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C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Physicochemical quality of Wadi Bounamoussa surface waters (Northeast of Algeria)

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Abstract

Nitrogen is a nutrient that causes inland waters and marine environements' eutrophication. The latter has become a worldwide environmental concern that considerably lessens the aquatic environments' quality. This study has focused on physicochemical aspect of Wadi Bounamoussa water, by the diagnosis of the watercourse eutrophication. The river drains a watershed mainly characterized by agricultural activities based on irrigated crops and livestock of sheep and cattle. Fertilizers being Nitrogen inputs and livestock waste are potential pollution source. Nitrogen can get into the watershed's hydro-system in the form of minerals or organic. Temperature, pH, dissolved oxygen, NH_4^+, NO_3^-, NO_2^- were monitored in water samples taken in September and in December 2013 corresponding to the low season, and also in March and June 2014 corresponding to water high season. These samples were obtained from ten stations located along the river downstream sequence between El Cheffia dam and El Batah River mouth. Few observations have been made based on results obtained from the physicochemical analysis. Temperature, pH level, electrical conductivity as well as silica were significantly higher during low water periods comparing to high ones. It has been noticed from the analysis of various water sampling stations the presence of chloride ions with an increasing gradient from upstream to downstream, where it's content has fluctuated between 30.52 $mg\cdot dm^{-3}$ and 9964.6 $mg\cdot dm^{-3}$. In conclusion, the presence of inorganic nitrogen is not considered as an eutrophication risk on the watercourse and its receiving environment.

Key words: *aspect, eutrophication, nitrogen, physicochemical parameters, Wadi Bounamoussa, water quality*

INTRODUCTION

Water composition depends on its surrounding environment, where the quality of water can determinate the physicochemical properties, the latter is affected deeply by the chemical and the biological processes [CHAOUI *et al.* 2013b].

Nitrogen is one of the essential nutrients for the growth of living things. Agriculture intensification and nutrients' excessive emissions in aquatic environments are undesirable factors, because they predominantly contribute to the eutrophication of such areas, which causes a total imbalance of aquatic ecosystems [GUASMI *et al.* 2006].

Eutrophication symptoms can provoke disorder, acidification, anoxia, mineral nitrogen contents and high phosphate, abundant organic matter, biota stress and reduction in biological diversity.

Pollution sources of natural water bodies by nitrogen substances are numerous. Agriculture and waste water from urbanized areas extensively emit these materials in aquatic ecosystems [BOUSSAHA, LAIFA 2016].

El Taref province is considered as a rural region and its water resources are heavily used for agricultural activities and also a supply of drinking water. Its waters quality deterioration is caused by farmland leaching as well as domestic and industrial liquid wastes. The burden of these releases is increasingly growing and hence affecting the socioeconomic development of the region [BAHROUN, KHERICI BOUSNOUBRA 2007].

The aim of this study is to examine the physicochemical state of the Bounamoussa River draining from its watershed located in El Taref region, in order to diagnose the watercourse eutrophication and its receiving environment.

MATERIAL AND METHODS

THE STUDY AREA

The study area is located in El Taref province situated in the extreme North-East of Algeria. It has the largest watershed is provided by a large river system with a total area of 11 509 km^2. It is a rural area of about 356 000 residents. It is bordered in the north by the Mediterranean Sea and Tunisia in the east [ZENATI, MESSADI 2009].

This wilaya consists of a hydrographic network composed of the Wadi El Kebir and the secondary tributary with Wadi Bounamoussa [BOUCHELAGHEM *et al.* 2014]. Wadi Bounamoussa is one of the major rivers of the province of El Taref. It flows in the southeast part of Annaba meandering with a fairly cashed bed of quaternary alluvium. Before leaving the mountains of Cheffia (Prov. El Taref), the river drains the small plain of Asfour that is attached to the plains of Annaba in eastern Zerizer before reaching the dune area [RAMDANI, LAIFA 2016]. It has a junction with Wadi Mafragh that crosses the dunes and empties into the Mediterranean Sea. However, the mouth has relatively low water flow speeds and is predominantly closed by a sandy barrier [NECIB *et al.* 2013].

WATER SAMPLING

Water was collected from the river to study the the physicochemical parameters. Samples were taken from 10 stations along the river (the geographic data of these stations are recorded in Table 1) starting from El Cheffia dam until the El Battah outlet (Fig. 1).

Table 1. The geographic locations of sampling stations along Bounamoussa River

Station name	Number	Abbreviation	Latitude N	Longitude E
Cheffia Dam	01	BE	36°35’49.3”	7°58’57.6”
Bouzitouna	02	BZ	36°38’40.6”	7°54’47.4”
Skoufi	03	SF	36°41’11.8”	7°57’36.3”
Nchayma (1)	04	N1	36°42’44.9”	7°57’30.1”
Nchayma (2)	05	N2	36°38’41.6”	7°56’47.4”
Pont de Zerizer	06	PZ	36°43’33.6”	7°56’35.2”
Borj Essammar	07	BJ	36°47’41.1”	7°49’56.0”
Pont Ben Mhidi	08	PB	36°44’24.2”	7°55’22.7”
Griette	09	GR	36°50’06.1”	7°57’13.8”
El Batah Station	10	SB	36°50’31.2”	7°57’13.8”

Source: own elaboration.

WATER ANALYSIS

Water samples were collected in the middle of the riverbed from shallow water layer of between 0–50 cm during the high water period (HW) and the low water period (LW) on 28.09.2013 (HW), 28.12.2013 (HW), 28.03.2014 (HW) and 28.06.2014 (LW). Samples are kept in good transport and storage conditions until their analysis. The temperature, pH and the electrical conductivity were measured in situ. The total hardness, chloride ions and silica levels were measured in the laboratory of the International Company of Chemical Fertilizer Productions (Fr. Société des Fertilisants d’Aigérie – FERTIAL).

Nitrite, nitrate, and ammonium were assayed at the laboratory of National Sanitation Office, Annaba (Fr. Office National de l’Assainissement – ONA) according to standard methods with the following references (Ammonium: NFT 90-015-1, nitrates: ISO 13395:1996, nitrites: ISO 6777:1984).

RESULTS

PHYSICOCHEMICAL CHARACTERISTICS OF WATER

The obtained results of physicochemical analysis are illustrated in Figure 2.

Water temperature is influenced by environmental conditions. Indeed, it is related to geography, land geology, ecosystem hydrology and especially the climate [BELGHITI *et al.* 2013].Water temperature is a significant factor in organic production. This is because it affects the latter physical and chemical properties; mainly its density, viscosity, its gas solubility (especially that of oxygen) and the rate of chemical and biochemical reactions [REGGAM *et al.* 2015]. Its minimum value (11°C) was recorded at station 2 in December and the maximum one (33°C) in the same station (Fig. 2a). These values reveal a slightly increasing gradient downstream than upstream of the rainy season to the dry season.

Water pH summarizes the stability of the established balance between the different forms of carbonic acid, which is linked to the buffer system developed by the carbonates and bicarbonates as well as by the presence of exogenous substances [N’DIAYE *et al.* 2013]. The pH measured values showed a spatial and temporal variation in the 10 stations. The pH was alkaline to acid with notable variations between 5.94 and 8.26. The lowest value was recorded at station 04 in the period of high water during September 2013. It can be explained by heavy rains during this period and this would have acidified this stream. The value of 8.26 was recorded at station 1 in low water period during June 2014 (Fig. 2b).

The conductivity measurement is a good assessment of the degree of mineralization of water which is each ion by its concentration and specific conductivity [BELGHITI *et al.* 2013].

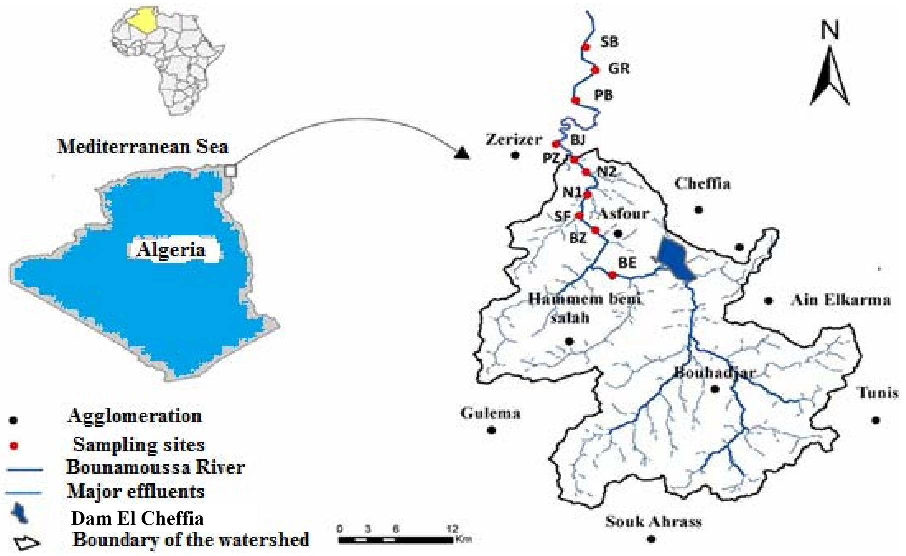

Fig. 1. The Bounamoussa River watershed and sampling sites; abbreviations of station names as in Tab. 1; source: own elaboration

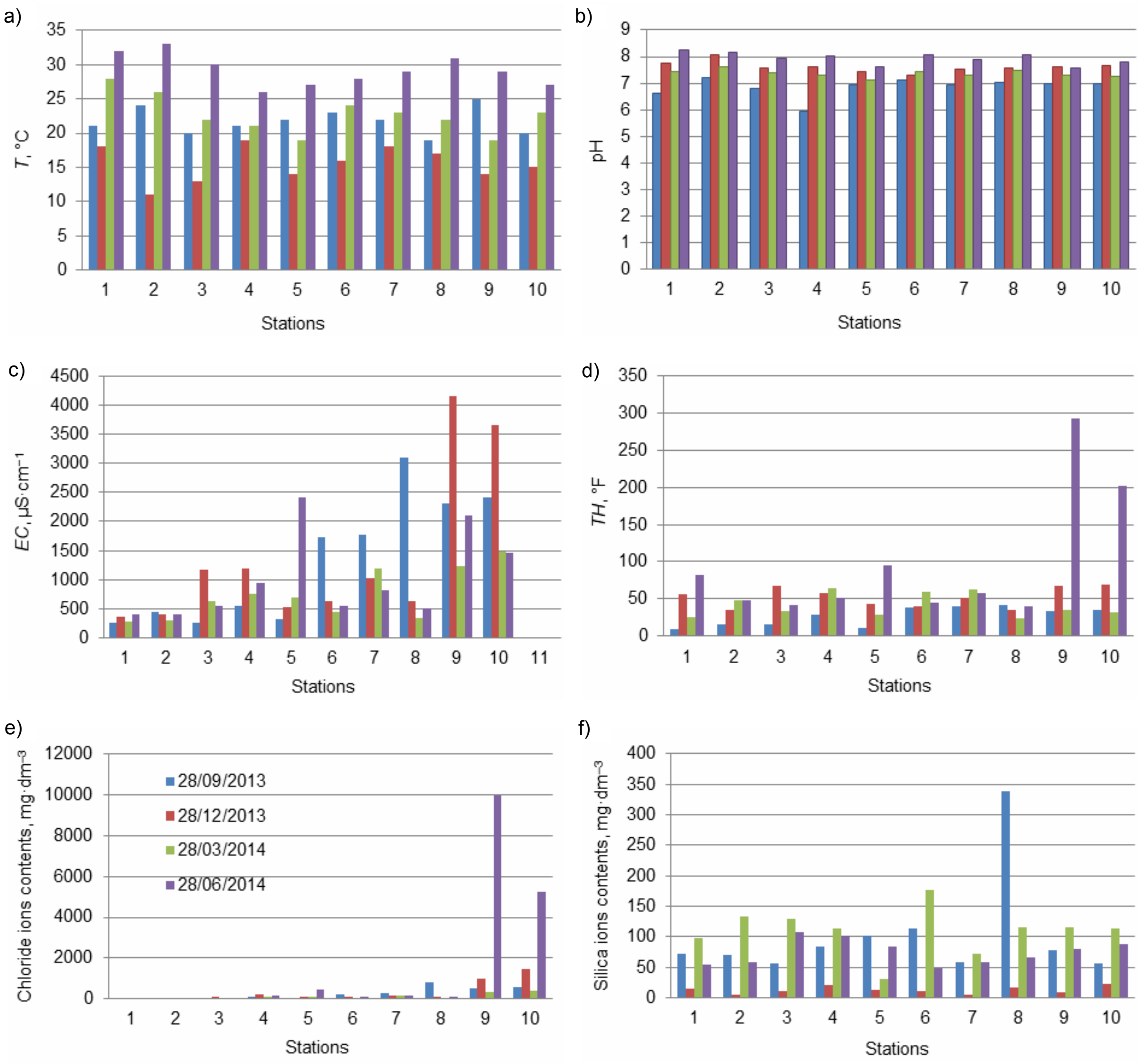

Fig. 2. Physicochemical parameters of water in Wadi Bounamoussa: a) temperature (*T*), b) pH, c) electrical conductivity (*EC*), d) total hardness (*TH*), e) chloride ions, f) silica ions; source: own study

For all water analysed samples, electrical conductivity values were between 266 μS·cm^{-1} at stations 1 and 3 in September 2013 and 4160 μS·cm^{-1} at station 9 in December 2013 (Fig. 2c).

These important values appear to be the result of soluble salts' contributions in the Bounamoussa River watershed leaching soil and by marine waters' intrusion in the river during the wet season.

Water total hardness (*TH*) is a parameter directly linked to the amount of calcium and magnesium [REGGAM *et al.* 2015]. The Bounamoussa River waters are characterized by total hardness, especially at the stations 9 and 10, respectively 293°F and 202°F (Fig. 2d). These high values (>30°F) could be explained by the soil nature and also by the sheep and cattle breeding facilities located in the study area. The lowest value was recorded at station 1 (9.1°F) in September (low water) and the highest value was at the station 9 (293°F) in June. It recorded increasing concentrations of these elements in the periods of low water to high water.

Chloride ions are in varying concentrations in natural waters, their seasonal average concentrations at different stations showed the existence of an increasing gradient from upstream to downstream. The contents fluctuate between 30.52 mg·dm^{-3} at the station 6 (September) and 9964.6 mg·dm^{-3} at station 9 downstream of the river (June) – Figure 2e. These variations are probably related to traversed ground's nature and sea influence. Their spatiotemporal evolution roughly follows that of the electrical conductivity. Heavy contents in chloride ions observed during the dry season would be linked to the level of low water and low values were recorded during the rainy season.

The Bounamoussa River water contents of silica's were of different values between the studied stations (Fig. 2f). They were high in March and June (low water). The lowest level of 5.65 mg·dm^{-3} was recorded during the period of high water in the station 7. Station 8 had the highest value (338 mg·dm^{-3}) noted during September. Wastewater from Ben Mhidi would be the cause since they are directly discharged into the river without treatment.

NITROGEN COMPOUND

The seasonal average concentrations of ammonium ions fluctuate between 0.147 mg·dm^{-3} and 0.28 mg·dm^{-3} in storm periods that are usually found in unpolluted rivers (Fig. 3). Value of 3.04 mg·dm^{-3} found in low water period could be explained by the ammonification process favoured by the temperature increase.

The average concentrations of nitrite ions were smaller than ammonium ions. The greatest value 0.570 mg·dm^{-3} was at station 10 in the period of high water. This value exceeds the standard (NO_2^- 0.1 mg·dm^{-3}) of surface waters suitable for human consumption. Under his nitrate form, nitrogen is preferentially absorbed.

Nitrate ions were the final stage of nitrogen oxidation. Their concentrations in natural waters were between 1 and 10 mg·dm^{-3}.

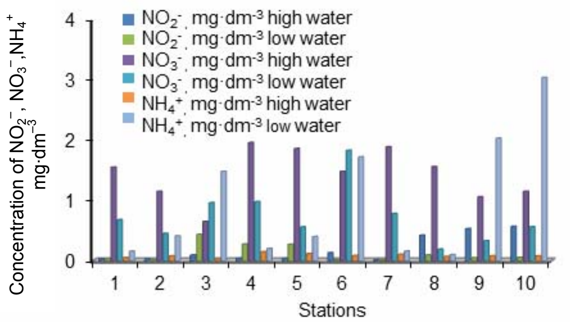

Fig. 3. Average concentrations of NO_2^-, NO_3^- and NH_4^+ in the Bounamoussa River; source: own study

The average concentrations of NO_3^- ions also showed an increase ranging between 0.65 mg·dm^{-3} and 1.89 mg·dm^{-3}; these values were at the lower limit of the range of nitrate ion concentrations in the unpolluted surface water. These results indicate that the studied waters along the Bounamoussa and its tributaries are not at risk of pollution from nitrate ions.

AMMONIUM NITRATE DIAGRAM

Ammonium nitrate diagram can give an explanation on ammonium and nitrates varying concentrations and their origins in water during the two sampling periods. The diagram illustrates various forms of pollution along the axes orientation in the ammonium nitrate as presented in the Figure 3.

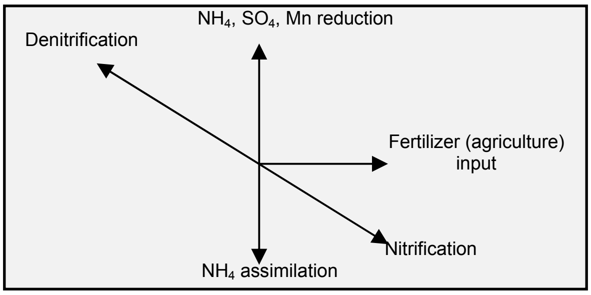

Fig. 4. Diagram of various forms of pollution according to the orientation in the ammonium nitrate-diagram; source [CHAOUI *et al.* 2013a]

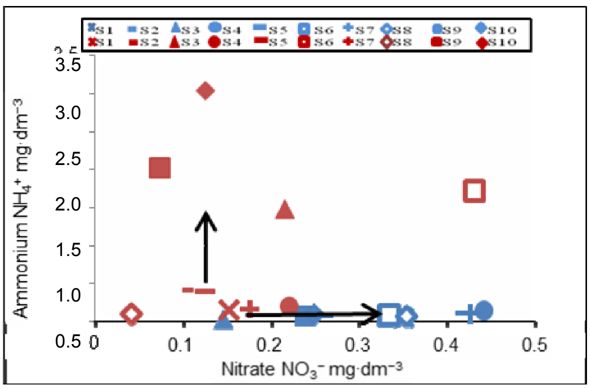

Fig. 5. Diagram (surface waters) of ammonium nitrate high water (average September and December 2013 in blue) and low water (average March and June 2014 in red); source: own study

Nitrogen pollution can be estimated by the measurement of nitrite ion contents, nitrate and ammonium ions. The nitrate ions (NO_3^-) are mineral nitrogen most mobile form. Thus, the excessive levels of this ion in the surface water are linked to the intensive use of nitrogen chemical fertilizers.

According to the ammonium nitrate diagram (Fig. 4, 5) the ammonium increases from high water period to low water period at most sampling stations. Certainly, agriculture is the main source of ammonium ion [REGGAM *et al.* 2015], like shown in ammonium nitrate diagram (Fig. 5).

STATISTICAL STUDY

The Analysis in Principal Components (ACP) is a tool for analysis of data which makes it possible to explain the structure of the correlations by using linear combinations of the original data.

The ACP aims to present, in a graphical form the maximum of contained information in data table based on the principle of double projection on the factorial axes.

The pH, the temperature, conductivity, total hardness, silicas, the nitrates, the nitrites, the chlorides and new ammonium variables are treated by ACP, followed in 10 stations over 12 months duration divided into two period; wet (high waters) and dries (low waters).

The ACP was carried out on a matrix of data made up of 10 lines representing the prospected sampling stations and 9 columns representing the measured physicochemical variables.

The goal of the analysis is to obtain a small number of linear combinations of the 10 variables which represent the major part of the variability of the data.

Period of high waters. The values of correlation calculated between the physicochemical parameters study (the temperature, pH, electric conductivity, total hardness, chlorides, silicas, nitrates, nitrites, and ammonium) which is relating to the period of high waters of the Wadi Bounamoussa; are carried in the Table 2 which represents the averages of the values recorded during the time of high waters.

The factorial design (F1, F2) watch an expression of more than 68% (Fig. 6). The axis F1 illustrates a variance equal to 40.02% which is expressed towards its positive pole by the ions nitrites, the ions chlorides and the electric conductivity which present a strongly significant correlation between them which results in a strong mineralization. The axis F2 illustrates a variance equal to 28.15% consisted a significant correlation between the ions nitrates and the ions ammoniums towards its pole positive, contrary to the pH which correlates negatively with this axis towards its pole negative. Thus one can say that the axis F2 indicates an organic pollution expressed by the phenomenon of nitrification.

Period of low waters. The values of correlation of the physicochemical parameters during the period of low waters are consigned in the Table 3.

The projection of these variables in the space of the axes F1 and F2 shows their good distribution and representation for the period of low waters 67.36% (Fig. 7). The axis F1 (47.12%) is expressed by its positive pole by the ions chlorides, the hardness total, opposed

Table 2. Stamp correlation of the physicochemical parameters (period of high waters)

Parameter	*T*, °C	pH	*EC*	TH	Cl^-	Silica	NO_2^-	NO_3^-	NH_4^+
T, °C	1	–	–	–	–	–	–	–	–
pH	–0.464	1	–	–	–	–	–	–	–
EC	0.063	0.132	1	–	–	–	–	–	–
TH	0.096	0.040	0.480	1	–	–	–	–	–
Cl^-	–0.087	0.179	**0.956**	0.616	1	–	–	–	–
Silica	–0.089	0.023	0.128	–0.040	0.108	1	–	–	–
NO_2^-	–0.172	0.226	**0.929**	0.537	**0.946**	0.331	1	–	–
NO_3^-	**0.660**	–0.469	–0.276	0.046	–0.290	0.207	–0.384	1	–
NH_4^+	0.546	–0.469	–0.022	0.185	–0.051	–0.047	–0.194	**0.776**	1

Explanations: *T* = temperature, *EC* = electrical conductivity, TH – total hardness.
Source: own study.

Table 3. Stamp correlation of the physicochemical parameters (period of low waters)

Parameter	*T*, °C	pH	*EC*	TH	Cl^-	Silica	NO_2^-	NO_3^-	NH_4^+
T, °C	1	–	–	–	–	–	–	–	–
pH	**0.844**	1	–	–	–	–	–	–	–
EC	**–0.765**	**–0.953**	1	–	–	–	–	–	–
TH	–0.403	–0.600	**0.782**	1	–	–	–	–	–
Cl^-	–0.374	–0.544	**0.722**	**0.977**	1	–	–	–	–
Silica	–0.022	0.312	–0.267	0.045	0.139	1	–	–	–
NO_2^-	–0.440	–0.277	0.081	–0.283	–0.239	0.239	1	–	–
NO_3^-	–0.061	0.163	–0.278	–0.279	–0.353	0.404	0.078	1	–
NH_4^+	–0.288	–0.360	0.474	**0.657**	**0.680**	0.507	–0.072	0.163	1

Explanations as in Tab. 2.
Source: own study.

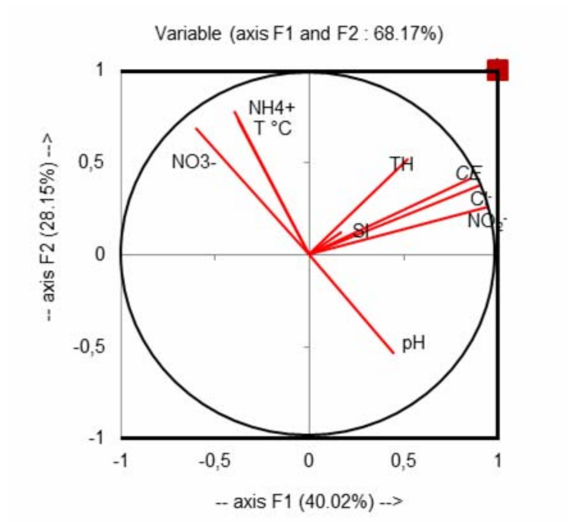

Fig. 6. Stamp correlation of the physicochemical parameters (period of high waters); source: own study

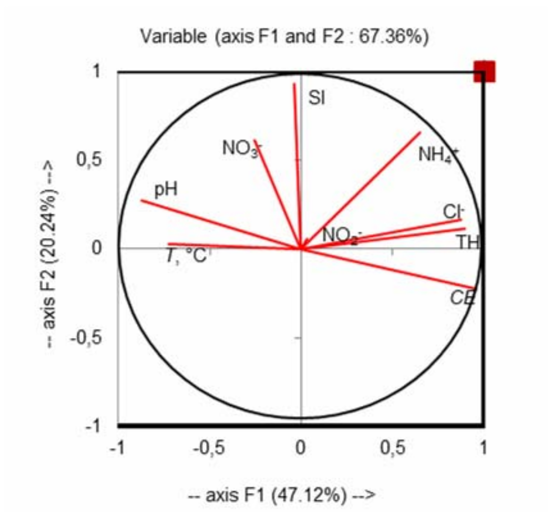

Fig. 7. Stamp correlation of the physicochemical parameters (period of low waters); source: own study

to the pH and the temperature. One can estimate that the axis F1 defines a gradient of mineralization. The water of Wadi Bounamoussa regarded as being a medium at least oxygenated, which testifies to a disturbed ecological state of the aquatic environment.

CONCLUSIONS

In general, measured contents of different ions along the rivers evolve gradually from upstream to downstream and result in a significant mineral and organic charge. Thus, among the 10 station studied, river's mouth was the most affected. It is dependent on the large amount of domestic wastewater and the discharges are being directly connected to the sea. Electrical conductivity and total hardness are the two indicators of water mineralization that evolve in parallel. A rise in electrical conductivity can be explained by the increase in water chloride concentrations, especially in the last two stations downstream.

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Fizyczne i chemiczne właściwości wód powierzchniowych uedu Bounamoussa w północnowschodniej Algierii

STRESZCZENIE

Azot jest pierwiastkiem biogennym, który powoduje eutrofizację wód śródlądowych i morskich. Eutrofizacja stała się przedmiotem zainteresowania w skali światowej, ponieważ znacząco pogarsza jakość środowiska wodnego. W badaniach prezentowanych w niniejszej pracy skupiono się na fizycznych i chemicznych parametrach jakości wody rzeki Bounamoussa celem zdiagnozowania eutrofizacji tego cieku. Rzeka drenuje zlewnię zdominowaną przez nawadniane uprawy roślin oraz chów owiec i bydła. Nawozy azotowe i odchody zwierzęce stanowią potencjalne źródło zanieczyszczeń. Azot dociera do systemu wodnego zarówno w postaci nieorganicznej, jak i organicznej. Monitorowano temperaturę, pH, stężenie rozpuszczonego tlenu, NH_4^+, NO_3^- i NO_2^- w próbkach wody pobranych we wrześniu i grudniu 2013 r. (stan niskiej wody) oraz w marcu i czerwcu 2014 (stan wysokiej wody). Próbki pobrano w 10 stanowiskach usytuowanych w dół biegu rzeki od zapory El Cheffa do ujścia rzeki Batah. Uzyskane wyniki dowodzą, że temperatura, pH, przewodność elektrolityczna i zawartość krzemu miały znacząco większe wartości w okresie niskich stanów wody niż w okresie wysokich stanów wody. Zanotowano rosnący gradient stężenia chlorków z biegiem rzeki – od 30,52 $mg \cdot dm^{-3}$ w górze rzeki do 9964,6 $mg \cdot dm^{-3}$ w dolnych odcinkach rzeki. We wnioskach stwierdzono, że obecność nieorganicznych form azotu nie stwarza ryzyka eutrofizacji rzeki i jej odbiornika.

Słowa kluczowe: *azot, eutrofizacja, jakość wody, ued Bounamoussa, właściwości fizyczne i chemiczne*