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Assessment of water pollution in the semi-arid region: case watershed Wadi Saida (Northwest of Algeria)

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ABSTRACT

In this study, an up-to-date analysis was performed on pollution conditions in the Wadi Saïda drainage basin (North West Algeria). We focused on the water in the streams that drain the basin. The results include a number of quality parameters and give the spatio-temporal variations in surface water pollution indicators over a period of several years. The principal parameters related to the monitoring and evaluation of the pollution of surface water are measured and analyzed. These parameters include the suspended solids, organic matter, nitrate, nitrite in addition to biochemical oxygen demand, and chemical oxygen demand. Analysis and comparison with other basins in Algeria are also performed. In the light of the results, a plan is proposed for the land use and protection of groundwater in Saida.

Keywords: Environmental pollution; Surface water; Pollution indicators; Physicochemical analysis; Water quality; Saïda Wadi; Algeria

1. Introduction

In recent years, the issue of water has become a strategic issue for a number of countries including Algeria [1]. Indeed, Algeria is currently facing serious water shortages due to its semi-arid terrain [2], low level of rainfall [3–5], and the geographic distortion between water-producing and water-consuming areas [6–8]. Prospective studies project that the country's water deficit may reach 2.1 billion cubic meters per year, by 2025 [9].

In addition, the degradation of water reserves due to the increase in the number of sources of pollution is now a reality [10]. Today, this threat has serious consequences on the overall national hydraulic potential. So, it is now necessary, if not essential, to develop a plan to protect water resources. This plan must address surface water as well as groundwater [11,12].

In Algeria, the investigation of this problem has mobilized several scientific meetings. The most significant are those organized in collaboration with Japan international cooperation agency (JICA) (See Table 1).

These efforts led to many studies related to the pollution and the protection of water sources. Thus,

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Table 1
Major scientific meetings related to the question of pollution and environment

Agencies and organizations	Subject matter	Date
MATET-ONEDD-JICA	Protection of the coastal zone of Algiers	April 2005
MATET-ONEDD-JICA	Quality standards and efforts to protect the environment	July 2007
MATET-ONEDD-JICA	Effective management of the environment	April 2008
MATET-ONEDD-JICA	Water Environmental Protection	April 2010

Note: MATET Ministry of Land Planning, Environment and Tourism: Algerian government, ONNED: The National Observatory for Environment and Sustainable Development, JICA: Japan International cooperation Agency.

recent studies have been conducted to study the vulnerability of the surroundings of water sources. The cases of wadis in which the flow regime is often intermittent or even occasional are treated in this work (See Table 2).

Our study particularly cites studies assessing the impact of pollution on surface waters in semi-arid areas [19] or on groundwater [20]. Modern techniques like using digital terrain models for pollution monitoring are also presented [21]. Other studies with experimental use of marine macrophytes for the calibration of the pollution are also made [10]. Finally, we note an interesting study addressing the evaluation of legislation on the protection of the environment [22].

In order to get advantage from the experiences of others, the government of Algeria has worked on an international scale and many plans have technical international cooperation, as shown in (Table 3).

Like other regions of Algeria, the Saïda region has experienced great upheaval regarding urbanism and industry, over the past few years. This state has led to the need for an up-to-date analysis of the current situation regarding pollution and its sources. The required update is particularly important, for the Saïda region, due to the limited hydrologic resources and considerable economic impact of its water reserves.

Indeed, Saïda has always been known for its mineral waters. These waters are extracted from the Saïda water basin, which is among those ranked in Algeria (ranked 10th out of the Algerian water basins with a potential capacity of over 10 million m^3) [23]. Until recently (2003), the groundwater in the basin region, which extends over an area of 800 km^2, was used to supply the town of Saïda with potable water and was used in Saïda industrial zone, in addition to serving as source for the production of Saïda's mineral waters [24].

The present study is, therefore, justified by the need for an up-to-date analysis of pollution conditions in the region. The area of interest is defined by the site referred to as the Wadi Saïda drainage basin, which has the advantage of covering a large part of the surface of the Saïda water reserves (sources of Saïda mineral waters). It also contains the Saïda waterway, which is the drainage basin's main thalweg and supplies most of the built-up areas in the region.

Table 2
Targeted papers relevant to pollution in wadis of Algeria

Reference	River basin or region	Ephemeral or intermittent	Main contribution
Afri et al. [13]	Rhumel Wadi, Constantine	intermittent	Contamination by trace metals due to sediments discharge
Bordjiba et al. [14]	Safsaf wadi, Marhoum wadi and Zeramna wadi, Skikda	Both	Hydrocarbons pollution effects on water quality
Djorfi et al. [15]	Zied Wadi, Annaba	intermittent	Impact of urban discharge on water quality
Nait Merzoug et al. [16]	Medjerda Wadi, Souk Ahras	intermittent	Impact of wastewater discharges on Water quality
Rouabhia et al. [17]	El Ma El Abiod, Tébessa	Ephemeral	Impact of pollution on the Hydro geochemistry of groundwater in a semi-arid region.
Kadour et al. [18]	Bechar Wadi, Bechar	Ephemeral	Impact of domestic wastewater discharge on the environment

Table 3
Typical examples of cooperation plans

Agencies	Subject matter	Date or period	Budget
European commission and Algerian government	Protection of the coastal zone of Algiers	August 2012	35 million euro
Ministry of Environment of Japan – ONEDD-MATET	Capacity Development of Environmental Monitoring in Algeria	2005–2008	260 million yen

Note: ONEDD: The National Observatory for Environment and Sustainable Development, MATET: The Ministry of Land Planning, Environment and Tourism Algerian Government.

Our study relates to the Wadi Saïda drainage basin, both upstream and downstream. The sewage system for the built-up areas located on the drainage basin joins the Saïda waterway at the end of its upstream portion at an average rate of around $15 \times 10^4\,m^3/day$. The waste content flowing through this system constitutes a worrying source of pollution [25].

The objective of the present study was, therefore, to determine the nature of this pollution and its impact on the environment and on the water quality based on the results obtained from the physicochemical analysis of surface water.

2. Presentation of the site

2.1. Geographical information

The Wadi Saïda drainage basin is located in northwestern Algeria. It forms part of the large Macta basin, one of the 17 great drainage basins in Algeria, which has a surface area of $14 \times 410\,km^2$. The Wadi Saïda basin occupies the south-eastern part of the Macta and its structure is that of a south-north trending valley. It extends into the Daia Mountains and the Saïda Mountains in the south and the east. The altitude of the basin varies between 520 and 1,238 m reaching a height of over 1,238 m in Djebel d´El-Aassa in south-western Saïda [8].

The portion of the drainage basin studied here is bordered in the south by the Ain-El-Hadjar limestone plateau, in the north by the Wadi Saïda valley, in the east by the Hassasnas depression and in the west by the length of Djebel Abdelkrim (Fig. 1).

The Wadi Saïda basin covers an area of $517.8\,km^2$ with a perimeter of 131.2 km. It has a capacity index of 1.61. It is circular and slightly elongated in shape and is oriented towards the geographical north. Its ground coordinates are (35˚00 to 34˚45) north and (00˚00 to 00˚15) east. It is divided into four subbasins: Tebouda, Ain Nazreg, Massif, and Saïda. Each subbasin is drained by the waterway with the same name. Their characteristics are shown in Table 4.

2.2. Geology, vegetation and topography

The meridional part of the Wadi Saïda basin is mainly made up of dolomites and limestone dating back to the Bajocian–Bathonian age. This formation has a thickness of up to 150 m and is highly karstified and fissured. It is permeable and contains a sizeable aquifer system. Quaternary sediments and deposits containing coarse fragments and silt can be found along the Saïda valley. In places, the formation contains groundwater. In the rest of the valley, Callovo–Oxfordian clay can be found. The basin is mainly made up of alternating layers of clay and sandstone. In places, the layers of sandstone contain small aquifer systems [26].

The basin studied here is mainly occupied by agricultural spaces, extended by a forest covering which is particularly dominated by populations of Aleppo Pine and Holly Oak [27].

The topography of the basin is marked by significant altitude differences, with a relatively high minimum altitude compared to the altitudes of adjacent areas of the basin. This leads to a relatively high runoff. The different hydrographics show a less-dense, well-organized, and fairly ramified stream system. The morphometric parameters of the basin are shown in Table 5.

2.3. Climate and hydrology

The Wadi Saïda basin is characterized by a semiarid climate with cold, wet winters and hot, dry summers. The average monthly temperatures range from 7.6 to 26.6˚C (Fig. 2). The Wadi Saïda basin, therefore, is subject to two main characteristic seasons during the year, which seem to split the climatic cycle into two equal but irregular periods: a very cold continental season from November to April during which the

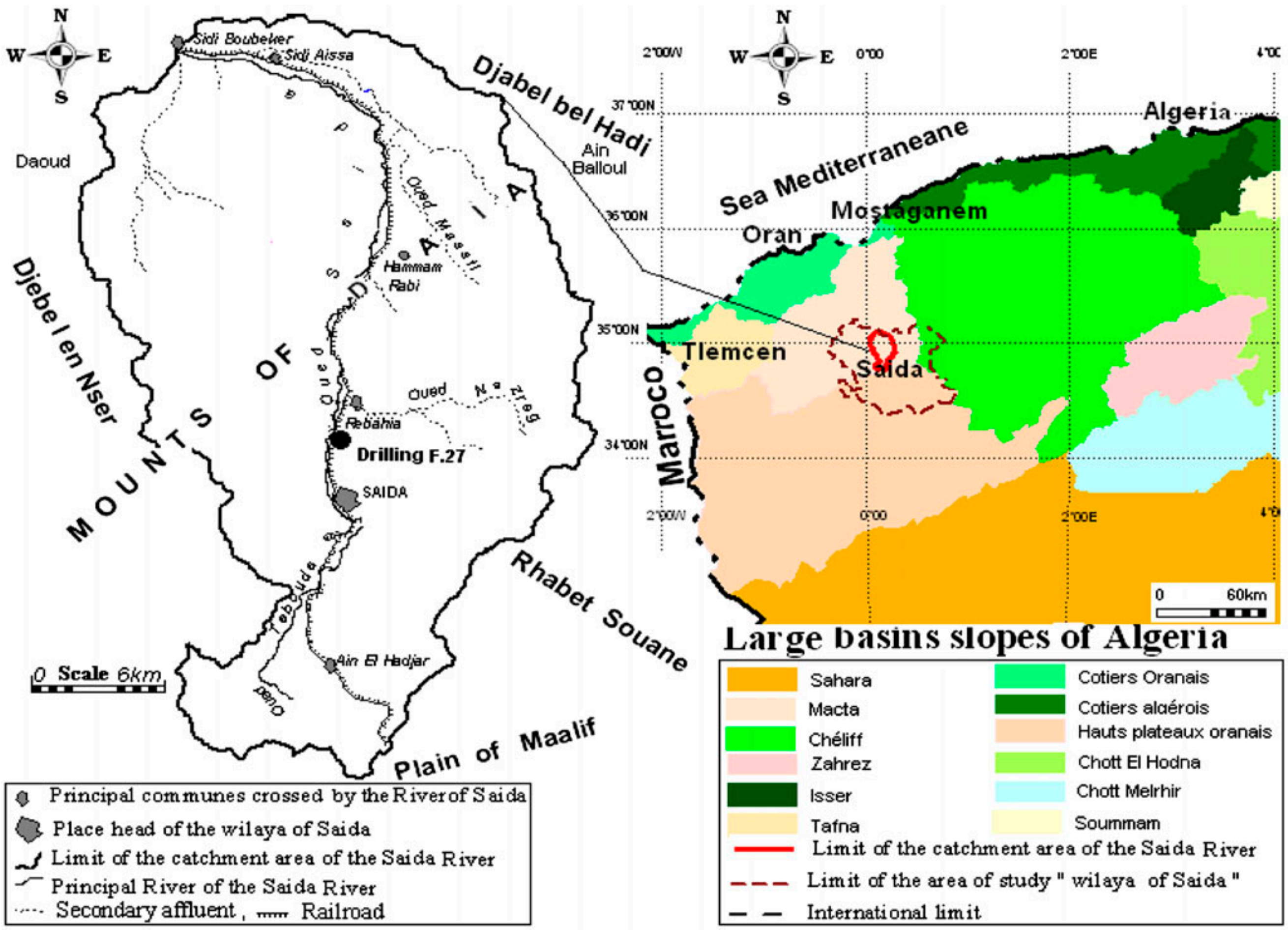

Fig. 1. Geographic location of the Wadi Saïda drainage basin (North West Algeria).

Table 4
Characteristics of the sub-basins of the Wadi Saïda drainage basin

Sub-basin	Area (km^2)	Waterway	Cumulative length of thalwegs (km)
Wadi Tebouda	94.16	Tebouda	12.60
Wadi Saïda	176.35	Saïda	43.5
Wadi Nezreg	67.34	Nezreg	10.82
Wadi Massif	35.84	Massil	21.92

average minimum temperature approaches 2.9˚C; and a hot, dry season with a maximum temperature of around 35.7˚C under the influence of the Saharan system.

However, according to the National Agency of Hydrologic Resources (ANRH) [28], the absolute maximum temperature in the summer can reach 42 to 47˚C during a Sirocco. In the winter season and under the continental influence, temperatures sometimes reach a low of 0˚C, which enhances formation of frost and ice.

Several other studies have highlighted the characterization of the climate into two main periods relating to temperature [29,30].

The annual rainfall appears to be relatively irregular with an average of 332.3 mm (Fig. 3) or a deficit of 104 mm compared to the average annual rainfall reported by Seltzer [18] for the period between 1913 and 1938, during which the deficit stood at around 436 mm. This rainfall shortage has been noted by other authors who have referred to the climatic fluctuations and arid tendencies of the region's climate [27,30,31].

Table 5
Characteristics of main morphometric variables in the Wadi Saïda drainage basin

Variables	Symbols	Units	Results
Surface	A	km^2	517.8
Equivalent perimeter	P	km	130.8
Gravelius coefficient	KC	–	1.61
Length of equivalent rectangle	L	km	56.2
Width of equivalent rectangle	L	km	09.2
Average altitude	H_{avg}	m	847.07
Overall slope index	I_g	%	0.92
Roche slope index	I_s	%	0.35
Average slope	I_{avg}	%	1.12
Total steepness	S	m	630
Drainage density	D_d	km/km^2	2.29
Time of concentration	TC	Hour	12 h and 11 min

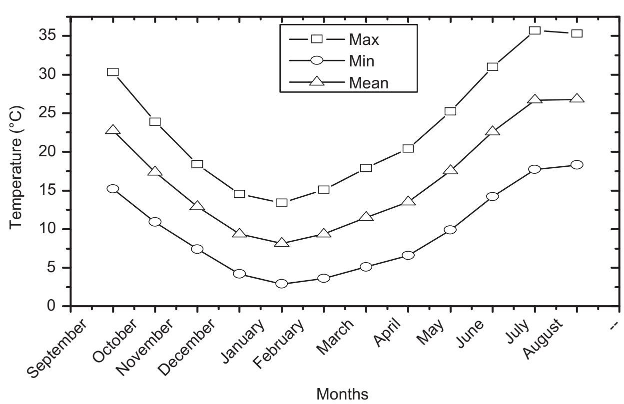

Fig. 2. Temperature variations in the Wadi Saïda drainage basin.

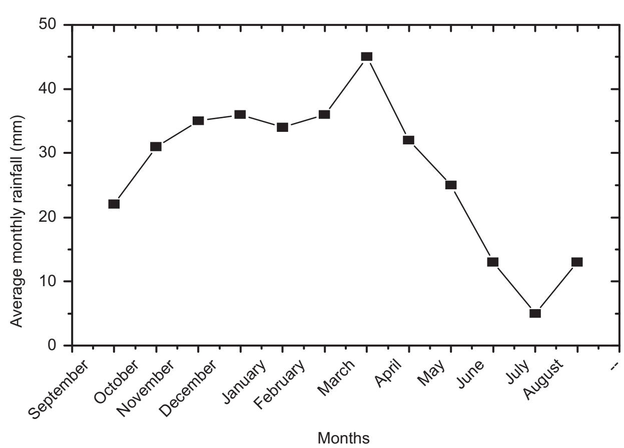

Fig. 3. Inter-annual rainfall variability between 1960 and 2005 in Wadi Saida drainage basin.

During the period from 1930 to 1999, Khaldi [8] reported the inter-annual variability of rainfall in western Algeria, which includes the Saïda region. This period was characterized by many years of rainfall deficit. Shortages were observed during the 1940s, 1980s, and 1990s. The author highlighted the persistence of total water deficits, which continued over several consecutive years. However, it is important to note that the climate type is not always constant and may be subjected to turbulent cyclical variations due to the climatic changes which have taken place in the recent years [1,6].

The Wadi Saïda waterway starts about 15 km south of the town of Saïda in the Ain El Hadjar hills and extends in the north direction over a total distance of more than 40 km. Several sources feed into it. The most important sources are Ain Tebouda (37 l/s), Ain El Baida (32 l/s), Sidi Maamar (23 l/s), and Vieux Saïda (12 l/s). The average annual flow rate of water to the outlet is estimated by 1.76 m^3/s [28].

The water flow regime is characterized by a strong inter-monthly and inter-annual irregularity. During wet periods, the flow increases with rainfall reaching up to 4.8 m^3/s in times of flooding. However, during dry periods, which usually extend from May to October, water flow rates are low and may be zero in the upstream part of the waterway. Thus the rate differs depending on whether it is measured in the upstream or downstream parts. In the upstream part, the discharges of wastewater from urban and industrial areas influence the water flow regime.

Based on the definition presented by Matthews [32], the Wadi Saïda system is intermittent, particularly in its downstream part. The mentioned author considers waterways with flowing water less than

Table 6
Location of sampling sites

Number of sampling sites	Sampling sites	Location	
		Longitude: X	Latitude: Y
1st sampling point	Upstream from drainage basin	266 810	172 249
2nd sampling point	Downstream from town of Saïda	265 718	175 140
3rd sampling point	Upstream from industrial zone	266 107	177 248
4th sampling point	Towards basin outlet	265 794	181 544

20% of the year to be temporary, and those with a water flow between 20% and 80% of the year to be intermittent.

3. Method and analysis

The aim of the experimental procedure was to evaluate the physicochemical characteristics of the surface water in the Wadi Saïda drainage basin by measuring and analyzing samples, which reflect the nature of the pollutants as best as we can.

Ten sampling points (sources, boreholes used for drinking water, and wastewater discharge points) were chosen in the Wadi Saïda downstream drainage basin. These sites represented the observation network, the objectives being to determine the pollution conditions, identify the sources of pollution, and ultimately, evaluate the impact of the pollutants on the quality of the water resources (Fig. 1). The sampling sites were selected according to two main indications. The first takes into account the morphology of the basin. The second indicates the most sensitive and significant sampling sites (like sensitive areas and pollution spots) in the Wadi Saïda drainage basin. Table 6 shows the location and the information of the sampling sites.

Samples were collected following the chronology shown in Table 7. The chronology is split into two periods (dry and wet period). The sampling periods correspond to the most pollution-sensitive periods over three consecutive years (2005–2007) (high-water-level period and low-water-level period). Therefore, for the dry period, we chose the months of May and August when temperature is at its highest levels. These high temperatures promote micro-organism growth, good oxygen dilution and an optimum yield for purification. For the winter season, we chose November and February because during these two months, rainfall reaches its peak and the dilution is high.

Table 7
Chronology of sampling analyses

Wet period	Dry period
November 2005	May 2006
February 2006	August 2006
November 2006	May 2007
February 2007	August 2007

The experimental procedure used to determine the physicochemical properties was carried out with reference to previous studies [33,34].

The design of the machine used to collect samples was also inspired by a previous study [35]. The sampler was inserted at 50 cm to 1 m, depending on the sampling site and on the water flow depth. The depth was taken into consideration in order to avoid any bias arising from surface water variations. For each site, 2 L of water were collected in polyethylene bottles. The physical and organoleptic measurements were performed on site. Chemical analyses were carried out in the laboratory in accordance with the required standards. Sources of standards of water quality mentioned in this publication are those indicated by statutory instruments [36]. The principle quality indicator of the water is tested. This parameters such as, temperature, pH, dissolved oxygen, organic matter, turbidity, and electrical conductivity (salinity) are important indicators of ecosystem health and can provide a measure of damage attributed to human and industrial activity [37].

4. Results

4.1. Presentation

The results of the analysis of wastewater are shown in Table 8. The main pollution-indicating variables are provided. The results are grouped together according to wet and dry periods. This is particularly useful for determining the influence of low water levels. Suspended matter (SM: corresponding on the part of solid that represents the visible and settleable particles), total solids (TS: this indicator expresses the mineral levels collected after evaporation of 1 L of water

Table 8
Physicochemical variables of surface water in the Wadi Saïda basin

Variable	Units	Dry period				Wet period			
		Min.	Avg.	Max.	σ	Min.	Avg.	Max.	σ
Temp.	℃	25	27.7	28	0.5	4.5	16.4	20.2	20
pH	-	8.15	8.32	8.90	0.4	7.3	7.94	8.47	0.75
Cond.	μS/cm	147	174	195	20.5	34.2	144.6	255	34.2
Ca^{2+}	mg / l	140	157	178	15.9	70.5	102.5	131.0	14.7
Mg^{2+}	mg / l	120.7	137.6	150.7	12.8	9.6	73.3	119.8	6.3
K^+	mg / l	12	21.8	33	25.5	5.8	15.65	25.5	11
Cl-	mg / l	161	231	257	46.7	27	107	186	27
SO_4^{-2}	mg / l	195	215	235	23	23	113.5	204	20
$H(CO_3^-)$	mg / l	365	390	423	69.5	69.5	210.6	351.8	27
NO_3^+	mg / l	50	71.9	85	4.54	70	81.3	94	3.3
NO_2^-	mg / l	0.02	6.01	1.2	0.09	0.07	0.08	0.09	0.03
NH_4^+	mg / l	0.09	0.35	0.5	0.04	0.08	0.1	0.4	0.01
Po_4^{-3}	mg / l	16	18.6	25	7.7	7.7	18.6	24.9	4.2
Zinc	mg / l	0.02	0.09	0.16	0.9	0.26	7.7	15	8.2
Iron	mg / l	3.9	4.4	5	0.4	0.4	8.7	17	0.4
Copper	mg / l	30	93.5	157	68.6	60.6	71.2	81.8	50
TS	mg / l	29	67	261	206	49	348	1,110	240
SM	mg / l	87	281	631	27	118.6	650.7	1,507	368
DOC	mg / l	170	270	370	97.9	30	191.1	293	89
BOO_5	mg / l	40	112	218	46	24	51	76	45

Note: σ: standard deviation.

subjected to 180 ℃ [38]), organic matter (OM: which depends on both biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD); i.e. M.O = (2 BOD_5 + COD)/3) [39] and nitrates provide interesting pollution indications of the total flow load in the Saïda waterway and help predict the quality of the wastewater. The suspended mater and the total solids are determinates from the indications given by Smith and Geenberg [40].

The analysis of the measurement data presented in Table 8 indicates particularly that the concentrations rate relatively high than most parameter indicators of pollution. The concentration of certain substances is largely superior to that of content threshold set by Algérian regulation [36]. This is particularly in the case of heavy metals (Iron, Copper, and Zinc).

Also, the results suggest that the concentrations of the other variables of pollution (nitrates [NO_3], phosphates [PO_4], the BOD_5, COD, OM, and SM) do not comply with standards specified by the Algerian regulation [36].

This applies in the case of the wet period than in the case of the dry period. However, it is much more significant in the latter period.

We note also that in dry period, the contents of the majority of pollution parameters are higher than those of the wet period. The low water level is generally associated with increased concentration. On other hand, the flow promotes the dilution of different chemical compounds. This justifies the decrease in the concentration.

The values of the standard deviation associated with the measurement data show clear dispersions including measures taken during the dry weather conditions. The main reason for this dispersion is the low flowrate. On the contrary, the dilution caused by the flow during the wet period, seems to better stabilize the concentration of the majority of physicochemical parameters.

There appears to be a degradation of water quality in the Wadi Saïda waterway in the presence of pollutants. Thus, in terms of the parameters associated with mineralization, the analyses indicate that iron, zinc, and copper are the main causes of contamination.

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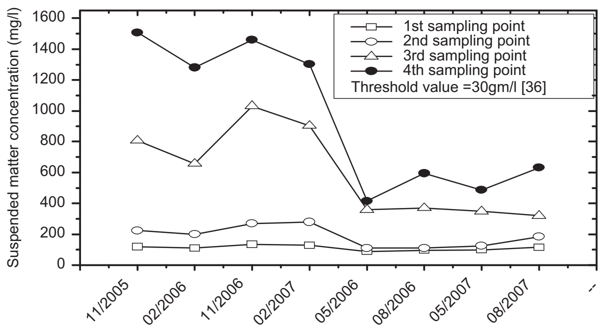

Fig. 4. Spatio temporal evolution of suspended matter in the wadi.

The results presented in Fig. 4 show that this load increases downstream. This increase seems to be more obvious during wet periods compared to dry periods and can be explained by the arrival of wastewater from urban areas and industrial zones. The increase can also be referred to the influence of occasional high-momentum wastewater discharge which promotes the re-suspension of solid particles deposited in the waterway bed. Moreover, the increased load in August 2007 can only be explained by the rainfall from storms observed during the sampling period.

The same remark is true for evolution of total solids in watershed (See Fig. 5).

In addition, even in wet periods, the sediment load in November is higher than that in February. Indeed, in November, rain showers are very heavy and aggressive. They fall on dry ground that has been damaged by long periods of aridity, and therefore, cause significant erosion. The sediments produced by this severe erosion are quickly transported by a strong stream into the water flow which, in turn, transports them to the basin outlet [41].

During dry periods, the maximum concentration of SM in the region is of 631 mg/l. It reaches a value of 1,507 mg/l during wet periods, with a seemingly high mineral fraction. However, during dry periods, the organic fraction of SM becomes predominant. The same finding has been reported for the Wadi Tafna basin (Northwestern Algeria) [11].

Figs. 6–8 outlines the spatio-temporal variations in some of the elements responsible for the degradation

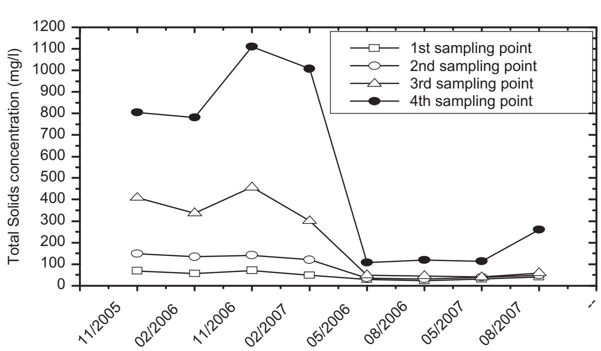

Fig. 5. Spatio temporal evolution of total solids in the wadi.

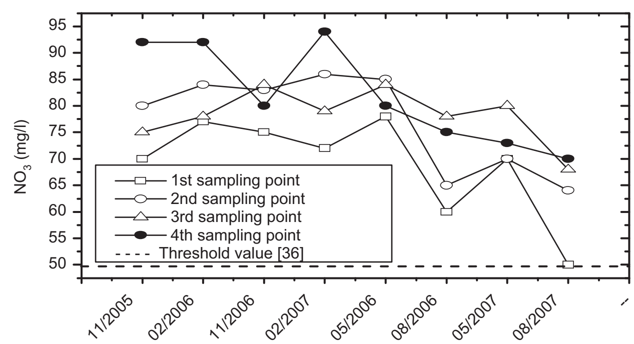

Fig. 6. Spatio temporal evolution of the nitrates [NO_3] in the wadi.

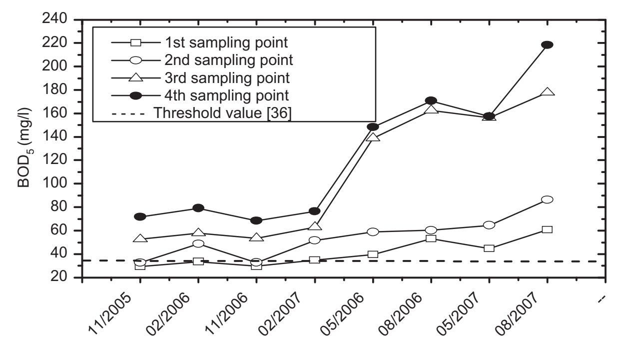

Fig. 7. Spatio temporal evolution of the BOD_5 in the wadi.

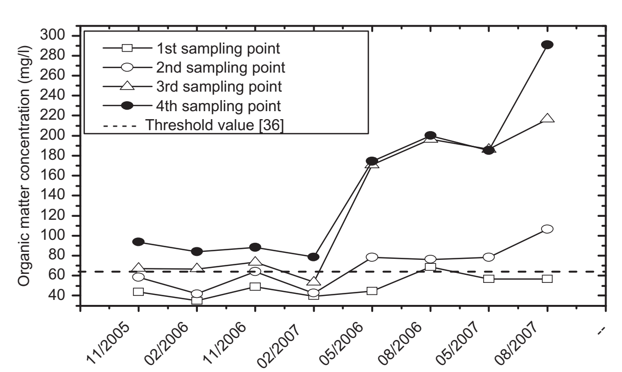

Fig. 8. Spatio temporal evolution of organic matter in the wadi.

Table 9
Biodegradability ratio of Wadi Saïda waste water

Sampling date	Upstream from drainage basin	Downstream from town of Saïda	Upstream from industrial zone	Towards outlet of drainage basin
22/11/2005	4	1.6	2.2	2.1
22/02/2006	2.8	2.1	2.6	2.4
22/05/2006	2.1	1.3	1.5	1.5
22/08/2006	2.2	1.2	1.5	1.5
22/11/2006	2.6	1.9	2.4	2.4
22/02/2007	2.5	1.6	1.5	1.5
22/05/2007	2.1	1.3	1.5	1.9

of water quality in the Wadi Saïda waterway (i.e. nitrates, biochemical oxygen demand, and organic matter). The high levels of nitrates in the wastewater discharged into the Wadi Saïda drainage basin clearly exceed the specified standards (50 mg/l) [36]. The concentration varies downstream with values ranging between 50 and 94 mg/l. This may be explained by the fact that the soil in the Wadi Saïda basin is dominated by intensive market gardening, in addition to the influence of wastewater from urban areas situated in the downstream part of the waterway.

In terms of indicators of organic material, their variation indicates that the associated concentrations are significantly superior to the thresholds established by standards. Results of the analyses indicate that levels lie between 24 and 218 mg/l for BOD_5 and between 30 and 370 mg/l for COD. The corresponding concentrations of organic matter are 28 and 290 mg/l. The results for biodegradability are illustrated in Table 9. The results of the analyses suggest that the biodegradability coefficient is in the interval of 2< (COD/BOD5) <5 in the upstream part of the Wadi Saïda drainage basin. This indicates that the natural purification process is not very efficient upstream. The biodegradability ratio is below 2 in the downstream part, which indicates that the wastewater can be naturally purified. However, the biodegradability coefficient was in the interval of $2 < (COD/BOD_5) < 5$ on 22 February 2006 which means of natural purification of wastewater at this date was insufficient. For the third and fourth sampling sites, since the biodegradability coefficient was in the interval of $2 < (COD/BOD_5) < 5$ during the winter period, the natural purification process could be deemed less efficient. For the summer period, however, the biodegradability ratio was below 2. In this case, natural water purification can be easily performed.

4.2. Analysis and discussion

The results of the wastewater analyses revealed the presence of nitrates, which are a strong indicator of pollution. Nitrate concentrations increase downstream, more precisely, in the waterway near the cemetery, downstream the basin. This may be explained by the fact that the soil in the Wadi Saïda basin is dominated by intensive market gardening and by the nontreated urban and industrial wastewater. Indeed, the analyses of the wastewater revealed the presence of a significant quantity of nitrates (94 mg/l).

Additionally and importantly, traces of metals such as copper, iron, and zinc were found in the wastewater. The presence of these metals is a strong indicator of the degradation of surface water quality in the Saïda region and may be partially explained by the inefficiency of certain wastewater treatment plants, particularly those, situated in the industrial zone.

The presence of organic matter confirms the degradation diagnosed. There were also worrying levels of phosphates at all the sampling sites.

The results obtained from the wastewater analyses, therefore, depict a worrying situation in terms of the state of the Wadi Saïda waterways. It is also clear that urban and industrial activities in the region pose a dangerous threat. If protective measures are not taken, the continual degradation of the quality of surface water, without even discussing the quality of groundwater in the region, will undoubtedly lead to a loss of the town's precious natural heritage, namely the Saïda mineral waters.

The state of the surface water in the Saïda region is not an isolated case in Algeria. Indeed, a number of studies have highlighted the degradation of surface water quality in Algeria [1,6,11,12,42].

A classification method is applied for our data processing and for the evaluation and comparison of the analyzed data. For each sampling site and

Table 10
Data from spatio-temporal measurements (mg/l) of pollution variables and quality categories of samples from Algerian waterways

Ref.	Bassin	*Measuring station*	Wadi	Excellent quality					Good quality					Fair quality					Poor quality					Excessive pollution				
				No_2 <0.1	No_3 <5	NH_4 <0.1	PO_4 <0.2	DCO <20	No_2 0.1 à 0.3	No_3 5 à 25	NH_4 0.1 à 0.5	PO_4 0.2 à 0.5	DCO 20 à 25	No_2 0.3 à 1	No_3 25 à 50	NH_4 0.5 à 2	PO_4 0.5 à 1	DCO 25 à 40	No_2 1 à 2	No_3 50 à 80	NH_4 2 à 8	PO_4 1 à 2	DCO 40 à 80	No_2 >2	No_3 >80	NH_4 >8	PO_4 >2	DCO >80
–	Oued Saida	Saida	Saida													0.5			1.2						94		25	370
[49]	Haut Tafna	ST160426	Tafna												32			37.4			2.4							
	Isser	ST160614	Isser																	55	7.4							56.1
	Mouillah	ST160202	Mouillah																						110	53		136
[41]	Hammam Boughrara	Hammam Boughrara	Tafna et Mouillah							11.6											5.4			9			2.8	116
[20]	Cheria	A/ Babouche	Oued Cheria																			1.64		5	100	10		
[46]	Zit-emba	Oued Ali	El-hammam		1.1	0.03							20.08				0.5		1.8									
[40]	Kébir-Rhumel	Constantine	Rhumel						0.1	11.9																15.2	6.96	103.7
		Grarem	Rhumel						0.14	23.5											3.93		76.3				3.42	
		El Ancer	Kébir	0.08																								
	Seybouse	M. Rochefort	Cherf	0.03																								
		Medjaz A II	Bouhamdane	0.01	3.74	0.02						0.23						25.6										
		Mirebeck	Seybouse Maritine	0.07						8.23						0.71						1.29						89.2
	Cotiers	O. Missa	Djendjenne	0.01	3.83	0.05											0.63						46.3					
		Zardizas aval	Saf-saf	0.02						5			21.3			0.77	0.66											
		Ain Cherchar	Kébir Ouest	0.07						17.1											4.73		55.6				3.08	

Note: [-] Present work, [52]. Tidjani et al. [44]: Tabet Helal and Ghellai [20]: Baali et al. [49]: Belhadj [43]: Mebarki.

respective waterway, this method consists of arranging the values of each of the five pollution parameters (NO_2, NO_3, Ammonium NH_4, PO_4 phosphates, and COD) into five categories of water quality (excellent, good, satisfactory, poor, and excessive pollution). The overall category for a sampling site or respective waterway corresponds to that of the parameter with the most unfavorable quality category [43]. The advantage of this method is that it is both, selective and exhaustive.

A similar classification method has been used by the ANRH [30–43]. In addition to the previously considered parameters, the ANRH takes into account BOD_5, OM, and bottom water oxygen. This method, which is often used for the qualification of surface water in Algeria [44], specifies four categories of quality (good, average, polluted, and much polluted). Other classification methods have also been proposed [45]. All these methods are consistent with the philosophy and the technical considerations cited in the specialized literature [46–48].

The results of the measurements of the Wadi Saïda pollution parameters are provided in Table 10. They are presented beside data from the literature relating to other Algerian waterways. Given that the sampling dates differ from case to case, the table only serves to provide an indicative comparison. As shown in the quality grid illustrated by the table and remembering that the overall quality category corresponds to the variable with the most unfavorable quality category, most of the waterways presented (9/16) are considered as having excessive pollution, Wadi Saïda included. The rest (4/16) falls into the poor pollution category. If the waterways presented are considered as being representative samples of the Algerian waterways, they are all characterized by worrying pollution indices. However, the quality seems to improve slightly for those in the eastern part compared to the rest of the country.

The indicative analyses carried out by the ANRH during the measurement campaign in 1990 already raised concerns about the water quality in the waterways feeding into several dams in North Algeria such as the Ghrib, Khedarra, Hamiz, and Derdeur [50].

For the analyses carried out in 1991–1992, Boudjadja [12] revealed signs of nitrate contamination for the Mazafran, Cheliff, Hamiz, and Ghrib waterways. He reported nitrate levels in excess of 50 mg/l.

Overall, this finding is consistent with conclusions drawn in other reports [30 and 43]. These reports found that, out of 11 hydrographic basins, seven were characterized by poor or even very poor water quality. Thus, in the western region of the country, considerable portions of the Tafna, Cheliff, Mina, Muoilah, Sarno, and Mebtoul waterways are affected by pollution [51–53].

A study dealing with the centre of Algeria confirmed the degradation of the majority of the waterways: 82% according to [54]. The entire El Harrach waterway is cited as being polluted [55,56]. In the east of the country, significant parts of the Mazafran, Rhummel, West Kébir, and Seybouse waterways are also polluted [43,57].

These findings are further confirmed for additional case studies and for larger high scales. We mention for example, the study of Tafna drainage basin made by Hadjel and Djediai [45]. In their analyses, the authors confirmed the degradation of water quality in the sub-basins of Mouillah and Hammam Boughrara. A very strong organic type of pollution was found.

The conclusions of the study, on the quality of dam waters in Algeria by the ANRH in 2000 raised the same issues [42,43]. The results from this study are illustrated in Table 11. About 41% of all the dams exploited at that year were characterized by poor water quality, whereas 25% of the dams were considered as having an average level of pollution.

The same findings were later reported in several case studies including the Sikkak dam (North West Algeria) [58]. Based on data relating to the physical and organic quality of the surface waters, Benmia and Auabed estimated that 89% of the dams in Central Algeria can be described as excessively polluted [54].

Table 11
Water quality in Algerian dams according to the ANRH [42,43]

Region	Average quality	Polluted	Very polluted	Not observed	Total
Oranie-Chott Chergui	1	1	7	1	10
Chellif-Zahrez	2	4	3	3	12
Alger-Soummam-Hodna	5	1	1	4	11
Constantinois-Mellègue	5	4	0	4	13
Sahara	–	–	–	5	5
Total	13	10	11	17	51

Based on the presented analysis, it is very clear that the alternation of natural milieu, especially the water resources, presents an important problem in Algeria today. The corresponding economical consequences of this problem are increasing every day. In an expert report [59], it is shown that the costs associated with the degradation of the environment were evaluated between 1.5 and 3.7 billion dollars per year, which is equivalent to 3 and 7% of the average gross domestic product (GDP). Also, there is the influence which has negative effects on public health and long-term degradation of natural ecosystems caused by such situations. The most urgent measures in terms of reducing costs are those related to the treatment of wastewater and protection of water resources. Also, we highly recommend educational and social activities in order to sensitize and aware the society [60].

Concerning the treated case as a practical example in the present study, it seems that the conservation of a healthy ecosystem in the drainage basin requires the installation of a protection plan that gathers the regulatory procedures and the technical program of the pollution removal of the wadi of Saïda.

This program is presented mainly by appropriate actions that point to determine a protection perimeter for geographic zones that are defined as sensitive areas.

5. Regulatory framework for prevention and protection against pollution

In Algeria, the political action of environmental protection has been truly initiated only from the early eighties [60]. Indeed, the first environmental framework legislation was developed in 1983 [61]. This law establishes the general principles of management and environmental protection including protection of water resources.

The protection component of the environmental framework on water resources has been specifically enhanced by the adoption of the law on water code [62], amended in 1996 [63] and then 2005 [64].

The provisions for rigorous monitoring of pollution sources are regulated.

The importance of this law lies in the fact that it has large sections devoted mainly to:

- The environmental management of water resources,
- Prevention and protection tale pollution, and
- Sanitation management.

Before they are released into the environment and degrade, the wastewater must always obey the standards established to protect sensitive loads against all types of pollution.

To do this, they must be transported to treatment plants where they undergo several stages of processing depending on the flow of their pollutant load and the sensitivity of the receiving environment. The guideline values for particular physicochemical properties are required.

The executive decree n°., 93–160 [65] regulates discharges of liquid effluents. Limit values are established. These values are to be strengthened by a new regulatory text. He is the executive decree no. 06–141 [36].

Established standards and guides are comparable to those given by the French regulation (Decree on withdrawals and water consumption as well as emissions of any kind of classified installations for environmental protection subject to authorization [66]). This is in accordance with Directive 2006/11/EC, European Directive [67].

6. Conclusion

The main objective of this study is to determine the nature and impact of pollution on the quality of the water in the Saïda region. We devised an experimental procedure to conduct an up-to-date analysis of surface water in the Wadi Saïda drainage basin.

The sampling sites were identified according to the location of human, agricultural, and industrial activities. The samples were collected during two highly contrasting periods of the year (dry season and wet season).

From the results obtained, we were able to reveal, by physicochemical analyses, the degradation of the surface water. We discovered that the physical, organic, mineral, and nitrogenous properties of the surface water all seemed to be affected. The pollution was caused by industrial waste, streams of incoming matter from agriculture, dirty water from human dwellings, and discharge from obsolete water-treatment plants, all of which affect the environment in the Wadi Saïda drainage basin.

The main pollutants are nitrates and the levels observed were sometimes worryingly high. However, the level remains comparable to those observed in other areas of the region. The same applies to the type and quantity of the other pollutants.

There is a justifiable need to develop a rescue plan for the Wadi Saïda water basin. Technical and regulatory measures are both strongly advised to ensure the preservation and protection of the waters in the Saïda region. These are essential recommendations for the preservation natural sources and quality mineral water from which Saida region made his notoriety.

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