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Diversity of Diatom epilithons and quality of water from the subbasin of Oued Mina (district of Tiaret, Algeria)

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After two years of work, we have explored most of water systems of the western region of Tiaret areas; represented mainly by the Oued Mina and Oued Louhou. The study started with a sampling, executed successively during Autumn and Spring, with the aim to identify the diatomic flora on the first part; and to analyze the ecology of these diatoms on the other part, regarding the Environmental factors through canonical correspondence analysis in order to estimate the organic pollution index. Our results highlighted 104 inventoried species, distributed on 20 different families, with 13 new taxa as a new record in Algeria: *Brachysira microcephala, Eunotia cataractarum, Hippodonta capitata, Luticola kotschyi, Luticola nivalis Neidium binodeforme, Neidium ampliatum, Neidium dubium, Nitzschia bita, Nitzschia sinuata var. Tabellaria. Pinnularia obscura, Stauroneis gracilis and Surirella crumena*. Otherwise, the calculation of the Organic Pollution Index OPI along the describing stations shows a degraded condition of the quality of water in Oued Mina, due to the discharge of domestic and industrial waste water from agglomerations. Four functional groups of the diatoms were revealed. A functional group *A* is presented by 21 species. The high trophy preference is a most important ecological property of the functional group *A*. Species which constitute this functional group are mainly eutraphentic. A functional group *B* is presented by 10 species. Species which constitute this functional group are mainly acidophilous. A functional group *C* is presented by 20 species. The preference of the low nitrogen level is a most important ecological property of the functional group *C*. A functional group *D* is presented by 8 species. Species which constitute this functional group are mainly facultatively nitrogen-heterotrophic taxa needing periodically elevated concentration of organically bound nitrogen.
Key words: Diatoms; ecological factors; canonical correspondence analysis; Organic Pollution Index OPI; pollution

Introduction

Algeria presents a high vascular plants floristic diversity, largely studied and known, broadly speaking. However, for the Cryptogamic flora, the studies are very few and rare. Indeed, the works done in this field still show gaps in taxonomic knowledge. Nevertheless, in recent years, some researchers have undertaken to study and enrich the diatom inventory in Algeria (Lange-Bertalot, 2001; Chaïb et al., 2011; Chaïb, Tison-Rosebery, 2012; Nehar et al., 2015).

However, studies on benthic diatoms of Algeria remain really rare, although such studies in Algeria were done more than a century ago by Mountain in 1846 and Ehrenberg 1854 (Nehar et al., 2015), taken recently by (Baudrimont, Recherches, 1974) which contributed to the enrichment of Algeria's freshwater diatoms inventory.

In this perspective and to contribute modestly to the enrichment of knowledge on the freshwater diatoms ecology, this work focuses on the study of environmental influence factors on the diatomic flora to estimate the diatomic indices to assess the water quality of the Tiaret region.

Material and methods

Study area

Tiaret district is subject to a semi-arid climate with an annual pluviometry between 300 and 400 mm, with a seasonal fluctuation of rains ranging from 157 mm in winter to 31 mm in summer (Miara et al., 2013). The length of the hydrographic network of the wilaya of Tiaret is closed 1938 Km, with 1049 Km for intermittent wadis and 889 Km for permanent ones, with mainly the Louhou wadi which drains the subbasin of the mina in its Southern part and the Mina Wadi, which is among the main tributaries of Chelif wadi and which travels a distance of approximately 90 km between the dam of Bakhada (Tiaret district) and Sidi M'hamed Benaouda (Relizane district) with a SE-NO orientation (Touaïbia, 2003).

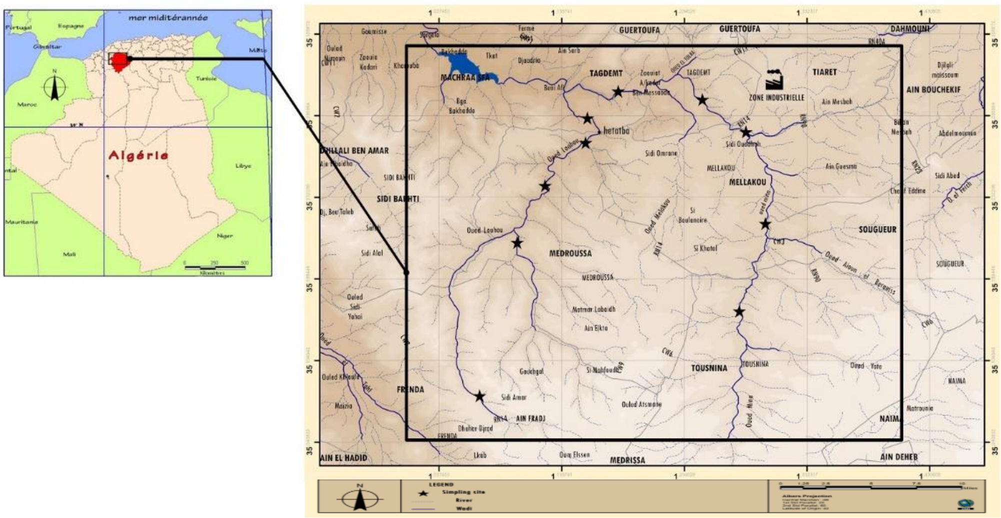

Fig. 1. Geographic and hydrographic location of the study area and sampling sites

Fifty samples were taken from the wadi bed from 10 sites (Fig. 1, Table 1) during autumn and spring seasons respectively in 2015 and 2016. The samples concern stones, shingles and pebbles covered on their superior face with a brownish bio-film characteristic with his high abundance of diatoms. After brushing and rinsing these simples with the distilled water, the bio-film is collected and then few drops of Lugol are added to preserve the cells of the epilithons until their study.
The physicochemical analyzes of the water samples of the sampling sites were realized in the laboratory of the University of Ibn Khaldoun of Tiaret, faculty of the sciences of nature and life. Temperature, pH and conductivity are measured in situ by a multiparameter (Carison MM4).

Table 1. Location of Sampling Sites

	Study site	*Abbreviation*	*Location*	*Altitude*
Wadi Mina	Tousnina	MA	35°08'34.93"N 1°16'42.23"E	1004
	Melakou	MU	35°12'41.91"N 1°17'56.31"E	944
	Sidi ouadah	SO	35°16'59.06"N 1°17'02.08"E	893
	Tagdemt	TT	35°18'32.37"N 1°14'54.27"E	812
	Beni Affen 1	BA1	35°18'55.31"N 1°10'54.98"E	672
Wadi Louhou	Sidi Amar	SA	35°04'45.42"N 1°04'10.81"E	1075
	Medroussa 1	MD1	35°11'53.58"N 1°06'05.63"E	825
	Medroussa 2	MD2	35°14'29.18"N 1°07'21.20"E	760
	Hetateba	HA	35°16'30.27"N 1°09'17.87"E	701
	Beni Affen 2	BA2	35°17'39.42"N 1°09'22.07"E	673

Identification

For microscopic observation of the frustules, the organic material must be removed by adding three volumes hydrogen peroxide (H_2O_2) with 30 %, for 15 to 20 minutes, and then a few drops HCl with a concentration of 35% are added to the samples of diatoms present in centrifuged tubes. Next, we dilute the preparations in a repeated process at least three times to remove all the oxidant. Finally, diatoms are dried and fixed on slide with Balm of Canada Balsam (RI = 1.55) for counting and identification of collected species based on numerous references (Krammer, Langebertalot, 1988; 1991a; 1991b; 2000; Lavoie et al., 2008; Prygiel, Coste, 2000).

Statistical analysis

To decrease the dimension of plant table nonmetric multidimensional scaling was applied (Minchin, 1987). As measures of distance between sample points in community space the following metrics have been used: Euclidean, Manhattan, Gower, Bray-Curtis, Kulczynski, Morisita, Horn-Morisita, Cao, Jaccard, Mountford, Raup-Crick, Canberra, Chao (Oksanen, 2017). The selection of appropriate distance metric and variants of primary data preliminary transformation was performed regarding the Spearman rank correlations coefficients between dissimilarity indices and gradient separation (Legendre, Gallagher, 2001).
Multidimention scaling was conducted using library ade4 (Dray et al., 2007) in the environment R (R Core Team, 2016).
In addition, to determine the water quality of the Mina sub-basin, the organic pollution index OPI (Leclercq, 2001) was calculated, using physicochemical data obtained at the laboratory of SNV faculty of Ibn Khaldoun University, Tiaret. The OPI depends on contents of water in ions ammonium, nitrite and total phosphorus and the BD05 (Table 2).

Table 2. Class Limits of the Organic Pollution Index (Leclercq, 2001)

Classes	BDO_5 (mgO_2/l)	NH_4 (mg/l)	NO^-_2 (µg/l)	PO^{3-}_4 (µg/l)
5	<2	< 0.1	< 5	< 15
4	2–5	0.1–0.9	6–10	16–75
3	5.1–10	1–2.4	11–50	76–250
2	10.1–15	2.5–6	51–150	251–900
1	>15	> 6	> 150	> 900

OPI definite 5 classes of contents for each of these parameters. The OPI is the average of the numbers of the classes of every parameter. The values of the OPI allow to distribute the organic pollutions of water in 5 levels.

Results and discussion

A total of 104 diatom taxa were recorded at the 10 sites during the two seasons (Table 3).

Table 3. Taxonomy diversity and species abundance

Species	Season	*MA*	MU	SO	TT	BA1	SA	MD1	MD2	HA	BA2
Achnanthidium exiguum	A	0.88	–	1.77	–	–	–	–	–	–	–
	S	–	2.21	0.76	0.52	2.32	–	–	6.63	–	4.52
Achnanthidium minutissimum	A	6.76	–	2.44	3.17	4.26	6.27	–	8.50	–	0.20
	S	0.46	9.94	8.84	21.26	13.21	1.94	–	14.52	–	0.27
Amphora ovalis	A	3.24	1.26	0.44	7.07	4.96	2.07	10.13	3.03	3.15	3.24
	S	2.07	10.13	3.03	3.15	3.24	1.26	0.44	7.07	4.96	2.07
Amphora pediculus	A	–	–	–	5.37	–	–	–	–	5.26	0.41
	S	–	–	3.28	–	–	–	10.51	1.08	1.15	–
Bacillaria paradoxa	A	–	–	–	–	–	–	–	–	7.32	4.50
	S	–	–	–	–	–	–	–	–	1.61	9.57
Brachysira microcephala	A	–	–	–	–	–	3.58	3.89	–	1.37	–
	S	–	–	–	–	0.36	7.10	0.39	1.43	0.23	2.13
Caloneis amphisbaena fo. subsalina	A	1.76	–	0.22	–	2.48	–	–	–	–	–
	S	–	–	–	2.89	6.25	7.10	–	–	–	–
Campylodiscus clypeus	A	–	–	–	–	–	2.09	0.46	–	2.52	3.27
	S	–	–	–	–	–	3.23	–	0.72	0.46	1.33
Cocconeis pediculus	A	–	–	–	1.71	0.71	0.30	0.23	–	–	–
	S	–	–	–	2.36	8.93	0.97	–	1.08	–	–

Craticula ambigua	A	6.76	1.26	2.88	–	0.35	–	–	–	–	–
	S	1.61	6.26	–	3.15	–	1.29	1.95	2.15	–	–
Ctenophora pulchella	A	0.59	2.27	5.10	–	–	0.60	29.52	14.57	–	4.50
	S	3.22	3.87	–	–	–	11.61	8.95	–	–	0.53
Cyclotella meneghiniana	A	–	0.25	–	–	–	8.66	3.20	0.40	5.95	8.38
	S	0.23	0.92	–	–	–	8.71	1.17	2.15	11.70	5.05
Cyclotella ocellata	A	–	–	–	0.24	1.42	–	–	–	5.03	1.64
	S	–	–	9.09	2.10	–	–	–	–	3.90	0.80
Cyclotella stelligera	A	–	–	–	–	–	5.07	2.06	4.86	2.97	–
	S	–	–	–	–	–	–	3.11	1.97	1.15	1.06
Cymatopleura elliptica	A	0.29	0.50	0.89	0.24	1.77	–	–	0.40	4.35	0.41
	S	0.46	3.87	0.51	0.26	1.43	0.65	–	1.97	–	–
Cymatopleura solea	A	–	3.02	–	–	–	0.60	4.35	4.86	–	0.20
	S	–	–	4.55	–	–	–	5.45	–	0.23	0.27
Cymbella neocistula	A	–	–	–	0.24	–	0.30	–	–	0.46	–
	S	1.15	–	–	–	18.75	–	4.28	0.90	–	1.33
Cymbopleura naviculiformis.	A	–	–	–	1.46	4.96	–	–	–	–	–
	S	–	–	1.26	2.10	5.18	–	–	3.41	–	–
Diatoma moniliformis	A	–	–	–	8.05	5.32	–	–	–	0.23	–
	S	–	–	1.26	3.15	1.07	–	–	0.18	1.15	–
Encyonema minutum	A	12.65	0.25	4.43	10.24	–	–	0.46	–	5.03	2.86
	S	0.69	–	2.27	2.89	8.21	–	0.39	3.05	–	–
Encyonema silesiacum	A	–	–	–	–	–	–	–	–	–	0.20
	S	–	–	–	–	–	–	–	0.18	–	–
Eunotia cataractarum	A	–	–	–	1.46	4.96	–	–	–	–	–
	S	–	–	1.26	2.10	5.18	–	–	3.41	–	–
Fallacia pygmaea	A	1.47	3.78	1.55	–	0.35	–	0.92	5.67	1.14	–
	S	1.84	4.05	–	–	0.18	1.29	–	1.25	–	0.27
Fragilaria capucina	A	–	–	–	–	–	7.16	3.20	–	–	4.50
	S	–	–	–	–	–	7.42	–	–	3.21	1.33
Fragilaria ulna var. acus	A	–	–	–	1.95	1.77	2.39	–	–	2.06	2.04
	S	–	–	–	6.82	2.14	1.94	–	1.43	5.50	3.72
Frustulia vulgaris	A	–	–	–	5.61	6.38	–	0.92	–	–	–
	S	–	–	–	5.77	3.75	1.94	–	2.51	–	–
Gomphonema laticollum	A	–	8.06	14.41	–	–	16.42	–	–	–	2.86
	S	5.06	6.08	13.64	–	–	1.29	–	–	5.05	2.39
Gomphonema olivaceum	A	11.18	38.04	–	–	–	0.30	5.03	–	–	–
	S	28.97	0.55	5.05	–	0.18	–	–	–	–	–
Gomphonema parvulum	A	3.53	4.79	2.44	–	–	0.30	3.20	2.43	–	–
	S	0.92	2.58	–	–	–	2.90	3.50	–	–	–
Gomphonema pumilum var rigidum	A	0.59	3.53	3.33	–	–	0.60	1.60	–	–	–
	S	1.38	2.03	–	–	–	0.65	–	–	–	1.60
Gyrosigma acuminatum	A	–	0.00	–	0.49	7.45	0.30	0.23	–	2.29	1.02
	S	–	–	6.57	3.67	1.79	–	0.39	2.69	–	1.60
Gyrosigma rautenbachiae	A	–	0.00	2.44	1.71	1.06	–	–	–	3.89	–
	S	–	0.55	1.26	3.15	1.96	–	–	2.15	–	–
Hantzschia amphioxys	A	3.53	0.00	3.55	8.78	0.71	–	–	–	–	–
	S	–	–	0.51	1.05	–	0.65	–	0.90	–	–
Hippodonta capitata	A	–	0.00	–	2.68	4.26	–	–	–	9.15	–
	S	–	–	0.25	1.84	0.71	–	–	0.72	–	–
Hippodonta hungarica	A	–	0.00	–	5.12	6.38	–	–	0.40	2.52	1.43
	S	–	–	–	5.25	1.79	–	–	0.54	0.92	2.93
Luticola kotschyi	A	–	5.54	–	–	–	–	–	–	–	9.61
	S	–	8.10	–	–	–	–	–	–	–	–

Luticola nivalis	A	–	0.50	–	0.49	5.32	6.27	–	–	1.83	4.50
	S	–	0.18	0.25	–	–	–	4.67	–	–	–
Mastogloia braunii	A	–	–	–	–	–	–	–	8.91	1.60	–
	S	–	4.05	–	–	–	6.77	–	–	2.06	–
Navicula capitatoradiata	A	–	–	–	2.44	5.32	0.30	–	–	–	–
	S	–	–	–	3.67	2.50	–	0.39	3.41	1.15	0.53
Navicula gregaria	A	–	–	1.77	1.71	–	0.60	–	–	3.20	–
	S	–	0.18	0.25	0.26	0.18	–	–	2.15	7.34	–
Navicula longicephala	A	–	0.25	0.67	0.24	2.48	–	–	1.62	–	–
	S	0.23	1.47	4.04	1.84	2.32	–	0.78	2.15	1.15	–
Navicula radiosa	A	–	0.25	–	3.41	6.03	5.67	3.20	–	–	–
	S	–	–	–	2.36	–	4.19	–	–	–	7.18
Navicula symmetrica	A	4.12	2.77	2.44	0.24	–	0.90	–	–	–	–
	S	2.99	4.24	1.26	0.26	0.18	–	–	–	–	–
Navicula tripunctata	A	0.29	–	0.22	–	1.42	–	4.12	4.45	–	–
	S	0.46	1.10	6.82	–	0.18	0.65	4.67	–	–	–
Neidium ampliatum	A	11.76	4.79	–	–	–	–	0.23	–	0.23	1.02
	S	0.46	0.18	–	–	–	–	–	0.90	0.23	4.52
Neidium binodeforme	A	–	–	–	–	–	–	–	–	3.20	–
	S	2.76	2.21	–	–	–	–	–	0.18	7.57	3.72
Neidium dubium	A	–	–	–	–	–	–	–	–	3.89	5.11
	S	–	–	–	–	–	–	–	–	11.70	3.19
Neidium productum	A	–	1.01	0.22	–	–	–	11.90	–	1.60	–
	S	–	–	2.02	–	–	1.29	0.39	–	–	–
Nitzschia bita	A	1.76	0.50	–	–	–	–	–	–	0.46	4.29
	S	0.92	1.47	–	–	–	–	–	4.30	2.06	1.06
Nitzschia hantzschiana	A	0.59	–	–	2.93	3.19	–	5.72	3.24	–	–
	S	–	–	3.54	0.26	1.07	3.87	8.17	–	–	–
Nitzschia palea	A	0.29	0.76	1.11	0.24	6.74	0.30	–	–	6.18	0.20
	S	3.68	2.03	4.04	7.09	1.61	–	–	8.60	1.15	0.27
Nitzschia recta	A	–	3.53	1.55	–	–	5.67	–	1.62	–	–
	S	–	0.92	–	–	–	4.19	0.78	–	–	3.72
Nitzschia sinuata var. tabellaria	A	–	–	–	–	–	–	1.60	–	10.07	–
	S	–	–	–	–	2.14	–	0.39	8.42	4.82	–
Pinnularia obscura	A	–	–	–	–	0.35	–	1.83	4.86	–	–
	S	–	–	–	–	–	0.65	5.84	–	–	–
Stauroneis gracilis	A	–	3.53	0.89	–	–	0.30	1.83	–	–	–
	S	5.52	2.21	–	–	–	0.32	8.17	–	–	–
Surirella brebissonii	A	19.71	7.05	37.92	–	–	9.25	3.20	14.17	–	14.52
	S	30.80	10.87	–	–	–	4.52	5.45	–	15.83	
Surirella crumena	A	–	–	–	0.24	–	2.39	0.69	4.45	–	–
	S	–	–	5.56	1.31	–	2.26	8.56	–	–	2.93
Surirella ovalis	A	1.18	0.25	0.22	5.12	0.35	0.30	–	–	2.06	6.75
	S	0.23	0.18	2.78	–	0.18	–	0.39	–	1.38	5.85
Ulnaria ulna	A	4.12	1.01	–	0.24	–	–	0.27	–	–	–
	S	2.07	0.92	–	3.67	2.50	–	0.13	9.86	–	–

Explanation: A= Automn; S= Spring

Most species have a cosmopolitan distribution and are also widespread throughout North Africa (Fig. 2).

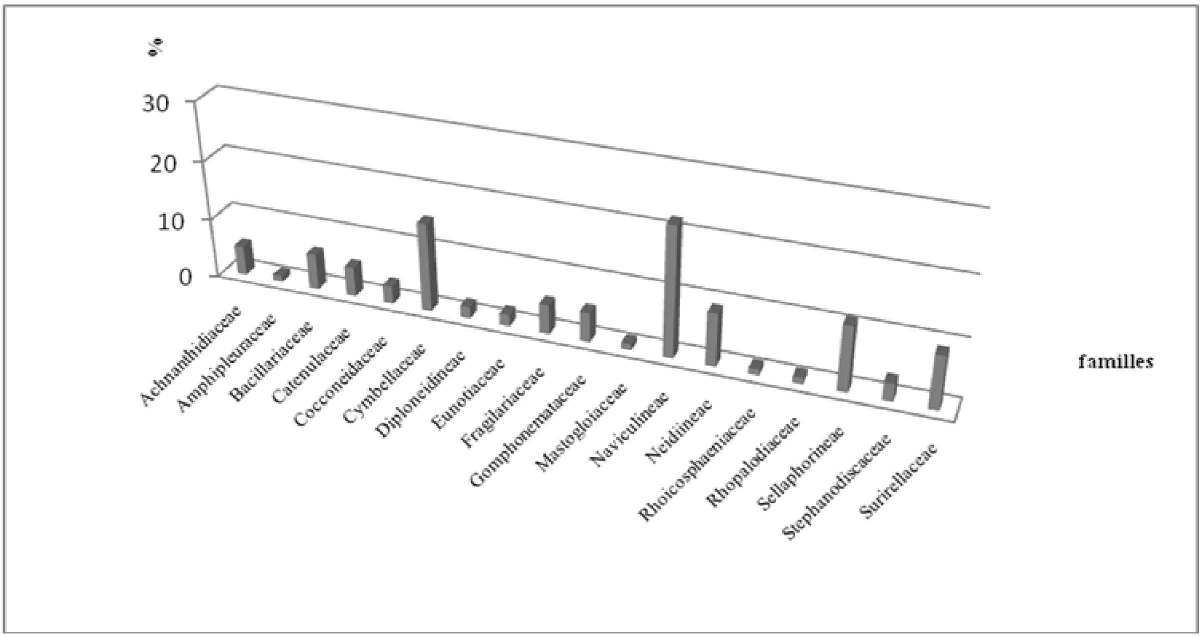

Fig. 2. Relative abundance of families in the study area

New 13 record taxa were observed for the first time in Algeria: *Brachysira microcephala, Eunotia cataractarum, Hippodonta capitata, Luticola kotschyi, Luticola nivalis, Neidium binodeforme, Neidium ampliatum, Neidium dubium, Nitzschia bita, Nitzschia sinuata var. Tabellaria. Pinnularia obscura, Stauroneis gracilis* and *Surirella crumena*. Most of the taxa belong respectively to the families *Naviculaceae* (20.75%), *Cymbellaceae* (14.15%), *Sellaphorineae* (10.38%) and *Neidiineae*, *Surirellaceae* (8.49%). The families of *Rhoicosphaeniaceae*, *Rhopalodiaceae*, *Amphipleuraceae* and *Mastogloiaceaes* are represented by one genus, our results agree with those of (Chaïb et al., 2011). On the other hand, the work of (Nehar et al., 2015) at Wadi Chellif has shown that the majority of species belong to the *Fragiariaceae* family.

Table 3 shows that the values of the diversity index during the two seasons are average with the Shannon index never exceeding 3.5 bits/species. At the currents of the two wadis, the diatom communities are less balanced.

During the autumn, the SO, BA1 and MD1 sites show a dominance of *Gomphonema olivaceum* var *olivaceum* with a frequency of 38.04% and 37.92% for respectively *Surirella brebissonii* and *Cyclotella meneghiniana*, while in spring it's *Achnanthidium minutissimum* which dominates with 21.26% in the SO station, which negatively affects H 'diversity and Shannon regularity "E".

The calculated mean values of the equitability index of the two seasons spring-autumn of the Wadi Mina (Table 4) oscillate between E = 0.67–0.89 and E = 0.82–0.90; and for Wadi Louhou, they are of E = 0.89–0.81 and E = 0.70–0.89 from which the imbalance of the diatomic community. Otherwise, some studies have demonstrated an abundance of *Achnanthidium minutissimum* with a frequency of 75% and 55% respectively during the summer at the sites studied where they note an equitability index of the wadi Kebir-East which are ranging between 0.37 and 0.81 in Hammam Bouhnifia and wadi Chélif between 0.33 and 0.65 (Chaïb, Tison-Rosebery, 2012; Nehar et al., 2015).

Table 4. Diatom diversity index in the study area

Index	Season	SA	MD1	MD2	HA	BA2	MA	MU	SO	TT	BA1
Shannon H	A	2.93	3.11	2.7	2.91	2.69	3.03	3.04	3.06	3.16	2.91
	S	2.31	2.34	2.51	2.62	2.73	2.63	2.23	2.44	3.08	2.43
Equitability E	A	0.82	0.88	0.79	0.87	0.88	0.87	0.83	0.85	0.9	0.82
	S	0.78	0.78	0.82	0.83	0.80	0.80	0.67	0.71	0.86	0.71

A = Autumn; S = Spring

According to the classification of (Van Dam et al., 1994), the diatom communities observed in the study area, are generally consisting of an alkalophilic mixture (Table. 5).

Moreover, the typical species of European acid waters can be adapted to alkaline waters in Algeria (Baudrimont, Recherches, 1974) confirmed in our case by the existence of *Brachysira microcephala*, considered by (Alexander et al., 2000) as a species that frequent neutral to slightly acidic waters. Similarly, for (Ciniglia et al., 2007) which also reports that *Pinnularia obscura* is very common in acid-environmented alga communities and the existence of the genus *Eunotia* represented by two species *Eunotia cataractarum* and *Eunotia formica* which are known as acidophilous (Van Dam et al., 1994).

Table. 5. Descriptive statistics of the bioindication assessment of the water parameters

Parameters	Median	Minimum	Maximum	Lower	Upper
Trophy	5.04	4.50	5.41	4.81	5.20
Saprobic	2.28	2.03	2.68	2.22	2.39
Salinity	2.35	2.01	2.57	2.22	2.44
pH	3.67	3.22	3.93	3.43	3.81
Nitrogen	1.88	1.58	2.69	1.67	2.17
Oxygen	2.32	1.94	2.82	2.08	2.55
Moisture	2.54	2.17	3.13	2.45	2.75
Pollution CEE	7.90	6.86	9.31	7.44	8.42

The dominant taxa at the Wadi Mina and Wadi Louhou sites, are generally with a moderately oxygenated environment, on the one hand confirmed by the presence of *Surirella brebissonii*, tolerant to brackish water and frequent fluctuations in salinity as confirmed by Leclercq (2000), in the other hand the poorly oxygenated ones, are represented by *Nitzschia palea* and *Nitzschia sinuata* var. *tabellaria*, where these cells are found in mesotrophic waters and they tolerate critical levels of pollution (Round, 1991; Takamura et al., 1989).

Some species that are sensitive to dissolved oxygen and require a high concentration of oxygen, represented by the species *Nitzschia dissipata* in our study. Most dominant species, namely *Gomphonema parvulum*, *Cyclotela ocillata*, *Navicula radiosa*, *Nitzschia palea*, and *Cymbella neocistula* have been characterized as tolerant to high electrolyte levels in rivers heavily contaminated by industrial wastes mentioned in the work of (Krammer, Langebertalot, 2000; Lange-Bertalot et al., 2006). Therefore, the presence of these species could be considered as indicators of similar conditions in the MA, MU, SO and TT sites. On the other side, one group is dominated by two pollutant sensitive species, *Achnanthidium minutissimum* and *Cocconeis pediculus*, indicating slightly moderate conditions, which may reflect intermediate pollution conditions according to (Jahn et al., 2009; Ndiritu, 2006) these species are susceptible to the contamination with industrial waste and organic load. *Achnanthidium minutissimum*, *Cocconeis pediculus* were the most common in urban sites TT, MD1, which were polluted by residential effluents and household MD2. However, several polluotolerant taxa are present in the same sites such as: *Navicula gregaria*, *Surirella brebissonii*, *Nitzschia palea* and *Gomphonema parvulum*), these species are known to be tolerant to several forms of pollution and indicate disturbed conditions (Della Bella et al., 2007; Teresa et al., 2013; Teresa et al., 2014).

Hantzschia amphioxys and *Encyonema silesiacum* observed in agricultural runoff areas, such as SO. HA, B1, and B2, have also been found in MU and SA sites, where nitrate and phosphate concentrations are high, these high concentrations of phosphates derived without a doubt from the industrial unit SOTREFIT Wire Drawing Company (industrial zone) Tiaret, and can also be the source of particularly acute pollution. However, the group containing the *Gomphonema olivaceum*, *Stauroneis gracilis*, *Fallacia pygmaea*, *Navicula symmetrica* and *Craticula ambigua* taxa is related to the high concentrations of ammonium and sulphates resulting from the agglomerations' wastewater, observed in TT, MD1, MD2, and SA, these species are in waters with high mineralization (Bennion et al., 2014; Lange-Bertalot et al., 2009; Thi Thuy et al., 2007).

The physicochemical characteristics of the under watershed of the mina develop a moderate paln of water with variations of spatio-temporal temperatures from one season to another, because we note a temperature fluctuating between 12 ° C and 20.1 °C in autumn and between 14.2 °C and 23.4 °C in spring. For electrical conductivity (EC), the values are characteristic of freshwater and show large and irregular variations, changing from one site to another with moderate mineralization of 941 uS cm^{-1} to high where the EC shows peak values of 5391.6 uS cm^{-1} in the Tagdemt area (TT Print sites) and 5620 uS cm^{-1} (SO Autom site) in relation to the high inputs of NH_4 and PO_4 from wadi Mina. The nitrite and nitrate contents (NO_2, NO_3) show less fluctuating variations during the months of September and March and do not differ between the different sites. Concerning the concentrations of dissolved oxygen, they are very variable and irregular in space and time for all the sites. For the localities of Sidi Ouadah and Ain Guesma (SO) with industrial activities and agrochemical drainage, we note hypoxic conditions with a value of 0.7 to 1.4 mg l-1 which indicates a high organic wastewater degradation like the localities of Tagdemt (TT) and Melakou (MU). So, the sub-watershed of Wadi Mina is characterized as a polluted and eutrophic system due to a constant drainage during the year and high nutritious elements of wastewater, from industrial, agricultural and urban activities, which OPI shows 2 pollution classes (moderate and strong) for the different sites studied. The evolution of the values of the OPI along the sites (Table 6), shows a deteriorated state of the quality of the wadi Mina water, due to the discharges of domestic and industrial wastewater from the agglomerations.

At sites TT, SO, MD1 and MD2, the OPI varies between 1.75 and 3.50, due doubtless to the discharges of the industrial zone of Zaaroura dumped in oued Tolba (the latest connects the industrial zone to Oued Mina) and intense urban activities very especially in the sites TT and SO, also the urban wastewater from the municipality of Medroussa (MD1) and the municipality of Frenda (SA) regarding wadi Louhou. According to (Laidani et al., 2009), the results provide a certain number of anomalies, notably in the waste management of the different industrial discharges, and reports certain number of pollution indicator parameters in the Wadi Mina sub-watershed and in the main industrial units in the Tiaret region, including the rejection of Tiaret Dairy Group (GIPLAIT), which have a high concentration of COD, BOD and suspended materials.

Table 6. Results of the organic pollution index

Site		Season	OPI_BDO	OPI_NH4	OPI_NO2	OPI_PO4	OPI	Level of organic pollution
Wadi Mina	MA	A	3	4	1	2	2.50	Strong organic pollution
		S	4	3	1	3	2.75	Strong organic pollution
	MU	A	4	4	1	3	3.00	Organic pollution curbed
		S	2	4	1	2	2.25	Strong organic pollution
	SO	A	2	3	1	2	2.00	Strong organic pollution
		S	3	4	1	2	2.50	Strong organic pollution
	TT	A	3	3	1	3	2.50	Strong organic pollution
		S	4	4	1	2	2.75	Strong organic pollution
Wadi Louhou	BA1	A	2	3	1	2	2.00	Strong organic pollution
		S	2	4	1	2	2.25	Strong organic pollution
	SA	A	2	4	1	3	2.50	Strong organic pollution
		S	3	4	1	2	2.50	Strong organic pollution
	MD1	A	2	5	2	3	3.00	Organic pollution curbed
		S	3	4	1	3	2.75	Strong organic pollution
	MD2	A	3	4	1	3	2.75	Strong organic pollution
		S	3	4	1	3	2.75	Strong organic pollution
	HA	A	2	4	1	2	2.25	Strong organic pollution
		S	3	5	1	2	2.75	Strong organic pollution
	BA2	A	3	4	1	3	2.75	Strong organic pollution
		S	2	5	2	3	3.00	Organic pollution curbed

The physico-chemical variables and bioindicator indexes are correlated (Table 7). These results reveled that bioindicator indexes are sensitive to relevant physico-chemical properties of water. Trophy indicator is correlated with concentration NH_4^+, NO_2^-, PO_4^{2-}, Ca^{2+}. Saprobic indicator is negatively correlated with O_2DIS. Salinity is correlated with electrical conductivity and concentration Ca^{2+}. Indicator of the pH is correlated not only with pH but with electrical conductivity, NO_2^-, PO_4^{2-}, NO_3^-. Nitrogen indicator reflects variation of the nitrogen containing ions (NH_4^+, NO_2^-, NO_3^-) and is negatively correlated with BDO. Surprisingly oxygen indicator is not characterized by statistically significant correlation with O_2DIS but correlated with O_2DIS, NO_2^-, BDO. Pollution CEE indicator reveals that the diatoms community sensitivity to contamination most correlated with temperature, Turbi, O_2DIS, NH_4^+, Cond.

Table 7. Correlation between physico-chemical variables and bioindicator indexes (presented correlations are significant at $p < 0.05$)

Physico-- chemical variables	Bioindicator scales							
	Trophy	Saprobic	Salinity	pH	Nitrogen	Oxygen	Moisture	Pollution CEE
T	–	–	–	–	–	–	–	–0.48
pH	–	–	–	0.74	–	–	–0.49	–
Cond	–	–	0.45	–0.56	–	–	–	0.54
Turbi	–	–	–	–	–	–	–	–0.45
O_2DIS	–	–0.57	–	–	–	–	0.52	–0.49
$CaCO_3$	–	–	–	–	–	0.47	–	–
NH_4^+	0.68	–	–	–	0.60	–	–	–0.53
NO_2^-	0.62	–	–	0.54	0.66	0.48	–	–
Cl^-	–	–	–	–	–	–	–	–
PO_4^{2-}	0.58	–	–	0.53	–	–	–	–
Ca^{2+}	0.46	–	0.59	–	–	–	–	–
BDO	–	–	–	–	–0.59	–0.47	–	–
NO_3^-	–	–	–	0.57	0.56	–	–	–
SO_4^{2-}	–	–	–	–	–	–	–	–
DCO	–	–	–	–	–	–	–	–

The principal component analysis of the physico-chemical variables revealed that the first five principal components are characterized by eigenvalues, which are greater than 1 (Table 8). The first five principal components explain 76.39% of total variability. Principal component 1 explains 22.56 % variability. It is characterized by a positive correlation with temperature, Turbi, O_2DIS, Cl^- and negative correlation with SO_4^{2-}. The principal component 2 explains 18.44% variability and is characterised by correlation with $CaCO_3$, Cl^-, Ca^{2+}. The principal component 3 explains 15.87% variability and is characterized by a positive correlation with temperature, Turbi, NO_3^-, and negative correlation with Cond and BDO. The principal component 4 explains 11.59% variability and is characterized by correlation with NO_2^-, Ca^{2+}. The principal component 5 explains 11.46% variability and is characterized by correlation with PO_4^{2-} and BDO.

Table 8. Principal component analysis of the physico-chemical variables of water at sampling sites (presented statistically significant correlation coefficients with $p < 0.05$)

Physico-chemical variables	PC 1	PC 2	PC 3	PC 4	PC 5
T	0.49	–	0.65	–	–
pH	–	–	–	–	–
Cond	–	–	–0.55	–	–
Turbi	0.46	–	0.70	–	–
O_2DIS	0.47	–	–	–	–
$CaCO_3$	–	0.55	–	–	–
NH_4^+	–	–	–	–	–
NO_2^-	–	–	–	–0.56	–
Cl^-	0.54	0.64	–	–	–
PO_4^{2-}	–	–	–	–	0.46
Ca^{2+}	–	0.54	–	–0.60	–
BDO	–	–	–0.53	–	0.58
NO_3^-	–	–	0.73	–	–
SO_4^{2-}	–0.82	–	–	–	–
DCO	–	–	–	–	–
Eigenvalue	3.38	2.77	2.38	1.74	1.19
% Total variance	22.56	18.44	15.87	11.59	7.93
Cumulative eigenvalue	3.38	6.15	8.53	10.27	11.46
Cumulative %	22.56	41.00	56.87	68.46	76.39

Table 9. Spearman rank correlation coefficients between dissimilarity indices and gradient separation with different data transformation methods

Distance	Data transformation methods										
	1	2	3	4	5	6	7	8	9	10	11
Euclidean	0.00	0.10	0.06	0.15	0.05	0.05	0.14	0.05	0.15	**0.24**	0.18
Manhattan	0.03	0.10	0.07	0.16	0.04	0.04	0.10	0.04	0.12	0.18	0.17
Gower	0.04	0.08	0.06	0.10	0.04	0.04	0.05	0.04	0.10	0.10	0.16
Bray-Curtis	0.15	0.17	0.16	0.16	0.16	0.15	0.15	0.16	0.17	0.17	0.17
Kulczynski	0.15	0.18	0.17	0.16	0.17	0.16	0.15	0.17	0.17	0.17	0.17
Morisita	0.13	0.17	0.13	0.07	–0.12	0.16	–0.14	–0.12	–0.14	–0.10	–0.13
Horn-Morisita	0.14	0.17	0.15	0.14	0.16	0.14	0.14	0.16	0.15	0.15	0.16
Cao	0.12	0.14	0.13	0.19	0.03	0.09	0.15	0.03	0.13	0.16	–0.20
Jaccard	0.15	0.17	0.16	0.16	0.16	0.15	0.15	0.16	0.17	0.17	0.17
Mountford	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.11	0.11	0.11
Raup-Crick	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Canberra	0.15	0.16	0.16	0.15	0.15	0.15	0.14	0.15	0.16	0.15	0.17
Chao	0.13	0.16	0.15	0.13	0.12	0.12	0.13	0.12	0.15	0.14	0.13
Mahalanobis	0.01	–0.08	0.03	0.13	–0.18	–0.10	0.05	0.10	–0.04	0.00	–0.17

bold marked the highest correlation coefficient; NA – not available; 1 – untransformed data; 2 – log-transformed data; 3 – square-root transformed data; 4 – divided by margin total; 5 – divided by margin maximum; 6 – divided by margin maximum and multiplied by the number of non-zero items, so that the average of non-zero entries is one; 7 – normalized (margin sum of squares equal to one); 8 –standardized values into range 0–1; 9 – Hellinger transformation; 10 – χ^2-transformation; 11 – Wisconsin transformation.

Principal components as markers of the environmental factors can be used to determine the optimal solution for the ordination of plant communities using the method of multidimensional scaling. The methodical approach is that of all the possible ecological distances within data matrix plants/sites and transformation methods to choose the one that gives the highest correlation with environmental factors.

Spearman rank correlations coefficients between dissimilarity indices and gradient separation with different data transformation methods have revealed that usage of χ^2-transformation data and Euclidean distance is the most appropriate approach to reflect the relationship between soil mechanical impedance and ecological factors (Table 9). In further calculations the experimental data will be used in the above-mentioned transformed way.

Stress is a goodness-of-fit statistic in multidimensional scaling based on the differences between the actual distances and their predicted values. One of the goals of multidimension scaling analysis is to keep the number of dimensions as small as possible. The usual technique is to solve the multidimensional scaling problem for a number of dimension values and adopt the smallest number of dimensions that achieves a reasonably small value of stress. An appropriate number of dimensions was chosen by performing ordinations of progressively higher numbers of dimensions. A stress versus number of dimensions scree diagram was then plotted, on which one can identify the point beyond which additional dimensions do not substantially lower the stress value (Fig. 3). A four-dimension variant of multidimensional scaling procedure was selected as the most appropriate decision.

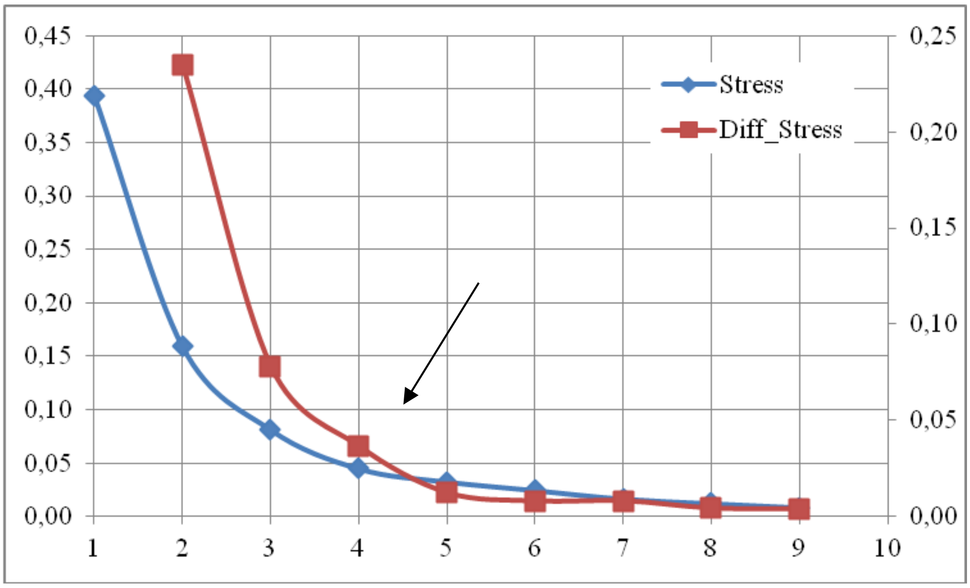

Fig. 3. Stress versus number of dimensions screen diagram. Arrow shows optimal number of dimension.
Notes: abscissa – the number of dimensions; ordinate – stress (left axis) or differential stress (right axis)

Four dimensions selected after nonmetric multidimensional scaling (NMDS) were interpreted by computing weighted average scores of ecological factors for ordination configuration (Table 10).

Table 10. Fitting environmental factors onto an ordination

Ecological factors	MDS1	MDS2	MDS3	MDS4	r^2	Pr(>r)	Significance codes
PC1	−0.61	−0.38	0.52	0.47	0.05	0.935	n.s.
PC2	0.34	−0.27	−0.13	0.89	0.57	0.007	**
PC3	0.25	−0.52	−0.37	−0.73	0.33	0.147	n.s.
PC4	0.19	0.03	0.98	0.11	0.61	0.009	**
PC5	0.13	0.31	0.43	−0.84	0.11	0.73	n.s.

Symbols: Significance codes: '***' – <0,001; '**' – <0,01; '*' – <0,05; n.s. – not significant

It has been established that such predictors as PC2 and PC4 are statistically significant. They are able to explain from 57 % and 61 % the dimension variation respectively. The dimension MDS1 may be interpreted as the measure of the community response to the variation of the calcium and chloride ions concentration which occurs in the connection with controversial changes of the physico-chemical variables marked by PC1. The dimension MDS2 is most sensitive to the synchronous changes of the physico-chemical variables marked by PC1, PC2, and PC3. The dimension MDS3 is most sensitive to the PC4. The dimension MDS4 is most sensitive to the PC2.

Fitting environmental factors onto an ordination by means linear models is a quite far from real character of the relation between ecological factors and community stricture. Smoothing surface for some ecological factors within ordination diagram shows complicated and nonlinear response of the vegetation due to ecological factors impact (Fig. 4).

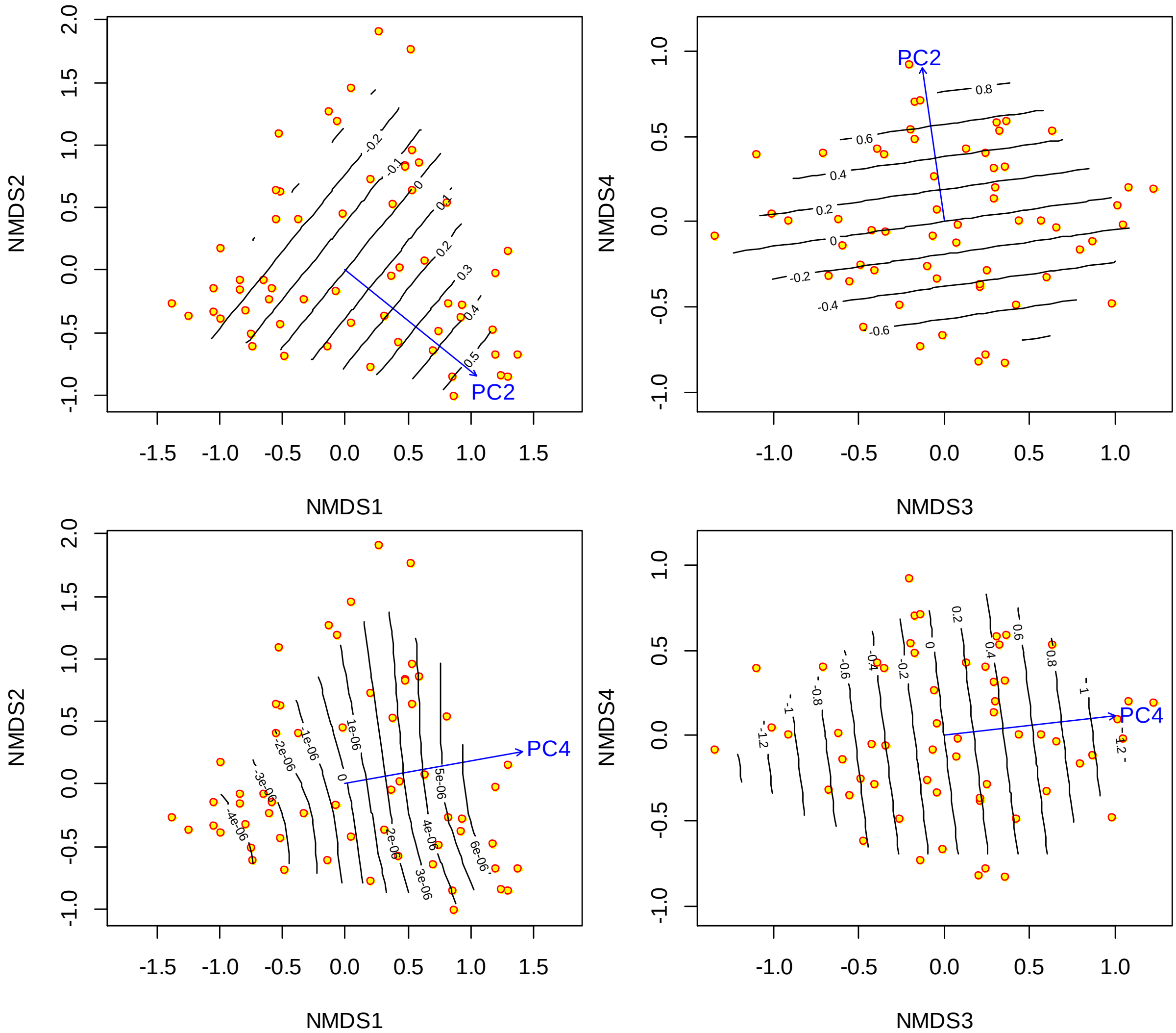

Fig. 4. Smoothing surface for some ecological factors within ordination diagram

Multidimensional scaling allows us to estimate how placement of sampling points, and plant species in the same space. Measured values for the plant can be used for cluster analysis of plant community. An important aspect of cluster analysis is to identify the optimal number of clusters. This problem was solved by means of Calinsky-Harabasz criteria (Fig. 5). Four of the clusters were found to be the optimal solution. Cluster solution can be represented as a dendrogram (Fig. 6). Also, ellipsoids can designate the configuration of species that belong to one cluster, in the dimension space (Fig. 7).

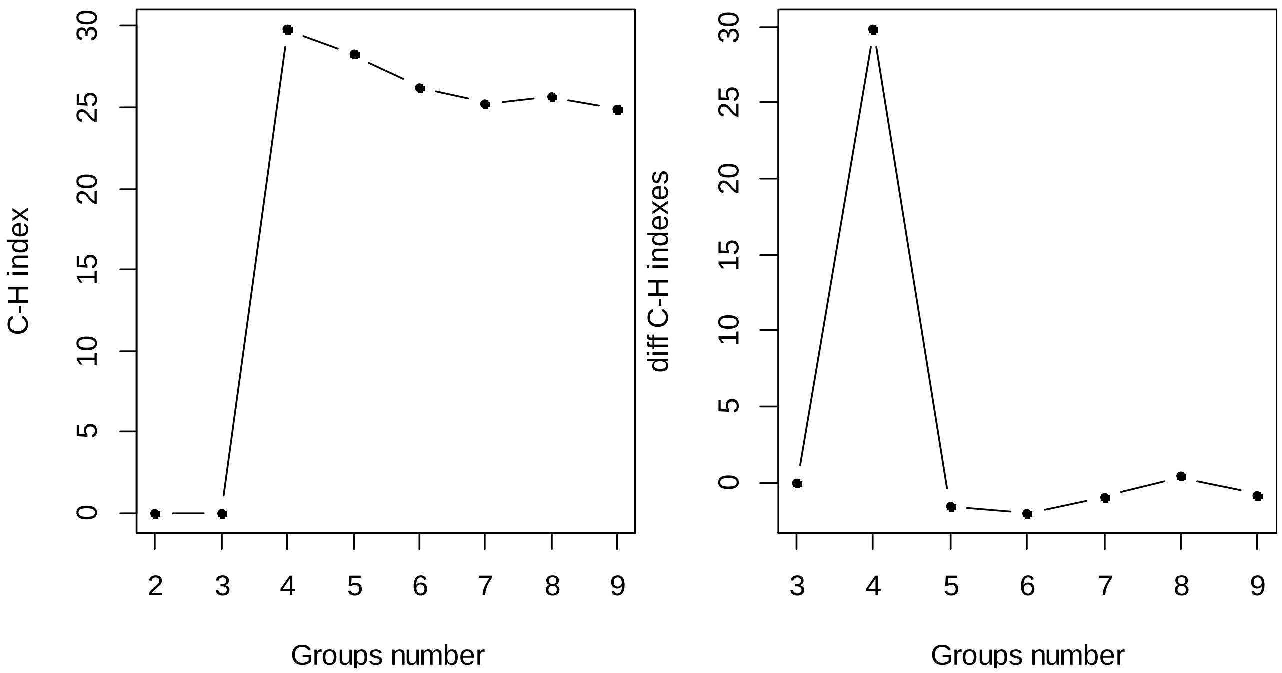

Fig. 5. Usage the Calinsky-Harabasz criteria (C-H index) to find the best vegetation community partition

The clusters can be viewed as a functional group. The information obtained allows to interpret the functional groups in terms of their environmental characteristics and bioindication properties (Table 6). A functional group *A* is presented by 21 species. Such species as *Gyrosigma rautenbachiae*, *Eunotia cataractarum*, *Cymbopleura naviculiformis* are the most typical for this functional group in sense the shortest Mahalanobis distances from group centroids. The high trophy preference is a most important ecological property of the functional group *A*. Species which constitute this functional group are mainly eutraphentic.
A functional group *B* is presented by 10 species. Such species as *Cymatopleura solea*, *Stauroneis gracilis*, *Surirella crumena* are the most typical for this functional group. The preference of the low pH is a most important ecological property of the functional group *B*. Species which constitute this functional group are mainly acidophilous.
A functional group *C* is presented by 20 species. Such species as *Bacillaria paradoxa*, *Neidium binodeforme*, *Luticola nivalis* are the most typical for this functional group. The preference of the low nitrogen level is a most important ecological property of the functional group *C*. Species which constitute this functional group are mainly tolerant to very small concentrations of organically bound nitrogen.
A functional group *D* is presented by 8 species. Such species as *Luticola kotschyi*, *Surirella brebissonii*, *Neidium ampliatum* are the most typical for this functional group. The preference of the high nitrogen level is a most important ecological property of the functional group *D*. Species which constitute this functional group are mainly facultatively nitrogen-heterotrophic taxa needing periodically elevated concentration of organically bound nitrogen.

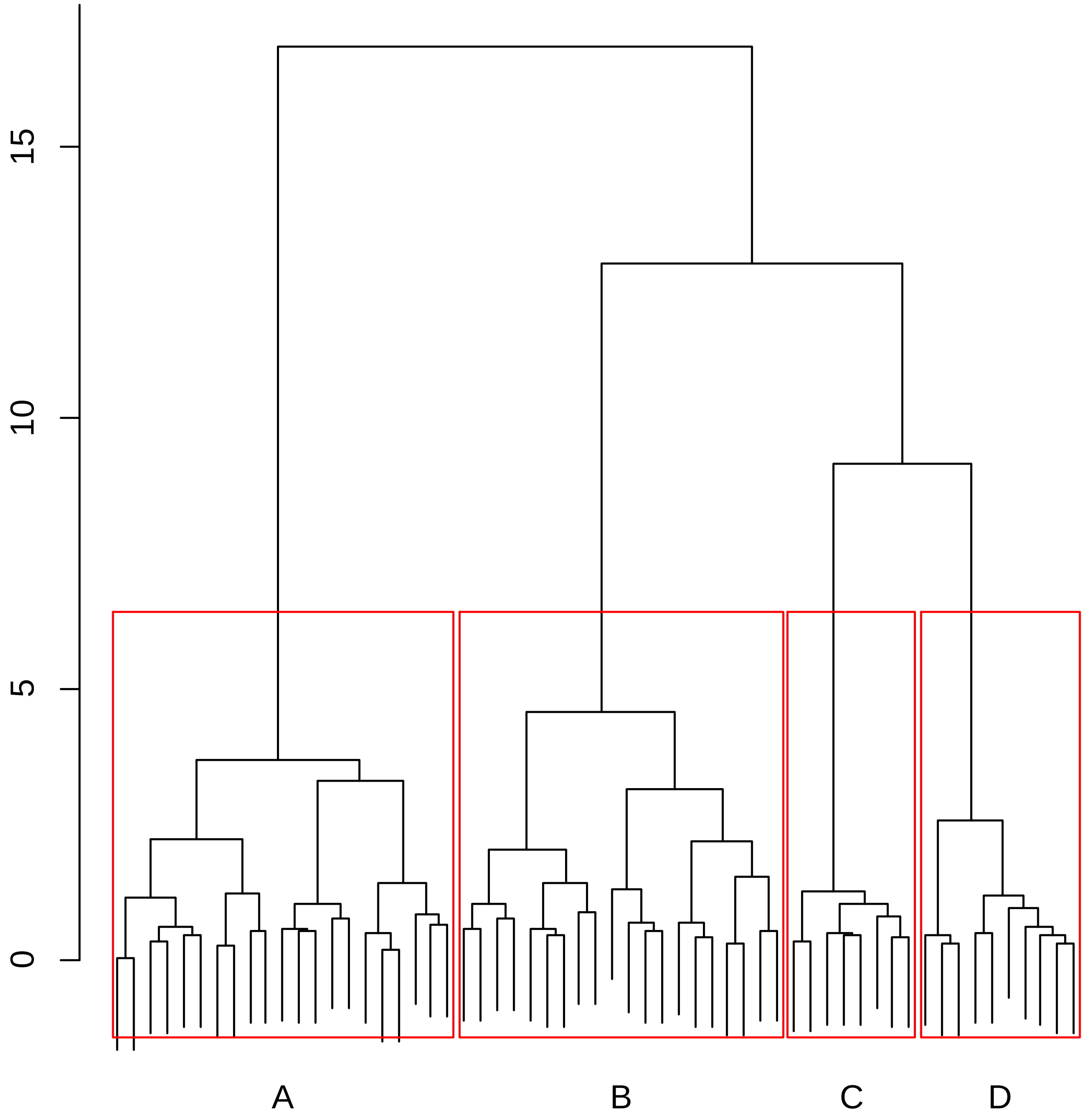

Fig. 6. Vegetation community cluster analysis (Ward method, Euclidian distance). A, B, C, D – clusters (functional groups)

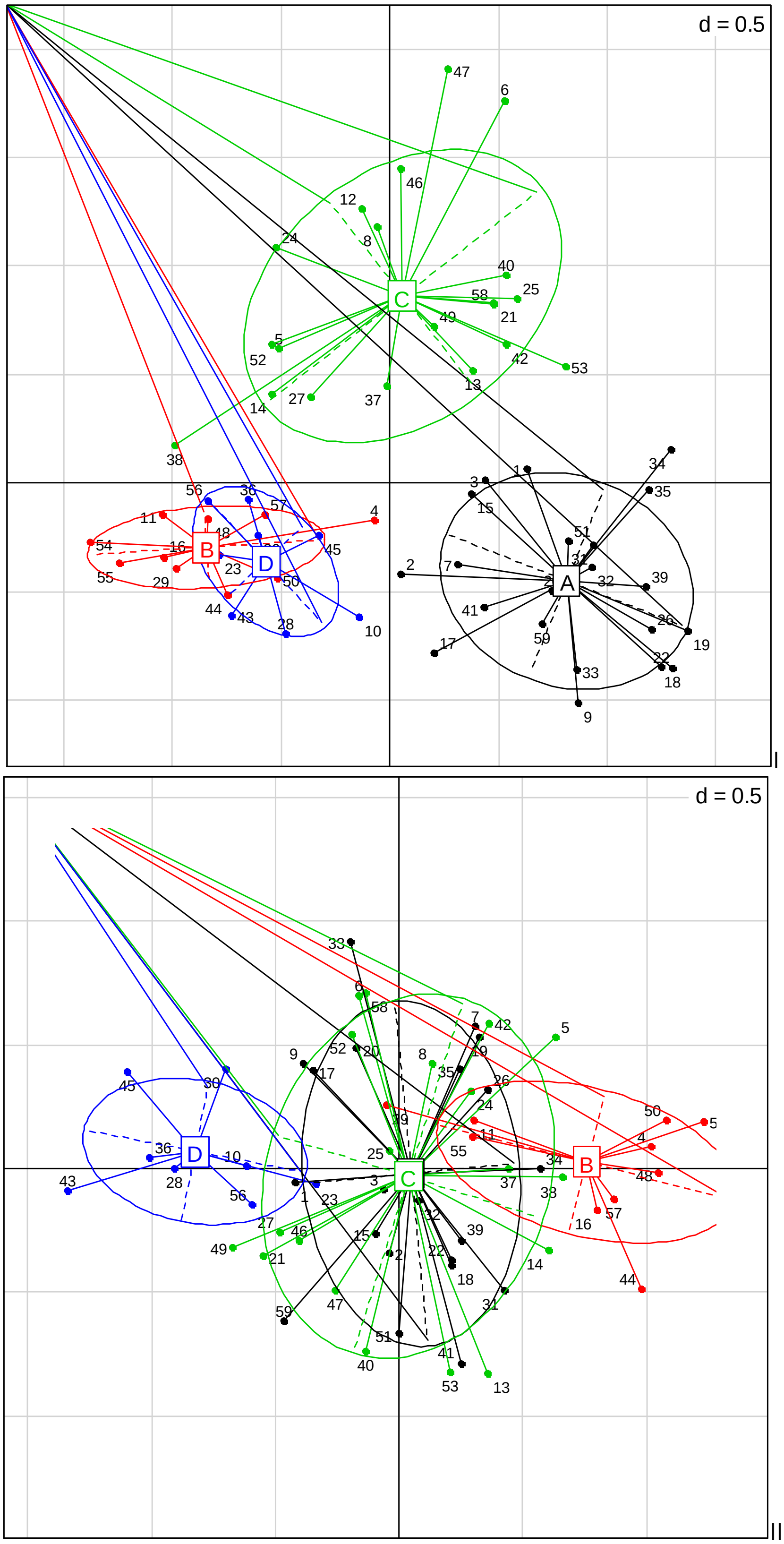

Fig. 7. Species distribution and cluster configuration in multidimensional space. I – dimension 1 and 2, II – dimension 3 and 4

1 – *Achnanthidium exiguum;* 2 – *Achnanthidium minutissimum;* 3 – *Amphora ovalis;* 4 – *Amphora pediculus;* 5 – *Brachysira microcephal;* 6 – *Bacillaria paradoxa;* 7 – *Caloneis amphisbaena. var. subsalina;* 8 – *Campylodiscus clypeus;* 9 – *Cocconeis pediculus;* 10 – *Craticula ambigua;* 11 – *Ctenophora pulchella;* 12 – *Cyclotella meneghiniana;* 13 – *Cyclotella ocellata;* 14 – *Cyclotella stelligera;* 15 – *Cymatopleura elliptica;* 16 – *Cymatopleura solea;* 17 – *Cymbella neocistula;* 18 – *Cymbopleura naviculiformis;* 19 – *Diatoma moniliformis;* 20 – *Encyonema minutum;* 21 – *Encyonema silesiacum;* 22 – *Eunotia cataractarum;* 23 – *Fallacia pygmaea;* 24 – *Fragilaria capucina;* 25 – *Fragilaria ulna var. acus;* 26 – *Frustulia vulgaris;* 27 – *Gomphonema laticollum;* 28 – *Gomphonema olivaceum;* 29 – *Gomphonema parvulum;* 30 – *Gomphonema pumilum var rigidum;* 31 – *Gyrosigma acuminatum;* 32 – *Gyrosigma rautenbachiae;* 33 – *Hantzschia amphioxys;* 34 – *Hippodonta capitata;* 35 – *Hippodonta hungarica;* 36 – *Luticola kotschyi;* 37 – *Luticola nivalis;* 38 – *Mastogloia braunii;* 39 – *Navicula capitatoradiata;* 40 – *Navicula gregaria;* 41 – *Navicula longicephala;* 42 – *Navicula radiosa;* 43 – *Navicula symmetrica;* 44 – *Navicula tripunctata;* 45 – *Neidium ampliatum;* 46 – *Neidium binodeforme;* 47 – *Neidium dubium;* 48 – *Neidium productum;* 49 – *Nitzschia bita;* 50 – *Nitzschia hantzschiania;* 51 – *Nitzschia palea;* 52 – *Nitzschia recta;* 53 – *Nitzschia sinuata var. tabellaria;* 54 – *Pinnularia obscura;* 55 – *Stauroneis gracilis;* 56 – *Surirella brebissonii;* 57 – *Surirella crumena;* 58 – *Surirella ovalis;* 59 – *Ulnaria ulna.*

Table 11. The ecological properties of the diatoms functional groups

Bioindicator scales	Functional groups				*F*-ratio	*p*-level
	A	B	C	D		
Trophy	5.43	4.70	4.80	4.63	2.43	0.08
Saprobic	2.43	2.10	2.35	2.13	0.65	0.59
Salinity	2.29	1.90	2.50	2.63	2.22	0.10
pH	3.90	2.90	3.40	4.38	11.74	0.00
Nitrogen	1.95	1.70	1.45	3.00	32.46	0.00
Oxygen	2.33	2.20	2.15	2.88	1.55	0.21
Moisture	2.43	3.40	2.30	2.50	4.06	0.01
Pollution CEE	8.05	7.70	9.60	6.50	3.35	0.03

Conclusion

In general, it can be concluded that the composition of the diatom communities of the wadi mina sub-basin is characterized by polysaprobic taxa namely, *Gomphonema parvulum*, *Cyclotelaocillata*, *Navicula radiosa*, *Nitzschia palea*, and *Cymbella neocistula*.

Both wadis are driven by variations of environmental factors, showing a dominance of halophytes, confirmed by the ordination results, whose epilithons diatoms distribution is closely related to the physicochemical elements of the water, especially to the conductivity, the pH, PO_4 and BOD, it's also associated with the different types and intensities of human activities that occur along the Mina wadi sub-basin. On the other hand, the study of diatoms and the application of OPI allowed to apprehend the quality of waters reflecting a high pollution, this is essentially due to the presence of species resistant to organic pollution.

The degradation of the studied waters follows a change in agricultural habits in this region, where the wide cereal areas of Tiaret have been replaced, especially along the wadis, by vegetable crops that require more chemical inputs (fertilizers and pesticides). Indeed, the irrational use of fertilizers in the region of Sidi Ouadah (SO) and Tagdemt (TT) and waste discharged by the ONAV unit (national office of poultry slaughterhouses), increase the concentration of NH_4 and NO_3, inducing a large pollution during autumn (table 04) of the sites MU, SO, MD1, MD2 and HA, whose OPI oscillates between 2.5 and 2.75. On the other hand, the remoteness of the BA1, BA2 and HA sites from the urban areas develops a moderate pollution for the two seasons, where the OPI oscillates between 3.25 and 3.5. For their part, Derradji et al. (2007) mention that the leaching of agriculture areas in winter allows a less significant state of pollution of the ecosystem in the spring season than that of autumn.

Finally, to a better knowledge, preservation, development, and using these diatomic resources with maximum efficiency in the field of bioindication of water quality, future prospects will be made: prospection a high number of sites along the Oued Mina, to control urban and agricultural pollution in order to optimize the development of water treatment centres along this highly anthropized hydrographic network. To improve the quality of water for the well-being of people who depend on this hydrosystem, through the implementation of a drainage program and installation of waste water treatment.

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