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Impact of Hydraulic Developments on the Quality of Surface Water in the Mafragh Watershed, El Tarf, Algeria

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ABSTRACT

The wadis are environments of great ecological and economic importance. They are the seat of several hydraulic developments. The latter disrupts the functioning of the wadi in different ways. They modify their hydrological regime, disrupt the ecological conditions upstream and downstream of the reservoir, reduce the self-purification capacities, and modify the processes of erosion and solid transport. It is in this perspective that we have carried out a study of the impact of hydraulic installations on the quality of the waters of the Mafragh watershed. The hydrographic network of the watershed receives the wastewater discharged by the localities and by the industries located along these rivers. This wastewater contributes to the degradation of the water quality of the wadis. The spatio-temporal variation of the water quality index showed a good quality at the level of the dams, while at the level of the sites, which are located downstream, the quality generally varies between bad and very bad during the study period.

INTRODUCTION

The Wadis are environments of great ecological and economic importance. They are the seat of intense human activity and hydraulic developments leading to spills of various types of pollutants, which disrupt the natural functioning of these ecosystems (Amiard 1989, Bryan & Langston 1992).

Several research studies around the world (Cheggour 1988, Dahbi 1989, Jarvie et al. 2003, Baran et al. 2007, Duh et al. 2008, Bharti & Katyal 2011, Manjusha et al. 2013, Sharma et al. 2014, Satish Chandra 2017) have shown the effect of hydraulic developments and anthropogenic discharges on the degradation of the physico-chemical quality of water in watercourses.

In the Algerian wadis, several authors have highlighted such contaminations (Debieche et al. 2003, Benrabah et al. 2013, Zenati 2010, Zenati et al. 2013, Bougherira et al. 2014, Bellazi et al. 2020) which are due to domestic and industrial activities. The Mafragh watershed, one of the most temperate and watered regions of Eastern Algeria, breathes through only one outlet, which is the Mafragh wadi. The construction of the dams was responsible for reducing the effects of flooding in the watershed. The expansion of urban and industrial areas has caused significant environmental consequences in terms of surface water pollution.

Several indexes of the physico-chemical quality of water have been developed and used in different countries around the world, such as France (MESD & Water Agencies 2003), Spain (Queralt 1982, Fernandez-Alaez et al. 1992) Canada, (Provencher & Lamontagne 1979, Hebert 1997, 2005), the United States (Otto 1978), Mexico (Alvarez 2006), etc.

The methodology followed in our study is to use the water quality index (WQI) of the Canadian Council of Ministers of the Environment (CCME) to provide a mathematical framework for assessing ambient water quality conditions regarding water quality objectives. It offers a high degree of flexibility design in terms of the type and number of variables to be measured, the study period, and the type of water body examined (watercourse, section, lake, etc.).

MATERIALS AND METHODS

Study Area

The Mafragh watershed is located in the extreme northeast of Algeria (Fig. 1), which is part of the Constantine coastal basins from where the definition of the Constantine-East coastal basin appropriated it. This basin, which has longitudes ranging from 7°45' to 8°45' East and latitudes ranging from 36°20' to 36°55' north, does not encompass the entire area of El Tarf state.

It is drained by two important watercourses, wadi Bounamoussa to the west and Wadi El Kebir East to the east. They converge towards the marsh (more than 8,900 ha) called the MeKhada tide and reach the sea through a single outlet, wadi Mafragh.

Wadi Bounamoussa originated under the name of Wadi El Kebir at Koudiat Ben Ahmed (1729 m). The confluence of Wadi El Kebir and Wadi Bouhadjar gives birth to Wadi Bounamoussa. It drains a watershed of 1,135 km^2. It receives tributaries such as Wadi Sudan, wadi Guerriah, and the Chabet El Erg to its confluence with Wadi El Kebir East. A dam is built on this wadi, intended to satisfy the demand for water for the city of Annaba, for industry, and the irrigated perimeter of Bounamoussa.

The second wadi, El Kebir East, has its upper course formed by three wadis: two in Tunisia, the Kebir proper and the Ballauta, and an Algerian Oued Bougous. Their confluence is located in the small pre-coastal plain of Mexena. It drains a watershed of (1685 km^2). Two Mexa and Bougous dams are built on this wadi intended for the supply of drinking water for the two states of El Tarf and Annaba.

In the plain of El Tarf, wadi El Kebir East receives Wadi Guergour and Wadi Bouhalloufa, inc1uding a dam under construction with a capacity of 50 hm^3 and Wadi Boulathan. In the northeast, it receives wadi Messida. In the dune massif of Bouteldja, wadi El Kebir East receives three tributaries: wadi Bourdim, wadi Bouglez, and Wadi El Bahaim. These tributaries play an important role in surface flow and the supply and drainage of groundwater.

The hydrographic network draining the region is the subject of 4 studies for the construction of dams, allowing the satisfaction of water needs of all sectors for the two states of El Tarf and Annaba. The projected dams have a lower capacity with 52 hm^3 at the Bougous dam, 20 hm^3/year at the Boulatane dam, 20 hm^3 at the Guergour dam, and 65 hm^3 at the Bounamoussa dam2.

The study region, by its agricultural vocation and its soil-climatic conditions, is an important agricultural pole in eastern Algeria. The cultivation practices identified are market gardening, industrial, grain farming, fodder, and tree crops, as well as pastoral farming.

Industry in the region occupies a less important place in the socio-economic development. It is dominated by small and medium-sized food industries characterized mainly by tomato paste.

Geological studies carried out by Joleaud (1936), Villa (1980), and Marre (1992) show the existence of two large sets:

The set of coastal plains is characterized by recent quaternary sediments, which constitute the bottom of this tectonic depression, and Numidian sandstones, which constitute the summits, the most important of which are located around the town of Daghoussa.

The allochthonous Sets of units constitute:

- Mauritanian flyschs, which are mainly composed of alternating clay and calcareous clay banks. They cover small areas upstream from El Kebir East.
- Massylian flysch is formed mainly by marls and clays with very thin sandstone and limestone banks. They are exposed in the various places of the mountain of Cheffia.

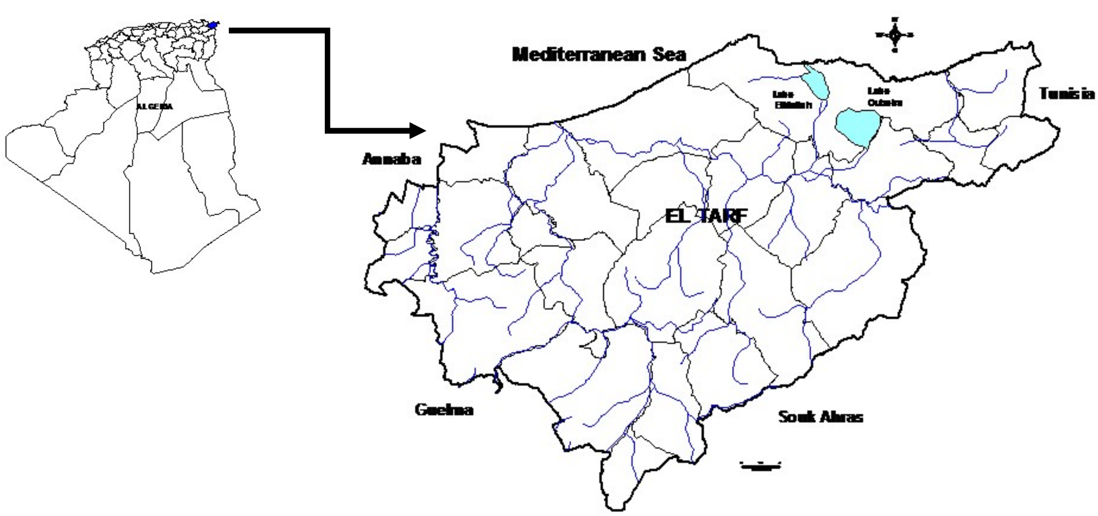

Fig. 1: Map of the location of the study area.

- The Numidian aquifer constitutes the southern relief of the watershed. This series is composed of Numidian sandstones, sub-Numidian clays, and supra-Numidian clays.

The general evolution of the climate in the region is characterized by a dry climate in September and October. Whereas, from November to April the climate is humid throughout the region. In May, the climate becomes dry to very dry. In June, it is very dry. The situation deteriorates further in July and August. The climate is then hyperarid in the majority of the stations.

Sample and Analysis

We assessed the level of water quality in the hydrographic network of the Mafragh watershed, which receives several discharges, based on a spatio-temporal sampling protocol covering the year 2017 and 11 sampling sites, namely (Fig. 2):

- Mexa Dam (D1),
- Cheffia Dam (D2),
- Wadi El Kebir East (S1, S5 et S6),
- Wadi Gourgour (S2),
- Wadi Bouhalloufa (S3),
- Wadi Boullathan (S4),
- Wadi Bounamoussa (S7 and S8),
- Wadi Mafragh (S9).

During the water sample collection campaigns, we respected the sampling standards "filtration (0.45 µm filter), acidification (5 mL HCl or HNO_3) and storage (4°C)" (AFNOR/T91E).

The physico-chemical parameters (pH, temperature, conductivity) are measured in situ using a multi-parameter WTW device (multi 340i / SET). The analysis of the chemical elements was carried out by volumetry (Cl^-), atomic absorption with flame, and colorimetry.

Methodology

The Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI) provides a mathematical framework for assessing ambient water quality conditions regarding specific objectives. It offers great flexibility in terms of the type and number of variables to be measured, the period of study, and the type of water body examined (watercourse, section, lake, etc.).

The calculation of the IQE Indexis:

$$IQE = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) \quad \ldots(1)$$

The calculation of the index is based on three terms:

Scope (F1) - number of variables non-conforming with water quality recommendations;

Frequency (F2) - number of times where these recommendations are not followed; and the amplitude (F3) - deviation of the non-conforming measurements compared to the corresponding recommendations.

The division of these terms by 1.732 comes from the fact that each of the three factors that make up the index can

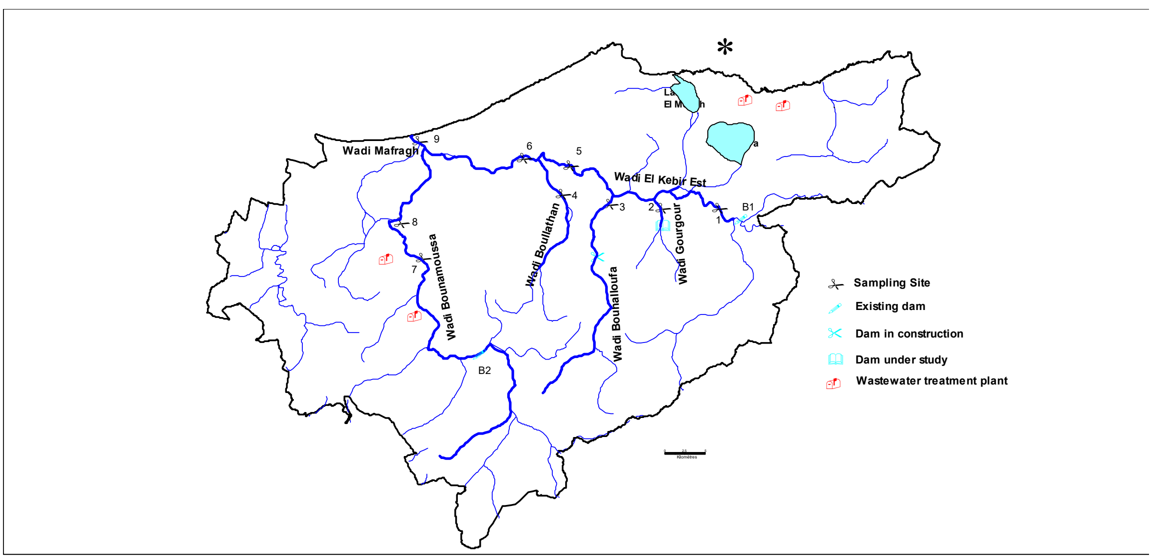

Fig. 2: Map of location of sites.

reach the value of 100. The maximum length is, therefore:

$$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30\,000} = 173.2 \quad \ldots(2)$$

This division by 1,732 has the effect of reducing the maximum length to 100. The index produces a value which is between 0 and 100. The higher the number, the better the quality of water.

Explanation of Each of the Index Terms

First of all, the term F1 (range) represents the percentage of parameters of which at least one measurement is non-conforming with the corresponding recommendation during the study period:

$$F_1 = \left(\frac{numberofnonconformingparameters}{total\ number\ of\ deparameters}\right) \times 100 \quad \ldots(3)$$

Then, the term F2 (frequency) represents the percentage of analytical results non-conforming with the recommendations.

$$F_2 = \left(\frac{numberofnonconformingresults}{total\ number\ ofresults}\right) \times 100 \quad \ldots(4)$$

Finally, the term F3 (amplitude) represents the gap between the non-conforming analytical results and the recommendations to which they relate. The term F3 is an asymptotic function that brings the normalized sum of the deviation coefficients (nsdc) compared to the recommendations within a range of values from 0 to 100.

$$F_3 = \left(\frac{nsdc}{0.01 * sndc + 0.01}\right) \quad \ldots(5)$$

To calculate the overall degree of nonconformity, add the gap coefficients of the nonconforming analytical results and divide this sum by the total number of analytical results. This variable is called the normalized sum of the deviation coefficients (nsdc).

$$nsdc = \left(\frac{\sum_i gapcoeffessanti}{totalnumberofresults}\right) \quad \ldots(6)$$

To determine the gap coefficient, we have three possibilities:

- If the result should not exceed the recommendation:

$$\text{Gap coeffesant i} = \left(\frac{nonconformingresultsi}{Recommandationi}\right) - 1 \quad \ldots(7)$$

If the result should not be inferior to the recommendation:

$$\text{Gap coefficient i} = \left(\frac{Recommandationi}{nonconformingresultsi}\right) - 1 \quad \ldots(8)$$

- If the recommendation is null (equal to zero):

Gap coefficient i = nonconforming results

RESULTS AND DISCUSSION

Hydrochemical Typology of Waters

The surface waters of the Mafragh watershed contain several chemical facies, among them calcium bicarbonate, sodium chloride, sodium bicarbonate, calcium chloride, and potassium bicarbonate facies. However, the calcium bicarbonate facies remain the most dominant. In detail, these waters are distributed between two hydrochemical poles:

- A calcium bicarbonate pole. It is the most dominant facies. It characterizes almost all of the surface waters, with a percentage of 72% of the total sum of the samples.
- A calcium and sodium chloride pole:
    - The calcium chloride facies are the second facies from the point of view of importance. It corresponds to 14% of the total sum of the samples. It is recorded at Wadi El Kebir East and its tributaries.
    - The sodium chloride facies are observed only at the level of Wadi Mafragh.

With the exception of station 9 of Wadi Mafragh, where the influence of the sea and the marshy zone on the concentrations of major elements has been noted, the other stations are under the influence of discharges of domestic and industrial wastewater record values of conductivity and major ion contents less high compared to that of wadi Mafragh (Table 1).

In order to establish a relationship between the different physico-chemical parameters and to better assess the effect of hydraulic developments and anthropogenic discharges on the water quality of the Mafragh watershed. The statistical processing of the principal component analysis and the analysis of variance was carried out on 9 sites and 12 variables: Conductivity, T, pH, Ca^{2+}, Mg^{2+}, Na^+, K^+, TAC, SO_4^{2-}, and Cl^-. NO_3^- and NO_2^-.

Data processing by PCA, using as variables the T°, pH, Conductivity, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NO_3^-, NO_2^- and TAC; and as noted, the 79 samples taken from the 9 sites prospected on the hydrographic network of the Mafragh watershed, reveal several axes. The first two express the maximum of the variance (56.43%). The information given by axis 1 corresponds to 31.6% of the variance, and axis 2 represents 24.83% (Fig. 3).

The distribution of physico-chemical variables according to the F1-F2 plan presented on the positive side of the F1 axis a positive correlation with the conductivity, Cl^-, Na^+, SO_4^{2-}, Ca^{2+}, and Mg^{2+}. This axis reflects a combination of indigenous ions and elements reflecting the mineralization of waters linked to anthropogenic activities. Moreover, the anthropic effect on these sites is noted by their high levels of descriptors of anthropization (Cl^-, Ca^{2+}, and Na^+), as underlined by Mary (1999) and Gouiadia (2008) in New Caledonia and Algeria, respectively.

Table 1: Mean and extended values of the measured physico-chemical parameters.

		T	pH	Cond	TAC	Cl^-	NO_2^-	NO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}
Site1	Max	26,06	8,10	889,00	145,00	53,16	5,20	25,00	64,38	105,60	113,11	17,77	104,32
	Min	10,59	7,13	443,00	100,00	13,41	0,01	0,00	3,36	4,32	25,99	9,93	29,31
	Moy	19,18	7,53	686,45	127,36	38,89	1,92	6,35	24,28	32,28	59,57	12,71	49,34
Site2	Max	22,50	7,55	1049,00	330,00	547,20	74,00	13,00	54,23	85,95	88,51	65,34	90,05
	Min	10,67	7,18	508,00	150,00	39,87	4,50	2,40	1,84	6,14	27,81	11,66	58,77
	Moy	15,43	7,40	891,43	223,00	218,13	18,33	7,17	14,16	53,97	65,33	23,56	68,48
Site3	Max	22,21	7,83	772,00	241,00	443,00	4,00	33,00	56,98	86,25	94,54	50,05	69,34
	Min	9,90	7,30	248,00	107,00	22,15	0,05	1,35	2,52	4,56	29,35	10,71	22,34
	Moy	14,92	7,50	568,57	164,14	161,19	2,41	8,11	17,43	49,96	62,83	19,94	44,57
Site4	Max	22,86	7,87	941,00	300,00	115,00	7,00	38,00	117,92	90,31	134,26	21,17	59,31
	Min	9,97	7,10	442,00	97,00	31,31	0,07	2,20	2,52	6,64	29,35	10,71	27,55
	Moy	15,48	7,44	828,71	190,04	73,84	4,07	10,97	37,39	56,31	70,73	15,52	39,25
Site5	Max	26,89	7,66	2223,00	240,00	443,00	5,10	47,00	373,19	86,04	128,24	36,53	210,30
	Min	9,83	6,86	522,00	80,00	66,45	0,00	0,10	5,82	9,08	38,30	10,18	26,38
	Moy	15,93	7,25	1307,86	161,63	173,52	2,40	9,27	100,95	48,61	83,92	18,73	102,49
Site6	Max	24,71	7,80	817,00	213,00	133,14	13,00	13,00	178,32	91,55	79,77	18,95	55,44
	Min	10,69	7,20	380,00	101,00	13,29	0,00	0,20	4,08	6,13	28,44	10,48	19,41
	Moy	15,92	7,46	659,00	154,29	85,49	3,71	4,68	38,05	50,92	63,48	13,07	36,01
Site7	Max	26,85	7,95	826,00	171,00	70,21	4,50	16,33	79,35	71,40	109,21	20,55	59,23
	Min	10,03	7,45	449,00	60,00	22,15	0,01	0,88	1,78	5,96	23,93	9,36	25,24
	Moy	19,15	7,72	663,09	131,23	54,79	1,30	7,93	37,54	29,36	65,20	15,53	43,28
Site8	Max	26,55	8,03	826,00	161,00	80,30	4,00	19,35	80,25	93,74	101,24	29,32	60,24
	Min	9,33	7,30	430,00	60,00	17,73	0,00	0,50	3,53	6,25	39,26	10,08	22,14
	Moy	19,04	7,68	632,45	125,01	59,21	1,19	8,39	41,34	36,90	70,36	18,61	46,21
Site9	Max	26,21	8,05	7780,00	256,00	2000,41	4,20	40,87	1998,36	95,04	290,46	139,92	143,06
	Min	11,15	7,38	473,00	100,00	48,73	0,11	0,00	4,15	10,03	42,78	10,89	56,37
	Moy	19,63	7,68	4701,00	207,39	1232,44	1,61	13,95	1136,17	45,68	172,39	63,69	123,11

According to axis F2, the variables most correlated to this main component are NO_2^-, K^+, NO_3- and T. This axis F2 reflects the impact of agriculture and the discharge of wastewater on certain watercourses like El Kebir East at site 00, wadi Guergour and Bouhalloufa.

Since other variables (TAC and pH) are close to the center of the factorial plan, their correlation is certainly not very strong. These variables are probably better explained by other main components, other than F1 and F2.

An ascending hierarchical classification made from individuals in a sampling cycle made it possible to complete the information from the CPA and to classify the sites into two groups. Two main groups are identified in Fig. 4.

The first group represents waters with very strong mineralization with very high Na^+ and Cl^- values, taken from Oued Mafragh. It is the most loaded with dissolved mineralization. It reflects the polluting load contained in the waters of the two Wadis of Bounamoussa and El Kebir East and the effect of the Mekhada marsh and the sea on the increase in the concentration of these two chemical ions.

High levels of HCO_3 mark the second group$^-$ and Ca^{2+}. It is the water taken from the rest of the sampling sites. These high levels reflect wastewater discharges and leaching of carbonate rocks.

The typology highlighted by the CPA and the CAH is linked to the contributions of mineral elements by anthropogenic activities of varying intensity depending on the sites is a natural mineralization process linked to water-rock contact and to the through fall phenomena. Indeed, the station under strong anthropic and geological influence records the highest values of conductivity and major ion contents. It is the Mafragh wadi station high in Cl^- and Na^+ are explained by the geology of the region (Mekhada

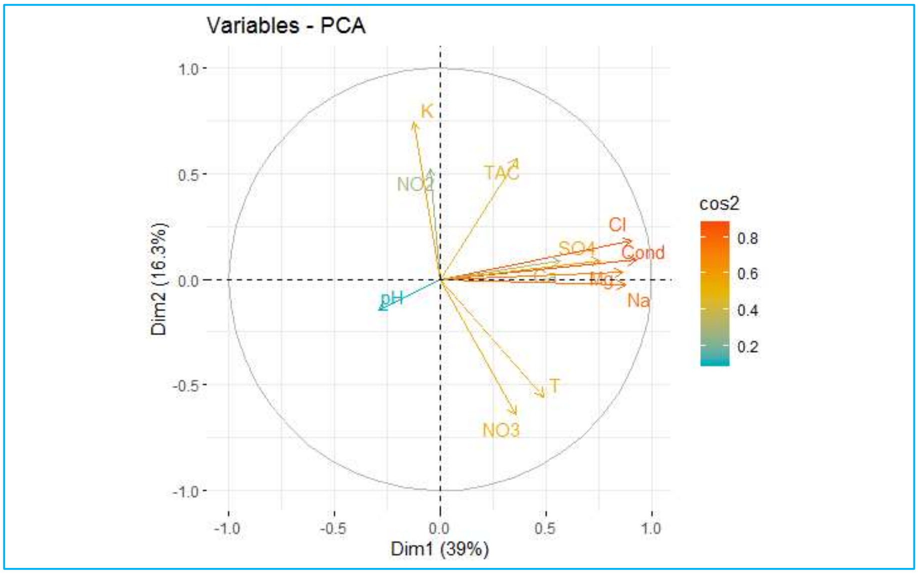

Fig. 3: Correlation circle of physico-chemical variables.

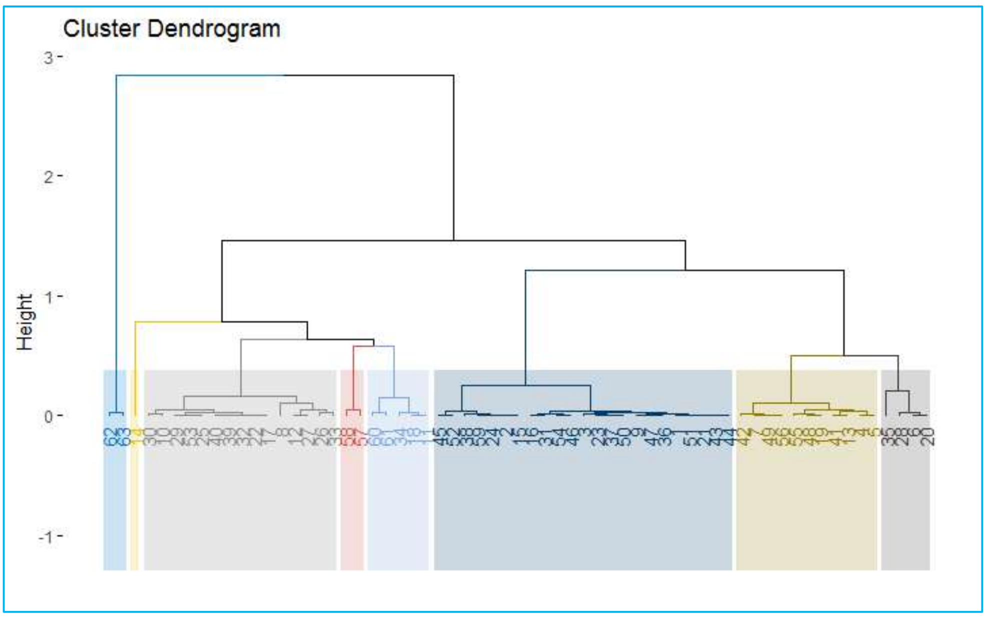

Fig. 4: Hierarchical classification of individuals

marsh), the contribution of discharges by the two wadis of Bounamoussa and El Kebir east and the sea.

In order to test the spatial effect and the temporal effect, the two-factor analysis of variance (Friedman test), carried out on the physico-chemical parameters of the waters of the Mafragh watershed, reveals significant differences ($P < 0, 05$) between stations (Table 2) for the contents of calcium, sodium, sulfate, chloride, complete alkaline titer, and conductivity.

Comparison of the variances by the same test does not reveal significant differences in the magnesium, nitrite, nitrate, and potassium content between seasons ($P \geq 0.05$).

Spatio-Temporal Variation of the Water Quality Index

In order to be able to follow the evolution of water quality at the scale of the Mafragh watershed, a calculation of the water quality index for all of the watershed sites monitored during 2017 has been realized. With regard to the two Mexa

Table 2: Comparison of the parameters according to the two factors “site” and “time”.

	T	pH	Cond	TAC	Cl^-	NO_2^-	NO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}
p	1	0.036	$8.1\ 10^{-7}$	0.0055	$4.1\ 10^{-7}$	0.027	0.88	0.00021	0.98	0.00087	0.011	$4.2\ 10^{-8}$

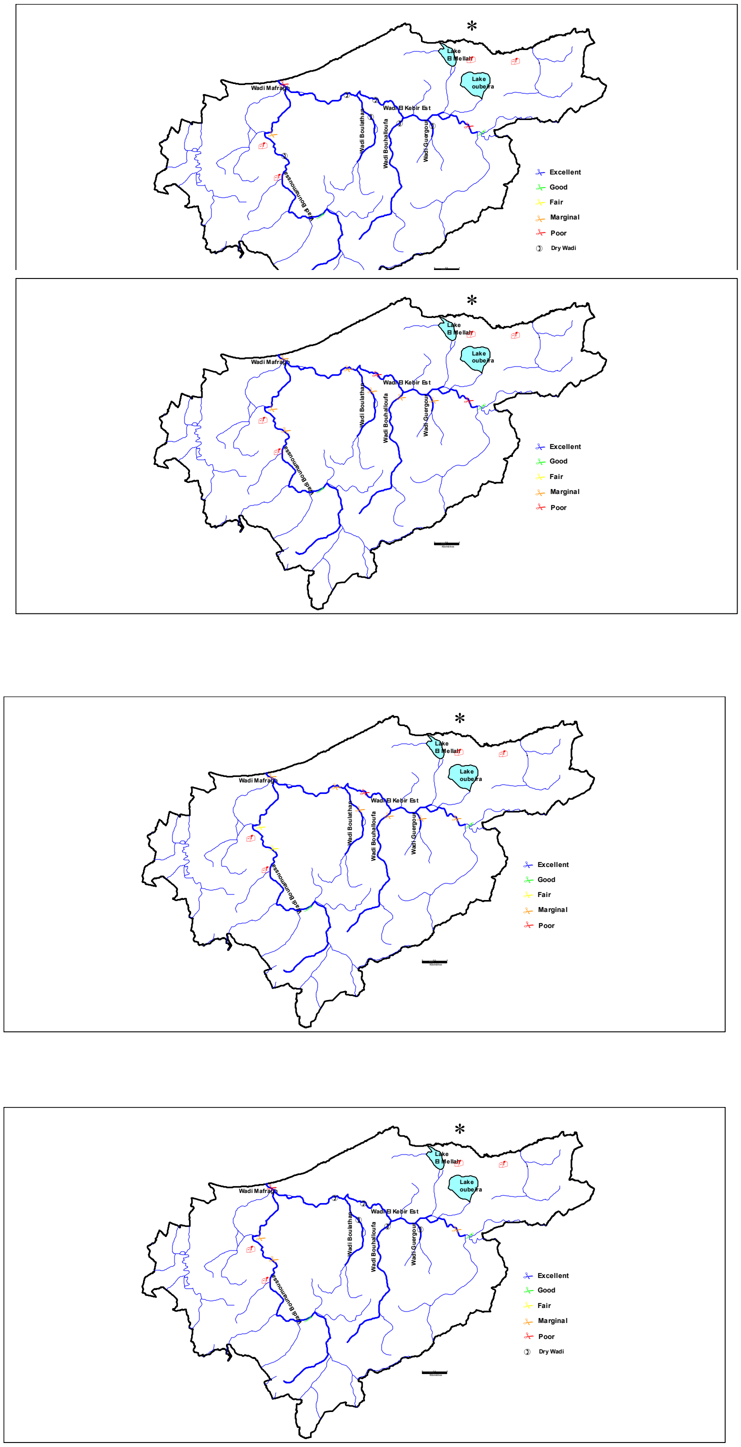

Fig. 5: Evolution of the water quality index.

and Cheffia dams, the time evolution of the overall quality shows that during 2017 a good quality. As for the level of the 9 sites (Fig. 5), the majority of the watercourses show very poor to poor quality.

During the spring, the quality showed a clear (fair) improvement in Oued Bounamoussa, in particular by the water releases from the Cheffia dam for farmers. These have greatly reduced the concentration of pollutants by diluting wadi water, increasing their flow rates and thus promoting their purification against the various polluting substances.

This quality deteriorated further during the summer and autumn at the level of watercourses due to a strong disturbance by anthropic activities and the drought that marked the summer period. The analysis of the minimum and maximum values of the physico-chemical quality parameters studied and the values of the surface water quality index at the level of the site during the period 2017 allows us to show large amplitudes of variations both spatially and temporally within the same site.

CONCLUSION

The deterioration in the water quality of the Mafragh watershed is mainly linked to upstream hydraulic developments and the absence of wastewater treatment plants. The sites studied reveal a multitude of impacts threatening the quality of the water (wastewater discharges without prior treatment).

The analysis of the physicochemical data obtained with regard to Algerian surface water quality standards indicates the quality of the majority of stations in the watershed is poor to very poor. This is explained by the fact that the water courses of this basin have an intermittent flow. They have black, mineralized water with very high salinity levels at Wadi Mafragh. Indeed, upstream hydraulic development does not ensure a continuous renewal of water and a dilution of pollutants in the water.

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