* brick factory, *4* paint plant (Snic), *6* Celpap Rosa (paper plant), *7* textile factory
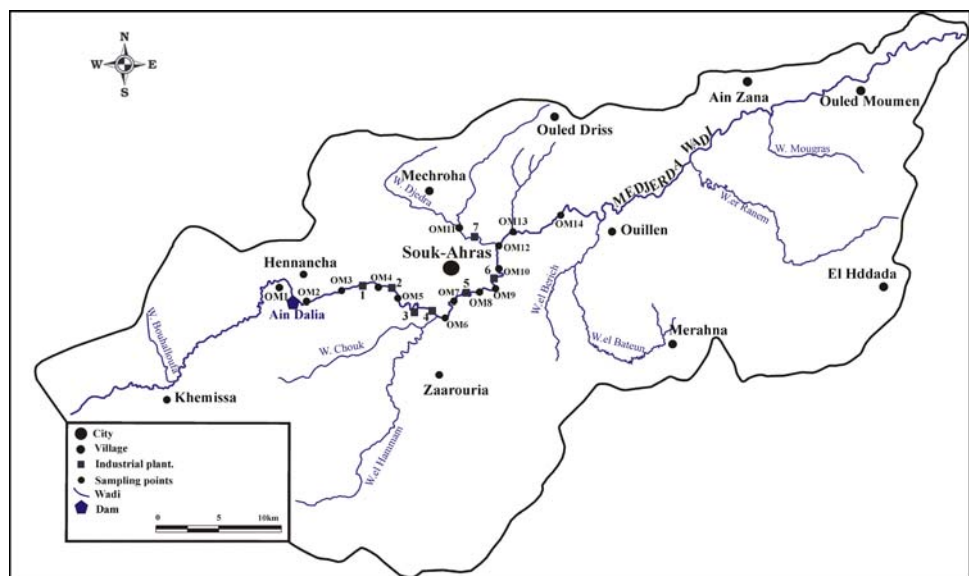
Table 2 Grid evaluation of organic pollution types (Leclercq 2001)

Limits of classes	Organic pollution level
5.0–4.6	None
4.5–4.0	Weak
3.9–3.0	Moderate
2.9–2.0	Strong
1.9–1.0	Very strong

The most elevated values were recorded at stations OM_{12} and OM_{14} (2017 and 1842 μS cm^{-1}, respectively).

Figures 3 and 4 show the spatial and temporal variation of Medjerda wadi flows at the selected stations during the period June–August 2006. These flows fluctuate throughout the wadi: maximum average flows were recorded at station OM_{12} (1.78 m^3 s^{-1}), at the confluence of the wadi Medjerda with the wadi Djedra and OM_{14} (2.13 m^3 s^{-1}), downstream of its junction with other rivers. Concerning the temporal variation (Fig. 4), the largest flows were recorded on 22 June 2006.

The mean values of conductivity (Fig. 5) vary, according to stations, between a minimum value recorded at station OM_2 (721.5 μS cm^{-1}) and a maximum value signalled at station OM_{12} (1739 μS cm^{-1}) downstream of the paint plant wastewater.

Conductivity values fluctuated according to flow rate upstream of OM_5 sampling site, from which it varies in the opposite direction of flow (Fig. 5). This conductivity variation could be linked to the dilution phenomenon because of wadi Medjerda tributaries (increased flow rate and conductivity decrease) or to discharge inputs particularly at OM_5 and OM_{12} stations (increase in conductivity and decrease of wadi flow).

Temperatures ranged between 21.8 and 36°C and recorded pH values were above 7.2.

Nitrate, nitrite, and ammonium were determined in the stream samples. In this study, nitrate values represent over 94% of inorganic N species in the samples. Figure 6 shows the measured nitrate concentration as monthly averages at the monitoring stations. Nitrite-N was found in concentrations ranging from 0 to 3.68 mg L^{-1} (average 0.35 mg L^{-1}); ammonium-N concentrations ranged from 0 to 6 mg L^{-1} (average 0.27 mg L^{-1}); nitrate-N ranged from 2 to 35 mg L^{-1} (average 12.1 mg L^{-1}) (Tables 2, 3; Fig. 6).

Orthophosphate and ammonium concentrations at stations OM_4 and OM_{12} are important. PO_4^{3-} concentrations reached maxima at OM4 and OM3 (5.6 and 6 mg L^{-1}, respectively; Fig. 7).

The elevated nitrate levels at the OM_{10} station (maximum value: 34.5 mg L^{-1}) and nitrite levels at OM_9 station (maximum value: 3.68 mg L^{-1}) give an idea on the deterioration of groundwater quality.

Table 3 Minimum, maximum, and standard deviations of amounts of nutrients, and COD and BOD$_5$

	NO_2^-	SD	NO_3^-	SD	NH_4^+	SD	PO_4^{3-}	SD	O_2	SD	COD	SD	BOD_5	SD
OM1	0.01–11	4.414	0.03–20.5	7.926	0.012–0.12	0.188	0.1–1.1	0.372	2.12–3.54	0.564	8–65	23.604	3–24	7.620
OM2	0.01–5	2.006	0.004–15	4.760	0.001–0.75	0.302	0.001–0.6	0.265	2.21–3.76	0.610	1.4–67	28.911	2.5–28	9.683
OM3	0.02–15	5.956	0.44–19	7.152	0.003–6	2.379	0.036–6	2.373	2.23–3.5	0.565	4.3–127	52.364	2.9–57	20.752
OM4	0.12–10	3.947	0.62–27	9.198	0.002–2.2	0.879	0.012–5.6	2.194	2.40–3.64	0.522	10.3–69	62.854	9–47	15.272
OM5	0.04–30	12.097	0–27	9.216	0.003–1.25	0.483	0.014–2.51	0.970	2.21–3.71	0.625	6.2–68	24.246	8–17	3.762
OM6	0.012–25	10.148	0.4–29	10.935	0–4	1.580	0.3–1.231	0.447	2.09–3.7	0.623	7.9–103	34.078	3.5–13	3.110
OM7	0.01–2.871	1.182	1–7	2.259	0.051–1	0.375	0–1.008	0.489	2.02–3.52	0.552	10.5–108	42.211	1.5–24	8.637
OM8	0.04–3	1.432	1–30	11.077	0.012–0.4	0.141	0.5–0.61	0.050	2.02–3.73	0.759	21.8–62	15.379	4–13.9	4.338
OM9	0.02–5	2.252	0.02–19	8.101	0.024–1.5	0.669	0–2.02	0.906	2.01–3.71	0.643	18–71	20.454	2–14	4.487
OM10	0.02–5	2.543	0.1–29	12.484	0.02–0.9	0.423	0.215–2.16	0.899	2.02–3.73	0.656	8.12–73	24.339	1.9–8	2.463
OM11	0.02–4	1.587	0–29	11.752	0.022–0.2	0.063	0–1	0.443	2.10–3.61	0.560	19.9–81	24.580	1.5–12	4.615
OM12	0.02–3	1.171	0–19	8.877	0.002–1.62	0.709	0–1.681	0.703	2.00–3.59	0.578	20–78	20.666	1.5–21.2	7.895
OM13	0.027–12	4.877	0.01–26	8.564	0–1.62	0.734	0–3.7	1.719	2.36–3.7	0.520	18–97	31.441	1–20.4	8.363
OM14	0.05–17	6.720	0–15.1	5.708	0.001–1.2	0.468	0–1.2	0.419	2.39–3.78	0.552	16–80	26.328	0–24	11.289

Table 4 Averages values of the properties measured

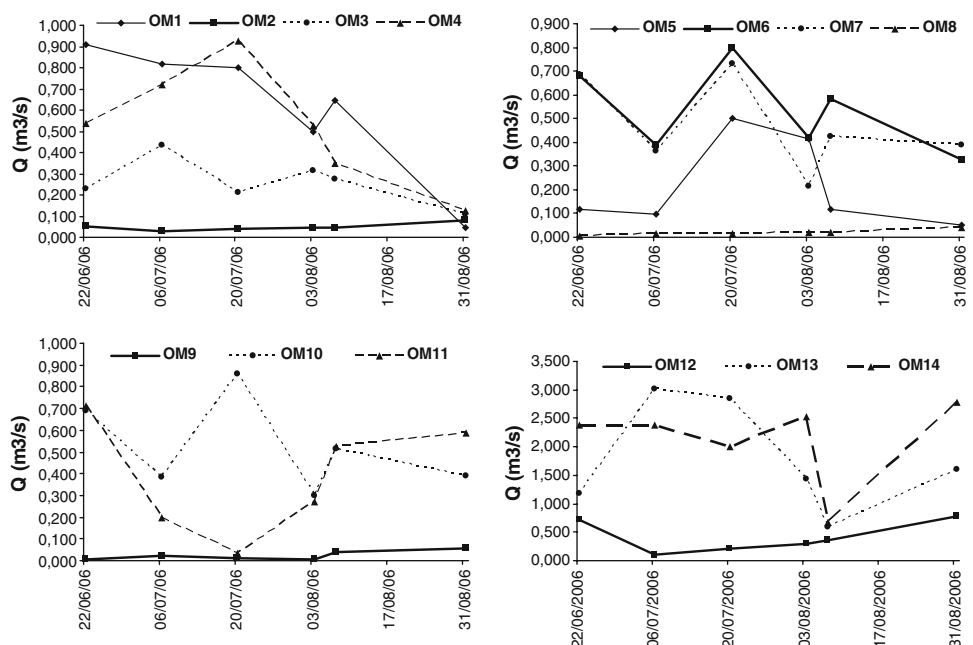|	NO_2^-	NO_3^-	NH_4^+	PO_4^{3-}	O_2	COD	BDO_5
OM1	0.2	13.2	0.1	0.4	2.7	24.5	8.7
OM2	0.09	7.69	0.14	0.17	2.78	20.52	8.10
OM3	0.09	7.69	0.14	0.17	2.78	20.52	8.1
OM4	0.38	15.32	0.59	1.34	3.02	50.88	18.07
OM5	0.31	21.20	0.29	0.59	2.89	34.03	11.60
OM6	0.15	16.87	0.90	0.83	2.88	40.02	8.67
OM7	0.09	7.69	0.14	0.17	2.55	20.52	8.1
OM8	0.35	9.45	0.12	0.49	2.99	32.88	7.97
OM9	1.92	12.32	0.26	0.77	2.72	29.15	10.57
OM10	0.09	21.88	0.32	0.45	2.84	33.17	8.90
OM11	0.13	6.34	0.05	0.76	2.88	42.83	9.46
OM12	0.18	13.62	0.55	1.16	2.73	47.57	10.26
OM13	0.19	14.98	0.21	1.61	3.15	56.17	10.02
OM14	0.68	14.27	0.03	1.08	3.2	54.25	10.10

Fig. 5 EC and flow variations at sampling stations on 22 June 2006

The Medjerda wadi receives, downstream of station OM3, wastewater effluent of Souk-Ahras agglomeration, highly loaded with organic matter, ammonium, and orthophosphates.

The average concentrations of dissolved oxygen are between 2.55 and 3.2 mg L^{-1} and indicate, in general, water of poor quality (Table 4).

Figure 8 shows temporal variation of dissolved oxygen during the period investigated. It evolves in the same manner during August and varies during the remaining period according to the inputs of wastewaters.

BOD_5 values recorded during the sampling campaign were high at OM4 station situated downstream of the wastewater discharge of Souk-Ahras city. At this station they reached 47 mg L^{-1} with an average of 18.07 mg L^{-1}. The maximum value was recorded at OM3 station (57 mg L^{-1}).

Fig. 3 Spatial variation of wadi flow at sampling stations

Fig. 4 Temporal variations of wadi flow at sampling stations
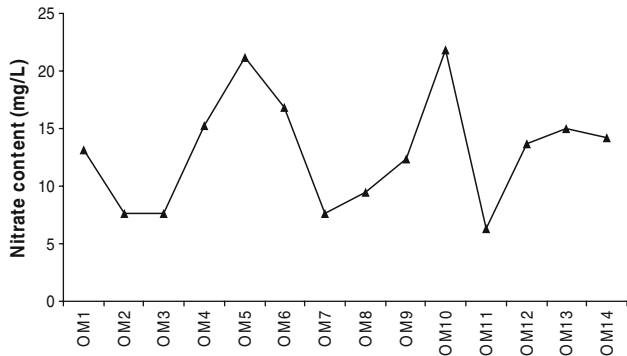
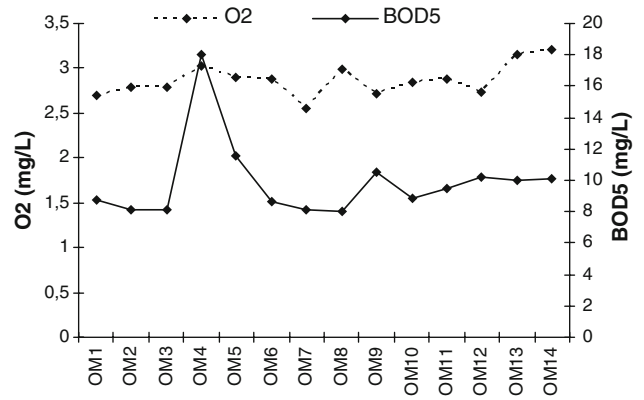Fig. 6 Nitrates variation at sampling stations

Fig. 9 BOD$_5$ and dissolved oxygen variations at sampling stations
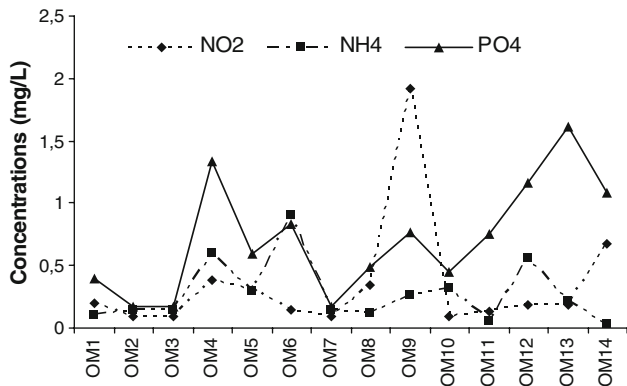

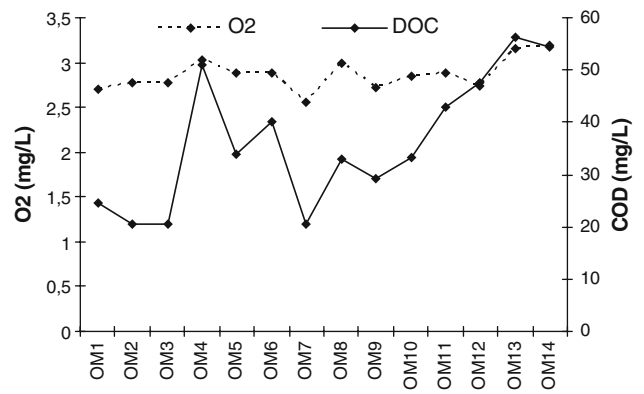Fig. 7 Nitrites, ammonium, and orthophosphates variations at sampling stations

Fig. 10 COD and dissolved oxygen variations at sampling stations

Figure 9 shows the variation of BOD$_5$ versus dissolved oxygen and shows that these two properties evolve in opposite directions.

Chemical oxygen demand (COD) and dissolved oxygen evolve, in general, in the same direction. COD is important between OM$_4$ and OM$_6$ stations, downstream of the domestic wastewaters discharges, and between OM$_{11}$ and
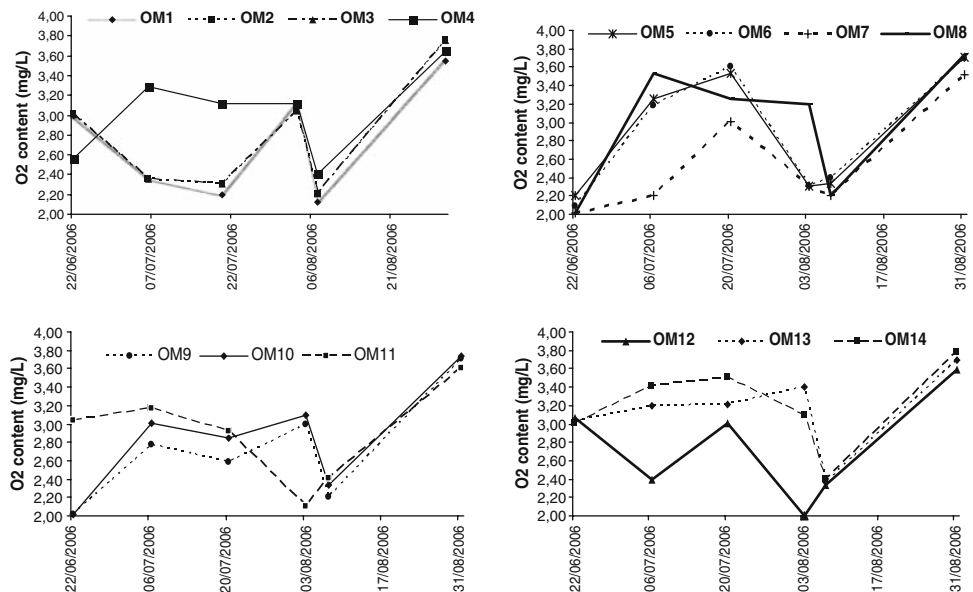
Fig. 8 Dissolved oxygen temporal variations

Fig. 11 Ammonium nitrate diagram

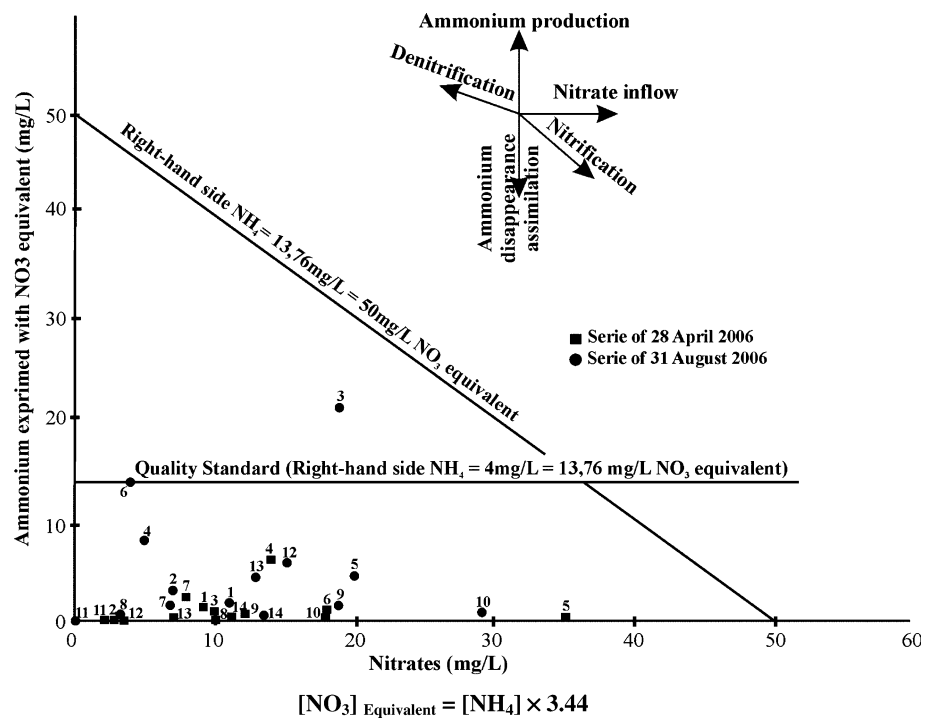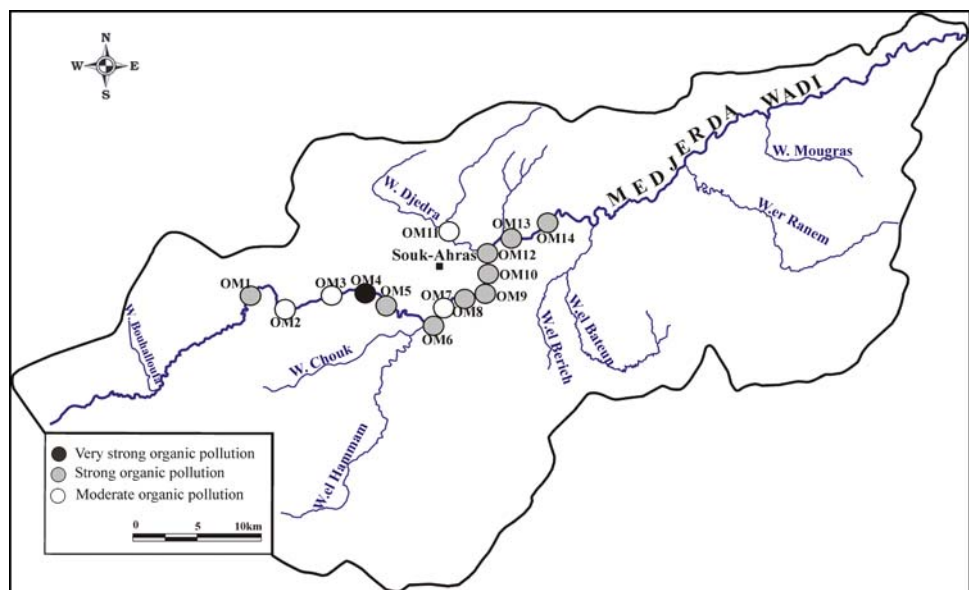
$$[NO_3]_{Equivalent} = [NH_4] \times 3.44$$

Fig. 12 Water quality of Medjerda wadi

OM$_{14}$, where wastewaters from the paint plant are discharged (Fig. 10).

To understand the behaviour of nitrates at the observation sites, we established diagrams of ammonium nitrate for two periods (April and August 2006). This diagram shows four groups (Fig. 11):

- The first group includes OM$_9$, OM$_{10}$, and OM$_{14}$ sampling points, which move in the horizontal direction (positive). This zone is characterized by a large amount of fertilizer purely agricultural-based nitrates leaching after utilization.

- The second group represented by OM$_1$, OM$_2$, OM$_3$, OM$_{12}$, and OM$_{13}$ sites, shows a shift in the direction of ammonium production. This phenomenon can lead to wadi eutrophication and then phytoplankton formation with proliferation of filamentous algae (Mosisch et al. 2001; OMS 2003), marked by a lack of oxygen.

- A third group, containing OM$_4$, OM$_5$, OM$_6$, OM$_8$, and OM$_{11}$ stations, marked by a move in the denitrification direction. It is located downstream of domestic effluent where organic pollution reached its peak. The presence of bacteria from wastewater discharges is noted.

- Finally, the fourth group represented by the OM_7 sampling site which moved vertically down and which is characterized by fixation of ammonium leading to disappearance.

Examination of the OPI shows that the wastewater effluent constitutes the main source of pollution especially at OM_4 sampling site. Indeed, water quality goes from a moderate pollution state (OPI 3) at the OM_2, OM_3, OM_7, and OM_{11} stations to a very strong pollution state (OPI 1.75) at station OM_4 (Fig. 12).

At stations OM_2, OM_3, and OM_7, water quality of wadi Medjerda is improved by the phenomenon of self purification and/or dilution because of tributaries contributions.

Conclusion

Assessment of the influence of pollutants discharges on water quality of Medjerda wadi shows significant adverse effects with regard to dissolved oxygen content, eutrophication, and concentrations of nutrients and organic matter.

The results obtained revealed that the main processes affecting water quality during the investigated period are represented by wastewaters discharges in the Medjerda wadi and its tributaries. However, the magnitude of water quality changes depends on the wadi regime, watershed characteristics, and human activities.

The spatial evolution of surface water quality shows that the Medjerda waters are affected by heavy organic pollution from fertilizer plants, domestic effluents, and untreated industrial wastewater discharges from the industries located in the watershed.

Agricultural return flow in the Souk-Ahras area and domestic effluents constitute a significant source of nutrient pollution which is very strong downstream of the domestic wastewaters discharge at station OM_4 and between OM_8 and OM_{14} sites.

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