

Spatial and Temporal Variability of Water Quality of an Urbanized River in Algeria: The Case of Soummam Wadi

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ABSTRACT: Spatial and temporal variations of water quality were investigated at four sites of an urbanized river in Algeria during a period of low water level in the years 2002, 2003, and 2004. Physical–chemical parameters (temperature, pH, conductivity, dissolved oxygen, suspended matter, chemical oxygen demand [COD], and 5-day biochemical oxygen demand [BOD₅]) were measured. The Soummam River showed a strong pollutant load, which was organic in origin and expressed by mean concentrations in suspended matter, COD and BOD₅ exceeding 150, 100, and 50 mg/L, respectively. The spatial variation highlighted two areas— (1) the first one gathers the upstream and central sites of the river, and (2) the second one is found downstream. In the downstream area, the pollutant load is almost twice as high as in the first area and, the percent saturation of dissolved oxygen is relatively weak (<55%). This load is the result of the significant volume of urban and industrial emissions in the river, the high temperature during low-water-level periods, and flood events, which occurred just before the period of low water level. The Soummam River was classified according to the criteria of appreciation of surface water and was found to be extremely polluted. This work is one of the first studies on the quality of rivers in Algeria. This research will be useful as a first step for future works in North Africa and will add to knowledge on the water quality in the Mediterranean Basin. *Water Environ. Res.*, **82**, 742 (2010).

KEYWORDS: organic pollution, surface waters, standards of surface water quality, water quality index.

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Introduction

The water quality of rivers and its variability depends notably on the variations of hydroclimatic factors and on the human effects on the environment. Temporal variability is related closely to the fluctuations of the quantity of water in rivers, whereas the spatial variability often is determined by the intensity and variety of the anthropic loads (Shil’Krot and Yasinskii, 2002; Shrestha and Kazama, 2006).

Worldwide, the quality of rivers is deteriorated by the various forms of pollution, in particular, in Algeria, where water resources have become increasingly limited, difficult to exploit, and often are exposed to significant amounts of wastewater. To assess the quality of rivers, some studies have used a water quality index (WQI) (Bordalo et al., 2006; Gold et al., 2003; Nives, 1999; Said

et al., 2004; Sanchez et al., 2006; Wu, 1999). The WQI is based on a mathematical relation that transforms several physical–chemical parameters of water into a single number, which, in turn, represents the level of water quality. This index is effective and is used widely to control the contamination of rivers, and correlations are studied between this index and physical–chemical parameters, such as dissolved oxygen (DO) (Sanchez et al., 2006), or biological parameters, such as the diatom index (Shrestha and Kazama, 2006; Wu, 1999).

In parallel, several countries have developed their specific indices of the water quality, such as the system of valuation of water quality (SEQ) proposed by the Agency of Water Seine-Normandie (Rouen, France), the National Sanitation Foundation water quality index (NSFWQI) in the United States developed by the National Sanitation Foundation (Detroit, Michigan), and the British Columbia water quality index (BCWQI) by the British Columbia Ministry of Environment of Canada (Vancouver, Canada) (Said et al., 2004). In Africa, and in particular in Algeria, the classification of water quality is done punctually according to the European standards. However, it is imperative to develop research in this field, which so far seems lacking in North Africa.

Among the big rivers in Algeria, there is the Soummam Wadi, located in the area of Bejaia, which is 150 km east from the capital city Algiers. The river drains into the Mediterranean Sea, after traveling 80 km from its source. Because of the demographic and industrial growth in the area during the last decade, the Soummam Wadi receives a significant part of urban, industrial, and agricultural residues, considerably damaging the ecosystem and the coastal marine environment.

In addition, on a global scale, the seasonal variations of precipitation have a significant effect on the concentrations of pollutants in the rivers (Meybeck and De Marsily, 1998; Shrestha and Kazama, 2006); the quality of the rivers is lower in winter than in the summer, because the dilution is weaker. For this reason, we propose a physical–chemical characterization of the water of the Soummam Wadi during a period of low water level. It is one of the first studies of the quality of water in Algeria with the following objectives: (1) to study the temporal and spatial variability of water quality of the Soummam Wadi, and (2) to determine its representativeness on a global scale.

Material and Methods

Study Area. The catchment area of the Soummam is 9125 km² and is spread over a mountainous zone and two plateaus and more than 1000 m of altitude (Figure 1). Bouira is in

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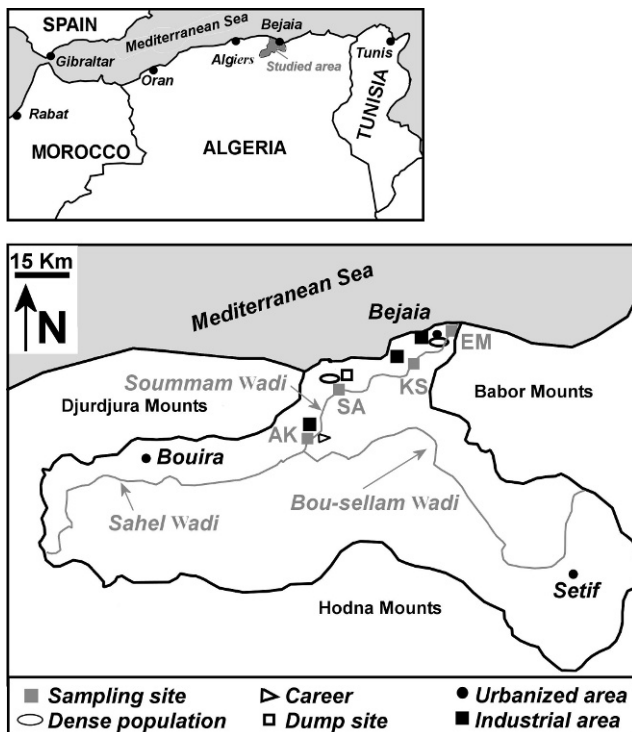


Figure 1—Location of the sampling sites.

the West and Sétif is in the Southeast. The basin is bordered on the North by the Mountains of Djurdjura, the Mediterranean Sea, and the coastal chains of the Small Kabylie, and on the South by the Mountains of Hodna. Several rivers flow through this watershed, including the Sahel, Bou sellam, and Soummam Rivers.

The studied area represents 12 of the total surface of the catchment area of Soummam, crossed by the Soummam Wadi, the latter of which originates from the junction at the town of Akbou of the two rivers Sahel and Bou-sellam. The length of the river is 80 km. The width of the flood plain varies between 350 and 1200 m, and the mean water channel is between 250 and 500 m (with a tightening up to 100 m in Sidi Aich). The depth of the river is between 0.7 and 4 m (Coyne and Bellier, 1973).

The Soummam Wadi flows into the Mediterranean Sea in Bejaia (Figure 1). Its mean discharge is 25 m³/s, but its risings are violent: the maximum flow recorded in 1970 was 116 m³/s. The minimum flow is 0.6 m³/s (Coyne and Belier, 1973).

From a geological point-of-view, the basin of the Soummam Wadi is broadly characterized by marl and limestone of the Oligocene on the left bank, and by sandstone, marl, limestone and clay of the early and late Cretaceous on the right bank (Duplan, 1952). The catchment area of the Soummam experiences two main climatic regions—a wet Mediterranean climate in Bejaia and the low part of the valley, and a dry continental climate characterized by cold winters and dry warm summers for the plateaus (Seltzer, 1946).

The maximum mean temperature is reached in August (25°C), and the minimal one in January (12°C). The lower Soummam averages from 600 to 900 mm of rainfall per year. The rainy period lasts 7 months, from October to April. In the summer, rain events are minimal, representing only 3 to 4% of the annual rain (Data of the National Office of Meteorology of Algeria, Dar El Beida Algiers, Algeria).

The studied river basin had an estimated population of 1 million inhabitants in 2007, with an average population density of 250 inhab/km², of which 50% are concentrated along the valley. Agricultural land occupies roughly 583 km², while the forest covers 225 km² (Data of the Direction of Management and Planning of Algeria, Bejaia). Industries (especially the food, cork, and textile industries) are established along the two banks. Some towns do not have any wastewater systems, and few industries have wastewater treatment plants, so that domestic and industrial effluents are discharged directly into the river without any preliminary treatment. According to the investigations we carried out in the 21 counties and in the principal industries of the study area, the annual volume of untreated water in the river was evaluated to be approximately 11.6.106 m³/y in 2002. Urban inputs constitute approximately 75% of the total volume.

Sampling and Analyses. The following four sites were selected according to the population density and the various industries located along the river (Figure 1):

- (1) Upstream in the town of Akbou (AK), with textile and dairy industries;
- (2) Sidi Aich (SA), in the central part of the river, a densely populated area located 150 m from a public discharge;
- (3) El Kseur (KS), characterized by the textile and food industries; and
- (4) Downstream in Bejaia (EM), an urban and industrial area (oil and textile industries).

The present study was carried out monthly during the last week of May, second week of June, and first week of July, during

Table 1—Average (AV), standard deviations (SD), and coefficients of variation (CV) for the physico-chemical parameters measured during the low water levels in 2002, 2003, and 2004 at the sampling sites of the Soummam Wadi (1 sample/month during 3 months/year, for 3 years = 9 samples /site).

Sites	Akbou (AK)			Sidi Aich (SA)			El Kseur (KS)			Bejaia (EM)		
	AV	SD	CV	AV	SD	CV	AV	SD	CV	AV	SD	CV
Temperature (°C)	23.9	4.45	0.18	24.6	4.58	0.19	24.3	5.68	0.23	24.7	3.68	0.15
pH	7.97	0.34	0.04	7.84	0.48	0.06	7.85	0.54	0.07	7.51	0.69	0.09
Conductivity (mS/cm)	7.77	1.28	0.16	7.28	1.75	0.24	7.16	1.68	0.23	8.53	0.16	0.16
DO (mg/L)	8.14	0.79	0.09	6.86	1.21	0.18	5.71	1.64	0.29	4.84	0.29	0.29
SM (mg/L)	131.0	59.6	0.45	126.3	27.5	0.21	110.1	30.1	0.27	188.8	53.3	0.28
BOD ₅ (mg/L)	57.2	22.41	0.39	52.2	17.7	0.34	49.9	13.4	0.27	104.6	18.3	0.17
COD (mg/L)	85.9	27.6	0.32	76.4	16.5	0.22	74.7	19.6	0.26	143.6	32.4	0.23

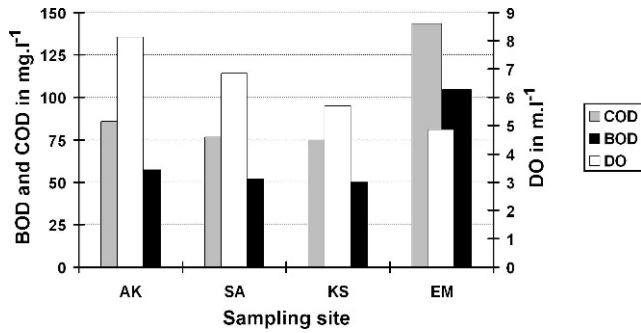


Figure 2—Average BOD₅, COD, and dissolved oxygen in the Soummam Wadi during the low water levels in 2002, 2003, and 2004.

periods of low water level, over 3 years (2002, 2003, and 2004). The water samples were collected in the morning at first in the upstream site (Akbou) at 8:00 a.m., then at the site (Sidi Aich) at 9:30 a.m., later at the third site (El Kseur) at 10:30 a.m., and also Bejaia at 12:00 p.m. We had one sampling point in each sampling site, making a total of 36 samples that were collected (1 sample/month during 3 months/year during 3 years = 9 samples/site). During all of the sampling campaign, the weather was sunny, and flooding from rainfall events occurred before or after our sampling.

The water samples were collected in polyethylene bottles of 1 L and stored at 4°C. Temperature, pH, dissolved oxygen, and conductivity were measured directly in the field. The other parameters, such as suspended matter (SM), BOD₅, and COD, were measured in the laboratory. pH was measured with a field pH meter (PHYWE, Göttingen, Germany). Dissolved oxygen was measured using a portable oxymeter (pIONneer, 20-DOX 20T, Tokyo, Japan). Conductivity was measured directly by a portable conductometer (W.T.W 1330, Weilheim, Germany) with thermal compensation. The concentration in suspended matter was measured after vacuum filtration using cellulose filters (0.45 µm). The BOD₅ was measured by the dilution method, and COD was determined by the method of oxidation with potassium bichromate (Rodier, 1996).

Results and Discussion

Spatial Variability of Water Quality of the Soummam Wadi. Inter-Site Comparison. Water quality parameters for

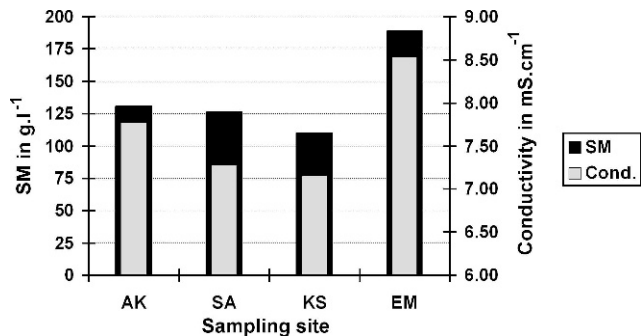


Figure 3—Mean conductivity and suspended matter concentrations at the sampling sites during the low water levels in 2002, 2003, and 2004.

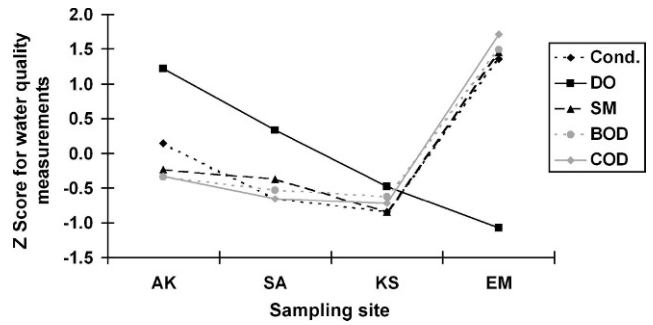


Figure 4—Longitudinal variation of water quality measurements from upstream to downstream along the Soummam Wadi (based on the monthly average during low water levels in 2002, 2003, and 2004).

May, June, and July of 2002, 2003, and 2004 in the various sites are given in Table 1. For all of the sites, the temperature was similar and ranged between 23.9 and 24.7°C, on average. However, it was slightly higher downstream than upstream. Within the same year and the same month, the variations between stations were the result of the sampling that was spread in the morning (beginning of the morning in the upstream and end of the morning in the downstream areas).

The average pH values ranged between 7.5 and 7.9, and a small decrease appeared between the upstream and downstream values.

The concentrations of BOD₅ and COD were twice as high at the site Bejaia downstream (104.6 and 143.6 mg/L, respectively) compared with the other sites (Figure 2). The concentrations in suspended matter ranged from 110 to 189 mg/L. The highest concentration was recorded downstream (Figure 3). The conductivity was high in every site (>7.16 mS/cm). The highest values were recorded in the downstream site Bejaia, where the average was 8.53 mS/cm (Figure 3). The measured parameters were expressed with different units. To carry out a direct comparison between the various sites, all of the average values were

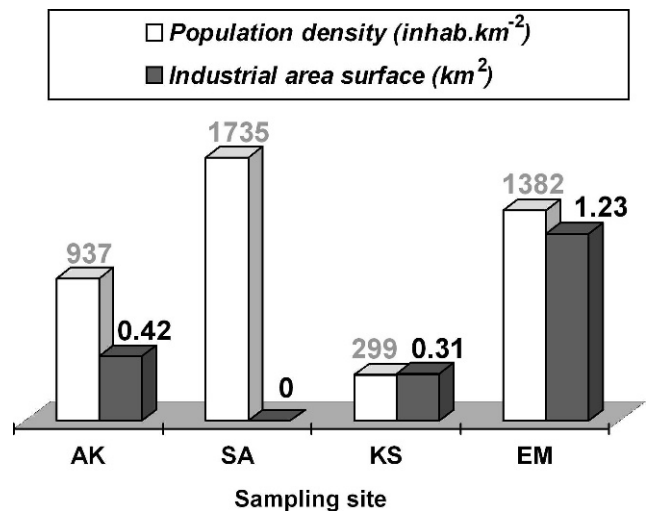


Figure 5—Density of population and surface of the industrial areas in the valley of the Soummam Wadi (Data of Direction of Management and Planning of Algeria).

Table 2—Average (AV) and standard deviations (SD) for the physico-chemical parameters measured in zones I and II of the Soummam Wadi during low water levels during 2002, 2003, and 2004.

		Temperature (°C)	pH	Conductivity (mS/cm)	DO (mg/L)	SM (mg/L)	BOD ₅ (mg/L)	COD (mg/L)
Zone I	2002	23.9 ± 0.77	8.21 ± 0.11	8.20 ± 0.42	6.04 ± 1.90	78.0 ± 21.5	35.5 ± 4.83	61.8 ± 2.68
	2003	25.2 ± 1.12	7.96 ± 0.09	8.52 ± 0.07	7.21 ± 0.75	143.8 ± 12.0	66.6 ± 9.74	96.3 ± 17.1
	2004	23.2 ± 1.43	7.49 ± 0.20	5.50 ± 0.66	7.45 ± 1.01	145.6 ± 31.7	57.1 ± 10.5	79.8 ± 8.06
Zone II	2002	23.7 ± 3.79	7.73 ± 0.74	9.26 ± 0.19	3.27 ± 0.21	130.7 ± 43.1	82.7 ± 6.43	120.7 ± 34.1
	2003	27.8 ± 1.66	7.89 ± 0.35	9.36 ± 0.30	5.87 ± 1.11	196.2 ± 5.41	118.1 ± 10.5	174.0 ± 20.3
	2004	22.7 ± 3.94	6.90 ± 0.61	6.96 ± 1.35	5.40 ± 1.06	239.7 ± 20.6	113.0 ± 8.89	136.0 ± 19.1

standardized by using Z scores (Figure 4) according to the method used by Chang (2005) for the study of the spatial and temporal variability of water quality in the Han river and its tributaries in Korea. The same trends were found for BOD₅, COD, suspended matter, and conductivity in the three upstream and central sites (Akbou, Sidi Aich, and El Kseur); then, a strong increase occurred at the downstream site (Bejaia). Only dissolved oxygen presented a regular decrease from upstream to downstream. These results made it possible to divide the Soummam Wadi into two distinct zones according to the water quality—(1) zone I gathering the three upstream and central sites (Akbou, Sidi Aich, and El Kseur), which have a relatively homogeneous water quality; and (2) zone II (site Bejaia), which presents an obvious degradation of water quality.

Factors Involved in the Spatial Variations of Water Quality. The low water quality at the Bejaia site can be explained by anthropogenic factors. This site is located in an urbanized zone (city of Bejaia), with a large population density (1380 inhab/km² in 1998) and industrialization (Figure 5). Moreover, this site receives all contaminated waters coming from upstream, where several industries are established along the two banks and domestic waters are discharged directly to the river. The water quality in the other sites (Akbou, Sidi Aich, and El Kseur) is similar. It also is not good because of the strong density of population in Sidi Aich (1735 inhab/km²). In Akbou and El Kseur, the population density is less significant, but the existence of the industrial area contributes to a higher pollutant load (Figure 5).

In more detail, the pH values (>7) (Table 1) can be explained by the calcareous nature of the grounds, though the variations of pH also are dependent on the nature of the acid and/or alkaline rejections, the precipitations, and the photosynthetic activity (Meybeck and De Marsily, 1998; Olias et al., 2005). The pH values recorded downstream (slightly lower than those upstream) could be the result of the proliferation of algae, whose decomposition induces the formation of organic acids (Jacobson et al., 2000; Sanchez et al., 2006). A strong eutrophication is observed at Bejaia and not at the other sites.

Dissolved oxygen is an essential parameter for an aquatic habitat; most fish cannot survive when the dissolved oxygen concentration is less than 3 mg/L (Chang, 2005). The variation of dissolved oxygen in water depends on many natural processes (respiration, photosynthesis, etc.). A strong decrease in the dissolved oxygen concentration is found from upstream to downstream (Figure 4) where dissolved oxygen <5 mg/L. This can be explained by the significant volume of urban effluents in this strongly urbanized zone (Figure 5) and by the industrial wastes (oil industries), in addition to the already contaminated waters coming from upstream. Thus, the decrease of dissolved oxygen concentration is not related to the temperature.

The lower values for dissolved oxygen found at site Akbou compared with the other sites of zone I are explained by the dairy industries located at Akbou, whose rejections are rich in organic biodegradable matter. Consequently, BOD₅ is high (57.1 mg/L). As the effects of high organic pollution can only be observed at a certain distance downstream because of the time necessary for the biodegradation of the organic matter (Pesson, 1976), the decrease of dissolved oxygen is observed at site Sidi Aich and even more at El Kseur (Table 1). Moreover, the river bed is wider in site El Kseur than in the other sites, and the slope is weaker (approximately 2‰). Dissolved oxygen varies considerably, according to the flowrate, which depends on the morphodynamic characteristics of the river (Pesson, 1976).

The BOD₅ and COD are indirect measurements of the dissolved oxygen quantity in water and represent the organic load. This load is the result of the urban and industrial waste, whose volume varies according to the density of population, the nature, and the importance of industries (Figure 5). The ratio of BOD₅/COD expresses the quantity of biodegradable matter compared with the total organic matter. It is approximately 0.7 at Bejaia, where the load is twice as high as in the other sites (Figure 2), and 0.6 in the other sites, the latter of which indicates a strong biodegradable organic matter concentration compared with the total organic matter. Suspended particles may affect the aquatic life when the concentration in suspended matter is high (Meybeck and De

Table 3—Maximal and minimal monthly temperatures (°C) in the area of Bejaia before each sampling campaign (National Office of Meteorology of Algeria).

Months	April		May		June		July	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
2002	10.6	20.7	13.5	23.2	17.4	26.4	20.5	27.9
2003	12.0	19.6	14.5	21.9	20.2	30.0	23.1	31.5
2004	10.5	19.9	13.1	21.5	17.0	25.7	20.7	29.5

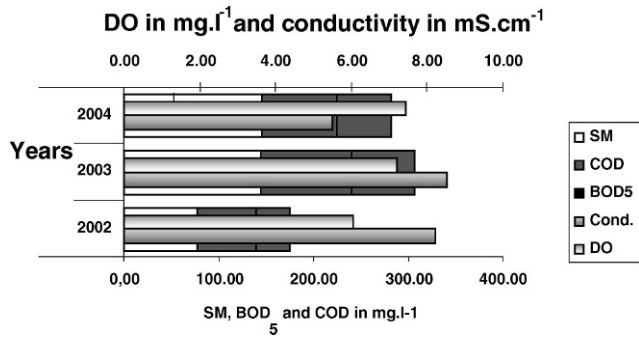


Figure 6—Mean BOD₅, COD, dissolved oxygen, conductivity, and suspended matter in zone I of the Soummam Wadi during the low water levels in 2002, 2003, and 2004.

Marsily, 1998; Sanchez et al., 2006). Suspended matter can be mineral (clay and mud) or organic (degradation of plants and animals), which involves a rise in demand for oxygen (Chang, 2005). The high concentration of suspended matter in all of the sites is a result of the industrial effluents, which generally are ejected without any treatment from municipal wastewater and from the arable land erosion. The higher concentrations of suspended matter measured at Akbou, Sidi Aich, and El Kseur may be explained by the extraction of sand near Akbou. The presence of a dump site near Sidi Aich also may explain the higher concentration of suspended matter than in El Kseur. The higher concentration of suspended matter in Bejaia is explained by the strong eutrophication observed at this site, as mentioned previously. Conductivity is proportional to the concentration of dissolved ions, making it possible to quantify the dissolved matter present in water (Chang, 2005). The dissolved matter in rivers generally is a result of the nature of the ground where water flows through and from industrial and domestic effluents. Conductivity is high for zones I and II. In addition to the urban and industrial effluents, a mineral spa is located downstream of Akbou (7.7 mS/cm). The high conductivity at Bejaia (8.5 mS/cm) may be the result of saline intrusion (Stamatis, 2001). In fact, the Mediterranean Sea does not present a variation of tides. Therefore, the zone of mixture of water is less developed. This only relates to the station of Béjaia located downstream of the river at approximately 200 m offshore, but not the other stations located in the central part and upstream of the river.

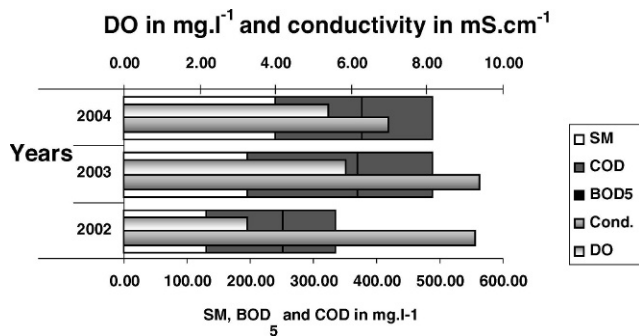


Figure 7—Mean BOD₅, COD, dissolved oxygen, conductivity and suspended matter in zone II of the Soummam Wadi during the low water levels in 2002, 2003, and 2004.

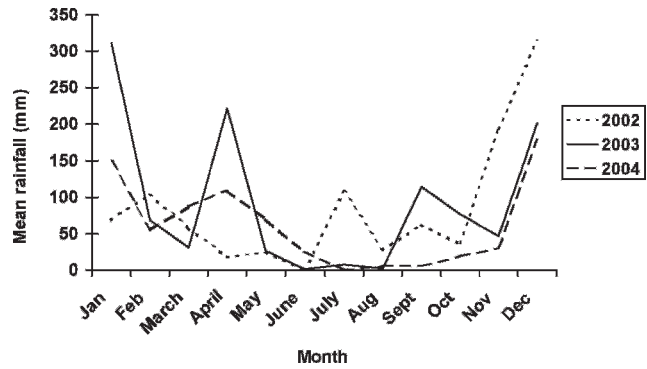


Figure 8—Monthly average precipitation in the area of Bejaia in 2002, 2003, and 2004 (National Office of Meteorology of Algeria).

Temporal Variability of Water Quality of the Soummam Wadi. Comparison During Low Water Levels. Parameters measured during low water levels (May, June, and July) in 2002, 2003, and 2004 are given in Table 2.

The water temperatures recorded in 2003 (between 25.1 and 27.7°C) were higher than those measured in 2002 and 2004 (between 22.7 and 23.8°C), for both zones I and zone II. The difference of temperature essentially was the result of the difference of temperature of the air from one year to another (Table 3). The pH was approximately 8 in 2002 and 2003 for the two zones, while there was a small decrease in 2004 in zone II (6.9). The lowest dissolved oxygen concentrations were recorded in 2002; its average concentration was 6.0 mg/L in zone I and 3.2 mg/L in zone II. It exceeded 7 mg/L in zone I and 5 mg/L in zone II in 2003 and 2004 (Table 2). The BOD₅ and COD increased between 2002 and 2003. The BOD₅ concentration in zone I was 35.5 and 66.5 mg/L in 2002 and 2003, respectively. The COD concentration in zone II was 120.7 and 174 mg/L in 2002 and 2003, respectively. In 2004, BOD₅ and COD decreased by 14.2 and 17.1%, respectively, in zone I, and by 4.2 and 21.8% in zone II (Figures 6 and 7). There was a clear increase in suspended matter between 2002 and 2003. Values increased by approximately 65 mg/L in the two zones from 2002 to 2003. In 2004, suspended matter increased by 43.4 mg/L in zone II (Figure 7). In 2002 and 2003, conductivity was approximately 8 and 9 mS/cm in zones I and II, respectively, and it decreased in 2004 by approximately 35.4% in zone I and 25.6% in zone II (Figures 6 and 7). According to these results, the low water level of the year 2003 is marked by a strong degradation of the water quality of the Soummam Wadi.

Factors Involved in the Temporal Variability of Water Quality. Most of the temporal variations of the water quality can be explained by climatic variations and mainly by the variations in precipitation. The water quality was low during the low water levels. The year 2003 was marked by a strong degradation of water quality of the Soummam Wadi. This was caused mainly by a flood event in April (Figure 8). The river overflowed and reached the roads, and several towns were isolated for a few days. These overflows were provoked by the degradation of the banks, which formed the borders between the bed of the river and the alluvial plain. The increase in pollutant loads is explained by the fact that high amounts of precipitation induce runoff, erosion, and resuspension of the deposits and the

Table 4—Standards of surface water quality (Bontoux, 1993).

Index/Classes	1A Excellent	1B Good	2 Passable	3 Poor	4 Except class
Temperature (°C)	<20	20 to 22	22 to 25	25 to 30	>30
pH	>6.5 to <8.5	6.5 to 8.5	39 331	5.5 to 9.5	<5.5 to >9.5
Conductivity (mS/cm)	<400	400 to 750	750 to 1500	1500 to 3000	>3000
CO (mg/L)	>7	5 to 7	3 to 5	<3	<3
BOD (mg/L)	<3	3 to 5	5 to 10	10 to 25	>25
COD (mg/L)	<20	20 to 25	25 to 40	40 to 80	>80
SM (mg/L)	<30	<30	<30	30 to 70	>70

associated pollutants (Meybeck and De Marsily, 1998; Moreno et al., 2006). Moreover, heavy precipitation increases the flowrate of the river and thus improves the diffusion of oxygen in water and the dilution of the dissolved pollutants. During the low water level of 2003, an improvement in the percent saturation of dissolved oxygen consequently was noted.

Furthermore, this area has experienced a large sprawl of the food industry, and the anthropogenic factors such as the increase of the volume of industrial waste also played a significant role in the temporal variation of water quality. For example, the volume of the discharge of a textile production and that of the oil industry at Bejaia increased from 1000 and 144 m³/d in 2002 to 2533 and 401 m³/d in 2003, respectively (Statistical Data of Direction of Management and Planning of Algeria). Finally, the temperature also influences the temporal variations, because it may control several physicochemical and biological processes. In this respect, temperatures were higher in 2003 (Table 2) and probably contributed to the increase of pollution by activating dissolution and degradation during the low water level. The year 2002 was marked by a low water level, which induced low concentrations of dissolved oxygen (Table 2). Precipitation occurred only in July after our sampling (Figure 8). Moreover, the increase in biological activity during the dry period involves a degradation of organic matter by the micro-organisms, which leads to more significant oxygen uptake (Meybeck and De Marsily, 1998; Neal et al., 2005; Olias et al., 2005). For the low water level in 2004, the pollutant load decreased compared with 2003. This was the dilution caused by the weak flood event, which occurred in April (Figure 8). However, suspended matter increased in zone II, probably as a result of the strong eutrophication observed during our sampling. This also explains the decrease of dissolved oxygen and pH in this zone compared with zone I (Table 2).

Classification of Water Quality of the Soummam Wadi on a Global Scale. *Classification of Water Quality of the Soummam Wadi.* According to the criteria of the overall assessment of surface water quality (Bontoux, 1993) (Table 4), temperature, pH, and dissolved oxygen indicated acceptable water quality only in

zone I (upstream and central sites of the Soummam Wadi). The other parameters were much higher than the standards and thus highlighted the bad water quality of the Soummam Wadi (zones I and II)—in particular, at the mouth of zone II (Table 5). These observations were consistent regardless of the year studied. Consequently, the waters of the Soummam Wadi were found to be inadequate for the majority of uses, such as recreational use, irrigation, or drinking (humans and animals), and this can constitute a threat for the public health and the environment.

Water Quality of the Soummam Wadi on a Global Scale. To evaluate the quality of the Soummam Wadi on a global scale, we carried out a comparison of the measured parameters with those of some rivers worldwide. This comparison was not easy, considering that the study period, the number of sites, and the parameters were different. Moreover, in recent studies, the quality of water is expressed by an index with a value that informs about the good or bad quality, but in which the responsible parameters often are not specified, such as in the basin of Mackenzie, Canada (Lumb et al., 2006) and in Dalmatia, Croatia (Nives, 1999). Nevertheless, our comparison took into account the minimal and maximum values of each parameter for some rivers (Han in Korea, Keelung in Taiwan, Fuji in Japan, Guadarrama in Spain, Provo in the United States, and Douro in Portugal) (Table 6). The water quality is variable and generally decreases from upstream to downstream, as was the case for the Soummam Wadi. Quality is worse in the urban areas, as for the Guadarrama River near the town of Las Rozas, Spain (Sanchez et al., 2006) and in the central part of the Han River close to Seoul, Korea (Chang, 2005). Water quality was low in the areas of discharge of the effluents, as for the Fuji River, Japan (Shrestha and Kazama, 2006). The river of Keelung is very polluted downstream, with dissolved oxygen values close to zero, because of the high concentrations of nutrients (eutrophication) from agricultural practices (Wu, 1999). A reduction in abundance and in total diversity was confirmed in the lower part of the Provo River, Utah, following the reduction in the dissolved oxygen rate caused by urban and industrial sprawl (Gray, 2004). The Douro River, Portugal, is globally polluted with a high conductivity and a low

Table 5—Classification of water of the Soummam Wadi according to standards of surface water quality (Bontoux, 1993).

		1A	1B	2	3	4
Zone I	2002	pH	DO	Temperature	COD	Conductivity, SM, BOD ₅
	2003	pH, DO		Temperature		Conductivity, SM, BOD ₅ , COD
	2004	pH, DO		Temperature	COD	Conductivity, SM, BOD ₅
Zone II	2002	pH		Temperature, DO		Conductivity, SM, BOD ₅ , COD
	2003	pH	DO		Temperature	Conductivity, SM, BOD ₅ , COD
	2004	pH	DO	Temperature		Conductivity, SM, BOD ₅ , COD

Table 6—Water quality parameters of the Soummam Wadi compared with worldwide data.

River Country Sampling years Watershed area	Soummam Algeria 2002 to 2004 1125 km ²	Han Korea 1993 to 2002 (-)	Keelung Taiwan 1996 to 1997 501 km ²	Fuji Japan 1995 to 2002 3570 km ²	Guadarrama Spain 2001 to 2003 59 km ²	Provo USA 1999 to 2002	Douro Portugal 1992 to 2001 19 600 km ²
Temperature (°C)	23.9 to 24.7	14.5 to 17.5		12.8 to 15.7	13.0 to 13.7	6.9 to 8.7	14.0 to 16.0
pH	7.5 to 7.9	7.3 to 8.1	6.5 to 6.9	7.5 to 8.3	6.8 to 7.0	7.2 to 8.7	7.4 to 7.8
Conductivity (mS/cm)	7160 to 8530	151 to 727	133 to 16 803	61.6 to 257.6	390 to 410	321 to 368	209 to 374
DO (mg/L)	4.8 to 8.1	2.4 to 9.9	0.9 to 8.8	7.9 to 10.5	5.7 to 9.9	9.7 to 10.1	6.2 to 7.8
BOD (mg/L)	49.8 to 104.5	2.1 to 95.8	1.0 to 12.8	0.7 to 3.1	3.8 to 6.1		1.3 to 2.4
COD (mg/L)	74.7 to 143.5	3.7 to 51.0	3.6 to 35.6	1.9 to 4.5	12.5 to 16.3		8.0 to 10.6
SM (mg/L)	110 to 189	8.4 to 70.0		2.7 to 17.9	5.7 to 35.5	2.0 to 3.0	10.5 to 14.0

dissolved oxygen concentration near the Spanish borders, whereas the downstream water presents good quality (Bordalo et al., 2006).

The Soummam Wadi presented a pollutant load that was higher than the mentioned rivers, because measurements were made solely in a period of low water level, when the water quality was worse compared with the other seasons (Bordalo et al., 2006; Sanchez et al., 2006). This load would be less significant if measurements were carried out throughout the year, as was the case for the other rivers. However, even if we used the highest values found in the other studies (Table 5), these were found to be much lower than the values recorded for the Soummam Wadi, except for the Keelung River, where the dissolved oxygen concentration and conductivity were 0.9 mg/L and 16.8 mS/cm, respectively. Taking into account the findings of the present study, we can conclude that the Soummam Wadi is an extremely polluted river on a worldwide scale.

Conclusions

The present constitutes one of the few studies of surface water quality in North Africa. It allowed us to determine the water quality of the Soummam Wadi during a period of low water level and its spatial and temporal variability. According to the criteria of appreciation of surface water quality, this river can be classified as being extremely polluted, and its water is inadequate for most uses. Except for temperature, pH, and dissolved oxygen, which reflected appropriate water quality for the upstream and central areas of the Soummam Wadi, the other parameters (BOD, COD, suspended matter, and conductivity) were very high and reached 50, 100, and 150 mg/L and 8 mS·cm⁻¹, respectively. Therefore, this reflected poor quality of the water of the whole of the river, regardless of the year. The Soummam Wadi showed a strong pollutant load, which was organic in origin. The spatial variation highlighted two distinct zones; zone II (downstream) presented a pollutant load almost twice as high as that of zone I (upstream and central sites). This was related directly to anthropogenic factors, such as the importance of the discharge of urban and industrial waste.

A temporal variation of water quality was highlighted, with degradation in 2003. This degradation can be explained by (1) climatic factors, such as a flood event, which induced a significant increase in the pollutant load associated with suspended matter (runoff, dissolution, and resuspension of deposits), and (2) the increase of the industrial waste. When the water quality of the Soummam Wadi was compared with other rivers on a global scale, the former was found to be much more polluted. Other

studies on the scale of the watershed of Soummam will be necessary to evaluate the effect of the land use, socio-economic development, and hydro-climatic factors on surface water quality. In several countries of the world, the water quality of rivers currently is described using a quality index, such as the WQI, which is calculated using mathematical models, but there is no specific index of evaluation of the quality of the rivers in Algeria or even in Africa. Therefore, it seems necessary to develop a model like the WQI to obtain a control of the water quality that would be faster to establish and easier to communicate for better resource management.

Credits

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