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تقييم جودة المياه في حوض بحيرة الرغاية (شمال الجزائر) باستخدام المنهجية التقليدية ومؤشرات جودة المياه

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الملخص

تُمثل مدينة الرغاية ، التي تقع في الجزائر (شمال الجزائر) نموذجًا قويًا للنشاط. تهدف هذه الدراسة لتقييم جودة المياه في حوض بحيرة الرغاية عن طريق تحديد الوضع الراهن ، التطور الزمني وتقسيم مصادر التلوث . تم أخذ ثلاث عينات من 14 محطة تُغطي البحيرة وروافدها الرئيسية . تم تحليل 16 مُعامل فيزيائي- كيميائي و3 مُعاملات ميكروبيولوجية. كما اُستخدم نظام تقييم جودة المياه السطحية (SW-QES) لوضع تصور للتطور الزمني للبيانات المتاحة في الفترة ما بين 1978-2017. استخدم البحث مؤشر جودة المياه (WQI) لتقييم جودة المياه وفقاً للمعايير المستخدمة لأغراض الري و لتحديد الاختلاف المكاني عبر حوض البحيرة . استخدمت الدراسة التصنيف الدولي لمنظمة التعاون الاقتصادي والتنمية (OECD) ومؤشر الحالة الغذائية (TSI) لتقييم الفئة التي تنتمي إليها البحيرة. كما تم استخدام مؤشر التلوث العضوي (OPI) ومؤشر الجودة المكروبيولوجية (MQI) لوضع خرائط توضح تلوث المنطقة محل الدراسة . تقدم البحيرة نموذجًا للتلوث المفرط منذ فترة السبعينات. يوضح معدل BOD_5 /COD (0.1) والذي تم تسجيله عام 2017 قابلية منخفضة للغاية للتحلل البيولوجي في مياه بحيرة الرغاية. يُشير مؤشر جودة المياه طبقاً لمجلس الوزراء الكندي للبيئة (14.31) (CCME-WQI) إلى النوعية الرديئة للمياه. كما يوضح البحث أن قيم أرجحية جودة المياه (WA-WQI) عالية للغاية (<4000) مما يشير إلى عدم ملائمة جودة المياه لأغراض الري. بحيرة الرغاية تنتمي للفئة المشبعة جدا ($TSI > 80$) ما تم تأكيده من خلال تصنيف . . . تصنيف منظمة التعاون الاقتصادي والتنمية .يُظهر البحث أن التوزيع المكاني لمؤشرات التلوث يشير إلى أن نهر رغاية ونهر البيار هما أهم مصادر التلوث . توضح حسابات أرجحية جودة المياه مع أو بدون القولونيات أن نهر رغاية هو أهم مصدر للتلوث الميكروبي. لاحظ البحث حدوث انخفاض طفيف في التلوث العضوي، وتحسن ملحوظ في الجودة الميكروبيولوجية عند مخرج البحيرة. ووفقًا لهذه النتائج ، فإن تصريف مياه الصرف الصحي بدون معالجة أومع معالجة غير كافيه هي المصدر الرئيس للتلوث في بحيرة رغاية والتي كانت بيئة مستقبلة لأعوام عديدة وستظل ملوثة اليوم وغدًا إذا لم نعمل بشكل فعال لإيقاف مصادر التلوث.

Water quality assessment in Réghaïa (North of Algeria) lake basin by using traditional approach and water quality indices

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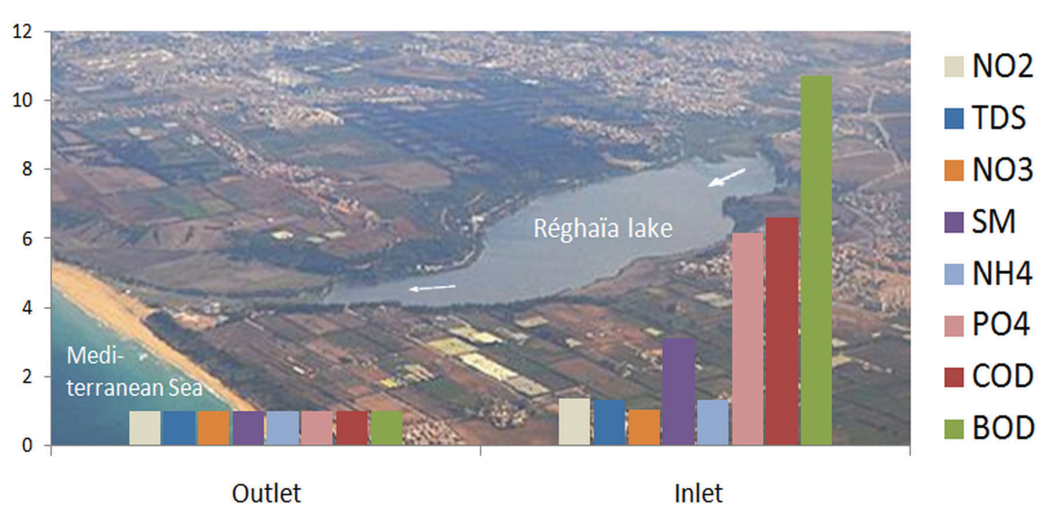
Abstract

Réghaïa town, located in Algiers (North of Algeria), presents a strong anthropogenic activity. The aim of this study is to assess water quality in the Réghaïa Lake basin by determining current status, temporal evolution and apportionment of pollution sources. Three samplings were carried out in fourteen stations covering the lake and its principal tributaries. Sixteen physico-chemical parameters and three microbiological parameters were analyzed. The Surface Water Quality Evaluation System (SW-QES) was used to visualize the temporal evolution of available data from 1978 to 2017. The water quality index (WQI) was used to assess the global water quality for irrigation purposes and its spatial variation across the basin. The Organization for Economic Co-Operation and Development (OECD) international classification and trophic state index (TSI) were used to evaluate the trophic category of the lake. The organic pollution index (OPI) and microbiological quality index (MQI) were used to establish pollution maps of the study area. The lake has presented excessive pollution since the 1970s. The BOD_5/COD ratio (0.1) recorded in 2017 indicates a very low biodegradability of Réghaïa Lake waters. The value of the Canadian Council of Ministers of the Environment-water quality index (CCME-WQI) (14.31) indicates poor water quality. The values of weighted arithmetic-water quality index (WA-WQI) are extremely high (>4000), which indicates unsuitable water quality for irrigation purposes. The hypertrophic nature of the Réghaïa lake was identified (TSI > 80) and confirmed by the OECD classification. Spatial distribution of pollution indicators shows that the Réghaïa River and ElBiar River are the most important pollution sources. Calculations of WA-WQI with and without Coliforms indicate that the Réghaïa River is the most important microbial pollution source. A slight decrease in organic pollution and remarkable improvement in microbiological quality was observed at the outlet of the lake. According to these results, sewage discharged without treatment or with insufficient treatment is the main pollution source of the Réghaïa Lake, which has been a receiving environment for many years, and will continue to be polluted if we do not react effectively by stopping the pollution sources.

Keywords: Réghaïa Lake; Ramsar site; Microbial pollution; Water quality assessment; SDG 6.3.

GRAPHICAL ABSTRACT



1. Introduction

In September 2015, 17 Sustainable Development Goals (SDG) were listed in the 2030 Agenda for Sustainable Development. The agenda includes dedicated goals for water (SDG 6), energy (SDG 7), food security (SDG 2) and others. For providing these primary human needs, water is an essential resource for each. It represents ¾ of the earth's surface and only 0.3% can be used by humans. Unfortunately, a significant part of this percentage is unusable. The main reason for that is the water quality requirement. Water quality is taken into account in SDG 6.3, which is measured by two indicators, namely: 6.3.1: Proportion of wastewater safely treated and 6.3.2: Proportion of bodies of water with good ambient water quality. The quality may be good enough for drinking but not suitable for use in an industry. The main question is: how do we express water quality?

The concept of water quality dates back to 1848 in Germany (Lumb *et al.,* 2011); The traditional approaches are based on a comparison of experimentally measured parameter values with existing guidelines, but it is very difficult to evaluate the quality from a large number of samples each containing concentrations of many parameters (Abukila, 2015). Water quality indices aim at giving value to the water quality. They translate concentrations of constituents present in a sample to a single value. They are structured to be interpreted in one of two ways. Firstly, increasing scale indices, the index numbers increase with the degree of pollution this is called a "pollution index". Secondly, decreasing scale indices or "quality indices", in which the index numbers decrease with the degree of pollution (Misaghi *et al.,* 2017). But "water quality" is a general term and "water pollution" is a special case which indicates undesirable water quality (Abbasi & Abbasi, 2012).

In this study, we have used two traditional approaches and four indices, namely: the Organization for Economic Co-Operation and Development (**OECD)** classification, Surface Water Quality Evaluation System (**SW-QES**), Water Quality Index (**WQI**), Trophic State Index **(TSI)**, Organic Pollution Index (**OPI**) and Microbiological Quality Index (**MQI**), respectively. These methods were used to assess water quality in Réghaïa Lake and its principal tributaries. Because of the demographic growth and industrial expansion in the area during the last decades, the lake receives a significant part of urban and industrial sewage and drains continuously into the Mediterranean Sea a large amount of water. A water pumping station is installed in the lake in order to irrigate farmland surrounding it, but, unfortunately, it is not functional because of the water pollution.

Pollution in the Réghaïa Lake basin is considered to be a significant problem and research on this issue is limited. The main objective of this study was to assess the water quality by determining its current status, temporal evolution and apportionment of pollution sources. Information presented in this study aims at establishing a water quality database where none existed previously.

2. Material and methods

2.1 Study area:

The Réghaïa Lake (Ramsar site since 2003) (Figure 1), located in North-Eastern of Algiers (36°45'-36°48'N,03°19'-03°21'E) near one of the most developed industrial regions in Algeria, has received considerable attention due to its severe pollution. In the nearby towns, a large amount of raw sewage and urban waste is deposited on the banks of the lake due to the lack of municipal waste management systems. These human activities threaten the quality of water by increasing concentration of mineral and organic matter. The Réghaïa River, ElBiar River and Réghaïa wastewater treatment plant drain treated and not treated wastewater into the lake. The outlet of the lake discharges into the Mediterranean Sea, which is extensively used for bathing, fishing and other recreational activities.

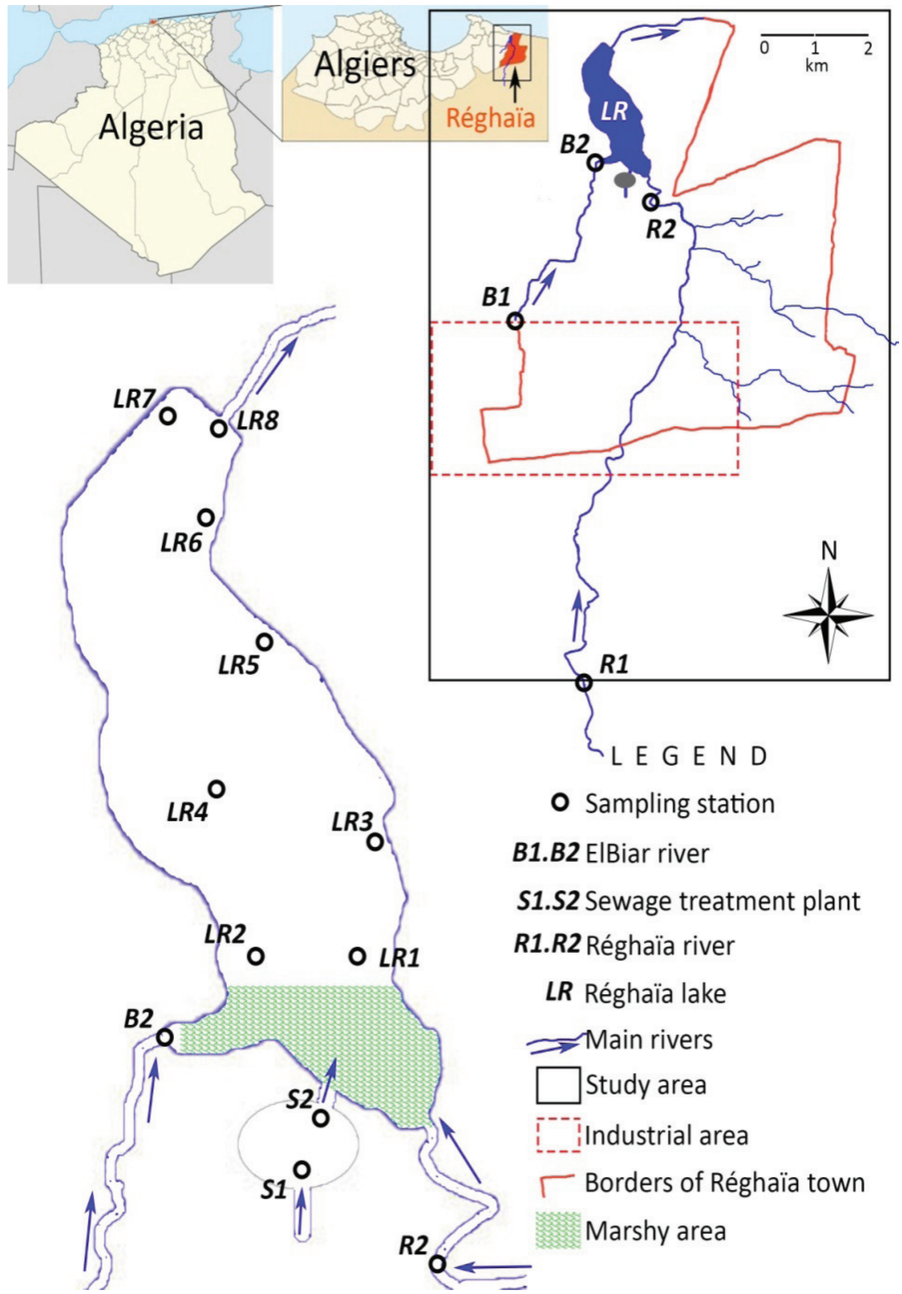


Fig. 1. Study area

2.2 Sample collection

For the purpose of this study, water samples were collected from 14 sampling stations (Figure 1, Table 1) monitored monthly from February to May 2017. There were eight (08) stations (LR1 to LR8) from Réghaïa lake and six (06) stations from its three tributaries: the Réghaïa River (R1 and R2), ElBiar River (B1 and B2) and Réghaïa wastewater treatment plant (S1 and S2), selected on the basis of their accessibility and contamination vulnerability.

Water samples were collected in sterile glass bottles for bacteriological analysis and polyethylene bottles for the other parameters, and transported on ice back to the laboratory.

Table 1. Sampling stations

Location (description)	Code	Coordinates
Khemis-El-Khechna	R1	36°40>40.10»N 3°19>44.17»E
Réghaïa	R2	36°45>21.13»N 3°20>26.30»E
Réghaïa-Rouiba industrial area (industrial wastewater)	B1	36°44>17.69»N 3°19>8.53»E
Ain-Kahla	B2	36°45>44.36»N 3°19>58.03»E
Wastewater treatment plant (Raw water)	S1	36°45>24.63»N 3°20>18.32»E
Wastewater treatment plant (Treated water)	S2	36°45>34.17»N 3°20>16.15»E
Réghaïa Lake	LR1	36°45>56.49»N 3°20>18.54»E
Réghaïa Lake	LR2	36°45>55.57»N 3°20>8.35»E
Réghaïa Lake	LR3	36°46>3.70»N 3°20>20.78»E
Réghaïa Lake	LR4	36°46>10.02»N 3°20>2.77»E
Réghaïa Lake	LR5	36°46>22.23»N 3°20>12.44»E
Réghaïa Lake (Pumping station for irrigation)	LR6	36°46>35.02»N 3°20>3.15»E
Réghaïa lake	LR7	36°46>44.23»N 3°19>56.68»E
Réghaïa Lake	LR8	36°46>45.77»N 3°20>4.84»E

2.3 Physico-chemical and microbiological analysis

The data set taken in this study is comprised of 19 parameters. Water temperature (T), pH, electrical conductivity (EC), dissolved oxygen (DO), total dissolved solids (TDS) and salinity (S) were determined *in situ* using previously calibrated HANNA® equipment HI 9829. Water transparency (SD) was determined by Secchi disc visibility. The remaining variables were characterized later at the laboratory using the procedures and methodologies recommended by the following international standards: chemical oxygen demand (COD)(ISO 6060), 5-day biochemical oxygen demand (BOD_5)(ISO 5815-1), suspended solids (SS)(ISO 11923), nitrite (NO_2)(ISO 6777), nitrate (NO_3)(ISO 7890-3), ammonia (NH_4)(ISO 7150/1), phosphorus (PO_4)(ISO 6878), *Enterococcis* (Ent) (ISO 7899-2), Total Coliforms (TC) and fecal Coliforms (FC)(ISO 9308-1).

2.4 Surface Water Quality Evaluation System

This system was used to visualize temporal (historical) evolution of pollution in Réghaïa Lake. A color code was used to build Table 2, in which each parameter value is translated to a color: blue, green, yellow, orange and red, which correspond respectively to very good, good, moderate bad and very bad water quality (MEDD & Agences de l'eau, 2003). Data used in this section were collected from the Higher National Agronomic School (ENSA) and Higher National Polytechnic School (ENSP) libraries.

2.5 Water quality index

To calculate WQI we have selected parameters that exist in the Algerian guidelines for interpretation of water (treated wastewater) quality for irrigation purposes namely: pH, EC, COD, BOD, SM, NO_3 and fecal Coliforms.

Table 2. Available historic data of the Réghaïa Lake

	April 1978	April 1986	April 1989	April 1993	April 2017
T	18.7	17	18.3	19	21.9
pH	7.1	8,20	8,16	7	8.77
DO	75.8	76,87	36.6	-	31.6
SS	74.7	125,00	358	244	40.33
PO4	0.58	7,00	1.16	0,6	1.01
BOD_5	21.3	141,00	36.8	100	8.81
COD	54.3	148,50	236	574	84.34
Ratio	0.39	0.95	0.16	0.17	0.10
Source	Haddoum,1978	Seghouani & Allia,1986	Bouam,1989	Adjerid,2000	Authors,2017

SS, PO_4, BOD_5 and COD (mgL^{-1}), T(°C), DO (%).

2.5.1 Weighted arithmetic-water quality index

The water quality status was assessed at 10 sampling stations using the WA-WQI in which water parameters are multiplied by a weighting factor and then aggregated using a simple arithmetic mean by the following equation (Tyagi *et al.,* 2013) (Ewaid & Abed, 2017):

$$WQI = \sum_{i=1}^{n}(Wi \times Qi \Big/ \sum_{i=1}^{n} Wi)$$

The sub-index (*Qi*) and the unit weight (*Wi*) of the *ith* parameter are calculated as follows:

$$Qi = [(Mi - li)/(Si - li)] \times 100$$

$$Wi = K/Si$$

Where, *Mi* is the monitored value, *Li* is the ideal value, *Si* is the standard value, *n* is the number of parameters selected and *K* is the proportionality constant that can be calculated by the following formula (Tyagi *et al.,* 2013):

$$K = 1 \Big/ \sum_{i=1}^{n}(1/Si)$$

Because of the elevated concentrations of total Coliforms, the index values were classified into two classes (without and with total Coliforms). Based on the calculated WQI, the water quality types are shown in Table 3.

Table 3. WQI categories.

CCME-WQI		WA-WQI		
Range	Water quality	Range	Water quality	Color code
95-100	Excellent	0-25	Excellent	
80-94	Good	26-50	Good	
65-79	Fair	51-75	Poor	
45-64	Marginal	75-100	Very poor	
0-44	Poor	>100	Unsuitable	

2.5.2 Canadian Council of Ministers of the Environment-water quality index

The CCME-WQI provides a measure of the deviation of water quality from water quality guidelines, it incorporates three factors (scope, frequency, amplitude), and produces a value between 0 and 100 divided into 5 water quality categories (Table 3.) to simplify presentation (CCME, 2001).

The CCME-WQI was calculated using the following equations:

$$WQI = 100 - \left(\sqrt{F_1^2 + F_2^2 + F_3^2}/1.732\right)$$

$$F_1 = 100\left(\text{Number of failed variables} \Big/ \text{Total number of variables}\right)$$

$$F_2 = 100\left(\text{Number of failed tests} \Big/ \text{Total number of tests}\right)$$

$$F_3 = (nse/0.01nse + 0.01)$$

Where *F1, F2, F3* are respectively scope, frequency and amplitude, *nse* is the normalized sum of excursions that can be calculated by the following formula:

$$nse = \sum_{i=1}^{n} excursion_i \Big/ Number\ of\ tests$$

Excursion is the number of times by which an individual concentration is greater than (or less than) the objective.

For the situation in which the test value must not exceed the objective:

$$excursion_i = \left(\text{Failed test value}_i \Big/ \text{Objective}\right) - 1$$

For the other situation:

$$excursion_i = \left(\text{Objective} \Big/ \text{Failed test value}_i\right) - 1$$

2.6 Trophic categories and trophic state index

We have used two methods to evaluate trophic category of Réghaïa Lake: OECD (1982) and Carlson (1977) classifications. The first method is based on the average values of total phosphorus, chlorophyll and Secchi-disc visibility compared to the values of trophic classes presented in Table 4. The 2nd method is based on the calculation of TSI using a logarithmic transformation of water transparency (SD), total phosphorus (TP), total nitrogen (TN) and chlorophyll (Chl-*a*). Because of the high pollution and dark color of water samples the chlorophyll measurement was not performed. The TSI was calculated according to the following equations:

$$TSI\ (TP) = 14.42\ ln(TP\ \mu g\ L^{-1}) + 4.15$$

$$TSI\ (SD) = 60 - \left(14.41\ ln(SD\ m)\right)$$

$$TSI\ (TN) = 14.43\ ln(TN\ mg\ L^{-1}) + 54.45$$

(TSI(TP) and TSI(SD) according to Carlson (1977), TSI(TN) according to Kratzer & Brezonik (1981)).

2.7 Organic pollution index and microbiological quality index

To establish a pollution map of the studied area and to furnish evidence of the spatial evolution of the global organic and microbiological pollution of the waters, OPI and MQI were calculated.

These indices were developed by spreading the values of pollution parameters (BOD_5, Ammonium, Nitrites and Phosphates for OPI, Total Coliforms, Fecal Coliforms and Fecal Enterococcis for MQI) into five classes as shown in Table 5. They were obtained by determining the class number of each analyzed parameter and then calculating the average of the class numbers.

The results were interpreted according to the grid evaluation mentioned in Table 6.

Table 4. Trophic categories

Parameters	Oligotrophy	Mesotrophy	Eutrophy	Hypertrophy
Total phosphorus (TP) (µg/l)	<10	10 – 35	35 – 100	>100
Chlorophyll-*a* (Chl-*a*) (µg/l)	<2.5	2.5 – 8	8 – 25	>25
Secchi Disc (SD) (m)	>6	6 – 3	3 – 1.5	<1.5
TSI value	<40	40-50	>50	-

Table 5. Class limits of pollution parameters (Leclercq, 2001).

	Classes	**5**	**4**	**3**	**2**	**1**
OPI	BOD_5 (mg O_2 L^{-1})	<2	2-5	5.1-10	10.1-15	>15
	Ammonia (mg N L^{-1})	<0.1	0.1-0.9	1.0-2.4	2.5-6.0	>6
	Nitrites (µg N L^{-1})	≤5	6-10	11-50	51-150	>150
	Phosphates (µg P L^{-1})	≤15	16-75	76-250	251-900	>900
MQI	Total Coliforms	<2000	2000-9000	9000-45000	45000-360000	>360000
	Fecal Coliforms	<100	100-500	500-2500	2500-20000	>20000
	Fecal Enterococcis	<5	5-10	10-50	50-500	>500

3. Results and discussion

In the period from 1978 to 2017, available data, presented in Table 2, indicates that all physico-chemical variables are observed with higher values in the majority of the cases. Water temperature showed low variations and ranged from 17 to 22°C with an average value of 19°C. Values of pH were found in the alkaline range. They ranged from 7 to 8.77 and remained within the recommended limit (6.5-8.5) of Algerian standards, but in 2017 the mean of pH values was greater than 8.5. DO concentrations decrease from 76% in 1978 to 32% in 2017. SS concentrations ranged from 40 (2017) to 358mgL^{-1} (1989).

Table 6. Grid evaluation (Leclercq, 2001).

<OPI>	<MQI>	Level	Color code
1.0-1.9	1.0-1.8	Very strong	
2.0-2.9	1.9-2.6	Strong	
3.0-3.9	2.7-3.4	Moderate	
4.0-4.5	3.5-4.2	Weak	
4.6-5.0	4.3-5.0	None	

Phosphates concentrations varied from 0.58 to 7mgL^{-}1. COD and BOD$_5$ varied from 54 to 574mg L^{-1} and from 8 to 141mgL^{-1} respectively.

WA-WQI was used to assess spatial variation of water quality (Table 7). The obtained values varied between 1938 (B1) and 80.5 (S2) without total Coliforms.

Table 7. Calculations of WA-WQI.

	Without FC		With FC	
	∑WiQi	WQI	∑WiQi	WQI
R1	109,8	113,7	218347,3	217261
R2	152,2	157,6	1896152,2	1886718,6
B1	1871,6	1938,1	8981,6	8936,9
B2	360,5	373,3	83310,5	82896,0
S1	304,6	315,4	7288054,6	7251795,6
S2	77,7	80,5	45107,7	44883,3
LR3	180,1	186,5	6622,5	6589,6
LR5	214,7	222,3	6416,2	6384,3
LR6	212,3	219,8	7203,8	7168,0
LR8	253,3	262,3	4104,5	4084,1

When total Coliforms are included in the calculations, the values are extremely high (>4000). The highest WA-WQI values of 7251795 and 1886718 were recorded in (S1) and (R2), respectively.

CCME-WQI was used to evaluate global water quality of the study area. As shown in Table 8, all variables present at least one sampling station with an improper value if compared to the Algerian standards.

According to Table 9, data shows that the values of TSI (SD), TSI (TP), TSI (TN) are extremely high: 80.6, 103.8, 101 respectively and that Réghaïa Lake is very polluted.

OPI varies from 1 (at all sampling stations) to 2 (at S2) (Table 10), which indicates very strong and strong organic pollution, respectively. MQI values indicate that microbiological water quality goes from very strong pollution at R1, R2, B2 and S1 sampling stations to moderate at the LR3, LR4, LR5, LR6, LR7 and LR8 ones (Table 11). For the rest of the stations, MQI values correspond to strong microbial pollution. The same evolution was observed with WA-WQI results. Indeed, the lowest value of about 4000 was obtained at the LR8 station when total Coliforms were taken into account (Table 8), when total Coliforms were excluded from the calculations, the lowest value was recorded in S2 (80.5) followed by R1 (113) then R2 (157).

Table 8. Data used for the calculations of CCME-WQI.

	R1	R2	B1	B2	S1	S2	LR3	LR5	LR6	LR8	Algerian standards
pH	7,9	8,0	5,2	6,5	7,5	7,6	8,5	8,8	8,8	9,2	6,5-8,5
EC	1.759	1.946	4.532	2.894	1.795	1.780	1.761	1.750	1.754	1.839	3
COD	120	203,4	28604	2485	706	37,7	110,7	122,2	138,1	137,6	90
BOD$_5$	9,2	22,4	219,6	276,6	260	7	15,7	17,4	18,5	9,6	30
SS	11,6	43,5	401,6	126,1	229	17,5	22,8	25,5	21,9	20	30
NO$_3$	6,5	9,4	34,5	19,6	1,3	0,7	6,3	5,8	5,9	9,4	30
F.C.	5525	48000	180	2100	184500	1140	163.13	157.03	177.03	97.5	100

COD, BOD$_5$, SS and NO$_3$ (mg L^{-1}), fecal Coliforms (F.C.) (x10^3/100ml), EC (mScm^{-1}). (F1=100), (F2=45,7), (F3=99,72), (sncé=351,33), (CCME-WQI = 14,31).

Table 9. Parameters and TSI calculated for each parameter.

Parameters	values	Trophy
TP (µg/l)	1000	Hypertrophy
TN (mgL^{-1})	25.2	-
SD (m)	0.24	Hypertrophy
TSI (SD)	80.6	Eutrophy
TSI (TP)	103.8	Eutrophy
TSI (TN)	101	Eutrophy
TSI mean	95.1	Eutrophy

3.1 Temporal evolution

Water temperature is one of the most important parameters for water quality and ecosystem studies. It can influence biological and chemical processes and impacts on the other parameters (Varol *et al.,* 2012). It has a positive correlation with EC, COD, nitrate, nitrite, total nitrogen, sulfate and chloride, and a negative correlation with pH and DO (Yaşar Korkanç *et al.,* 2017). Low variation has not a significant effect on the other parameters.

Table 10. OPI results.

	R1	R2	B1	B2	S1	S2	LR3	LR5	LR6	LR8
BOD_5	9,2	22,4	219,6	276,6	260	7	15,7	17,4	18,5	9,5
NH_4	90	240	1731	772	740	150	315	310	275	285
NO_2	39,8	31,9	9,9	32,4	21,5	26,4	16,3	20,5	18,6	22,6
PO_4	14500	7940	1730	7974			1155	1320	1362	1290
TP					10500	1030				
OPI	**1,75**	**1**	**1**	**1**	**1**	**2**	**1**	**1**	**1**	**1,25**

BOD_5, NH_4 (mg L^{-1}), NO_2, PO_4,TP (µg L^{-1})

Temporal variation of dissolved oxygen in Réghaïa lake is noticeable. In surface water, DO is very important for determining the health of aquatic ecosystems and preserving the aquatic life (Prasad, 2016). Natural bioremediation of polluted waters requires a large amount of oxygen. Fish cannot survive when its concentration is too low, Haddoum (1978) reported the existence of fish (carp) in the Réghaïa River, wich is not the case in 2017.

Suspended solids have an important effect on water quality of aquatic ecosystems (Bilotta & Brazier, 2008). Aquatic life is really affected by high concentration (Varol *et al.,* 2012). In Réghaïa lake water variations of SS fluctuates between bad and very bad water quality.

Phosphorus is the limiting nutrient for eutrophication and algal productivity. Increases in concentrations may be both of natural and anthropogenic origin (Diamantini *et al.,* 2018). High phosphate concentration can be attributed to intensive anthropic activities. In our study area the recorded values correspond to moderate and very bad water quality.

COD and BOD_5 are the most important parameters for quantifying organic pollution. Elevated levels of COD indicate water pollution, which is linked to wastewaters discharged from domestic, industrial or agricultural activities (Varol *et al.,* 2012). Also, elevated levels of BOD_5 indicate water pollution, but linked to biodegradable organic matter (Chun & Yizhong, 1999).

Table 11. MQI results

	TC	FC	FE	MQI
R1	6250000	55250	856	1
R2	28900000	480000	1267	1
B1	550000	1800	8	2.66
B2	185000	21000	316	1.66
S1	505000000	1845000	5611	1
S2	202500	11400	164	2
LR1	80259	4125	90	2
LR2	70889	5011	96	2
LR3	13278	1631	38	3
LR4	8692	1611	31	3.33
LR5	15011	1570	26	3
LR6	10618	1770	27	3
LR7	9785	1852	22	3
LR8	3050	975	32	3.33

(TC, FC, FE in $CFUmL^{-1}$)

The biodegradability can also be expressed by the ratio BOD_5/COD, which translates the decomposition ability of organic matter by microorganisms (Khattabi *et al.,* 2007). More than 0.3, wastewater has a better biodegradability, less than 0.3, it is difficult to be biodegraded (Chun & Yizhong, 1999). Values encountered in untreated wastewaters varies from 0.4 to 0.8 (Bouhezila *et al.,* 2011).

According to the color code in Table 2, the lowest level of pollution was observed in 1978, and the highest one was observed in 1986. But the BOD_5/COD ratio was more than 0.3 before 1986, and unfortunately the lowest Value (0.10) was obtained in 2017 which indicated less biodegradability of Réghaïa Lake waters.

3.2 Water quality evaluation for irrigation purposes

According to the classification given in Table 3, all observed values of WA-WQI (with and without TC) indicate unsuitable water quality for irrigation purposes except station (S2) (without total Coliforms), which indicates very poor water quality. In Table 8, the major non-compliances correspond to tot-Coli and COD results. The value of CCME-WQI (14.31) indicates poor water quality.

3.3 Trophic state of the lake

According to the international classification (OECD, 1982), means of measured parameters (TP, SD) presented in Table 9 confirms the hypertrophic stat of the Réghaïa Lake. In addition, a TSI value upper 50 is associated with high productivity (El-Serehy *et al.,* 2018). With such high productivity and excess pollutants, natural inhibition of the lake's severe degradation is impossible (Dunalska *et al.,* 2015).

3.4 Spatial variations

Aquatic ecosystems react to pollution by means of a number of mechanisms aiming to restore their original conditions. This process, referred to as self-purification, is governed by multiple phenomena involving physical, chemical and biological processes.

The Physico-chemical ones are often controlled by biological factors or strongly dependent on them. (Ostroumov, 2005). Dilution, adsorption, sedimentation and volatilization are the most important physical mechanisms. Precipitation reactions and acid-base reactions are very important for removing ions and maintaining the natural water pH (Vagnetti *et al.,* 2003).

Organisms such as bacteria and protozoa can transform or accumulate organic substances and some inorganic substances present in the water body and obtain the necessary energy for their survival. Plants can also protect ecosystems by accumulating heavy metals, control eutrophication by assimilating nitrogen and phosphorus, produce oxygen during day time by photosynthesis, and increase the retention of pollutants by increasing the residence time of water (Prasad, 2016). Mutual interaction between plant roots and associated microorganisms can also remove pollutants from contaminated environment (Ubogu & Odokuma, 2019). In addition, water flow on the vegetated surfaces of wetlands may impact a wide range of processes, including exchanges at the sediment-water interface (Leonard & Reed, 2002).

In the study area, Réghaïa Lake and its principal tributaries, spatial evolution of OPI and MQI (Fig.2) shows that: Réghaïa River (R1-R2) and ElBiar River (B1-B2) constitutes the main sources of pollution. A slight increase (1 to 1.25) of OPI was recorded in the outlet of the lake, translating into a slight decrease in organic pollution, possibly due to decomposition of organic pollution matter by microorganisms and Physico-chemical phenomena. Similar results have been obtained by Olaseeni et al. (2018); the values of pollution parameters increase when closer to the pollution source.

A remarkable improvement in microbiological quality was observed if we compare the inlets (R2-S2-B2) with the outlet (LR8) of the lake. It might be because of physical phenomena such as adsorption and decantation, but the toxic effects of polluted water can also affect the mortality of bacteria. This phenomenon has been studied by several researchers (Khattabi *et al.,* 2007) (Howell *et al.,* 1996). The same evolution was observed with WA-WQI results. Indeed, the lowest value was obtained at the LR8 station when total Coliforms were taken into account (Table 8.). This improvement in water quality can be attributed to the marshy area (Figure 1) which increases the residence time of water and consequently accelerates self-purification (Leonard & Reed, 2002), (Prasad, 2016).

Water pH indicates acidic or basic nature, it has a profound effects on water quality (Şener *et al.,* 2017). Nitrite, nitrates, and ammonium concentrations are also important parameters affecting water quality (Guasmi *et al.,* 2010).

In reality, the quality of water body at any point reflects several major influences including all parameters. According to Fig.3, spatial variations of BOD_5, COD, SS,

NO_2, NO_3, EC, pH, TDS, Salinity and PO_4 indicate that the ElBiar river is the most important pollution source of the lake. But if we compare the values of WQI without total Coliforms with WQI with total Coliforms (Figure 3) we can conclude that the Réghaïa River (R2) contributes to microbial pollution of the lake more than the ElBiar River (B2), and the outlet of the Réghaïa wastewater treatment plant (S2) is the least polluted point, which contributes to the dilution of pollution.

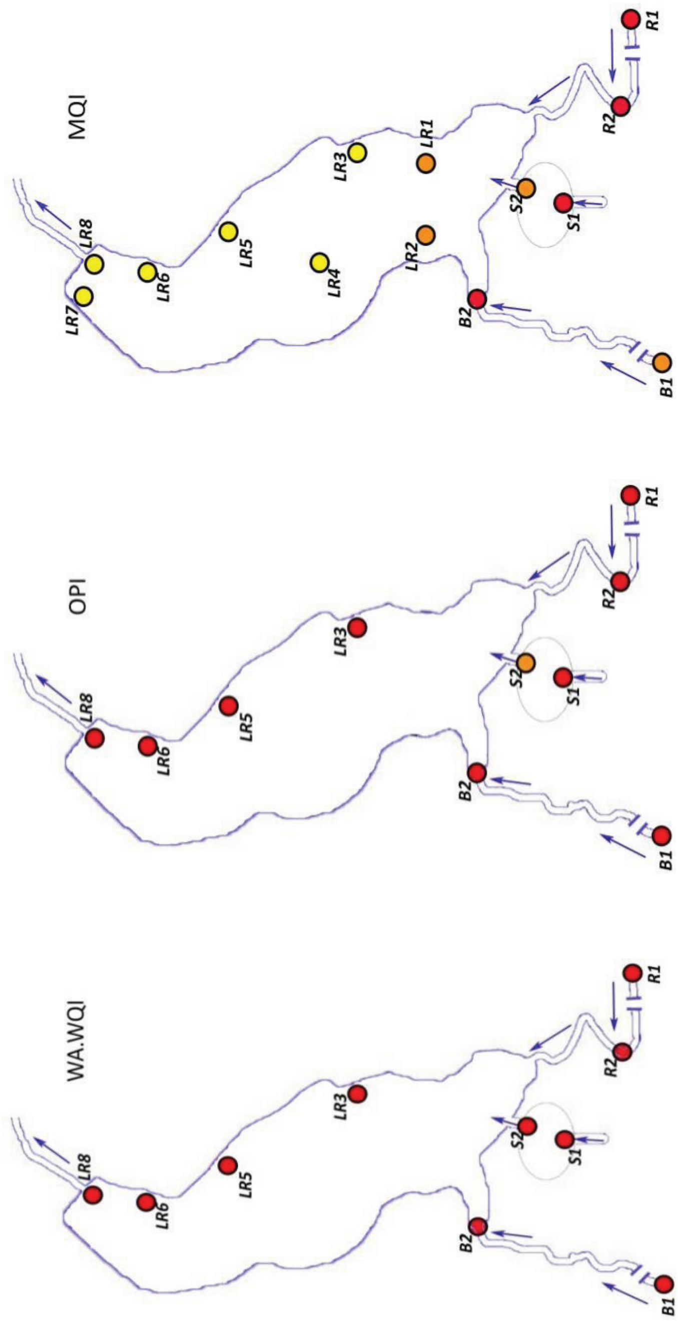
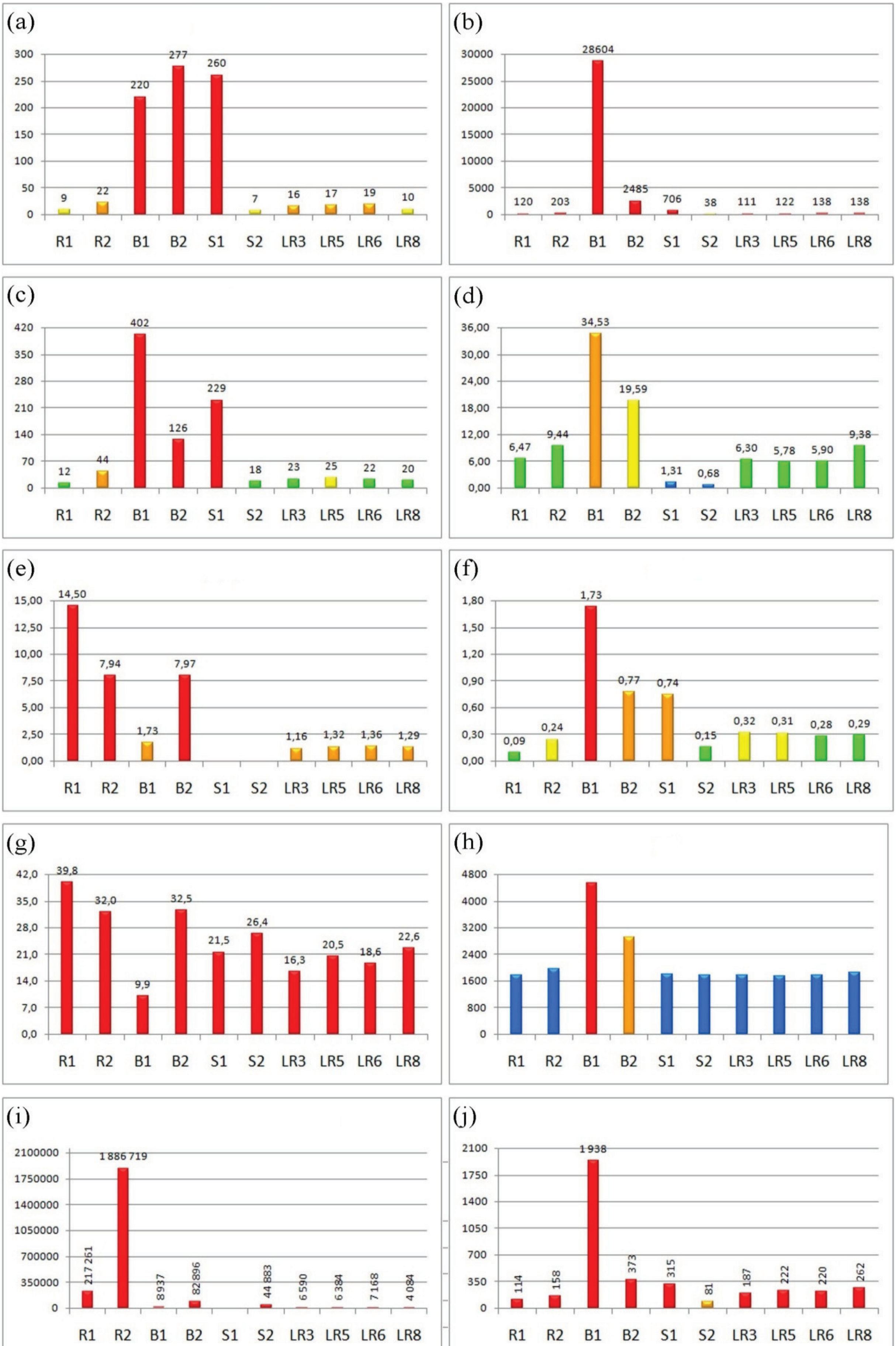


Fig. 2. OPI, MQI and WQI pollution maps.


(a)
9
22
220
277
260
7
16
17
19
10
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8
(b)
120
203
28604
2485
706
38
111
122
138
138
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8
(c)
12
44
402
126
229
18
23
25
22
20
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8
(d)
6,47
9,44
34,53
19,59
1,31
0,68
6,30
5,78
5,90
9,38
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8
(e)
14,50
7,94
1,73
7,97
1,16
1,32
1,36
1,29
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8
(f)
0,09
0,24
1,73
0,77
0,74
0,15
0,32
0,31
0,28
0,29
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8
(g)
39,8
32,0
9,9
32,5
21,5
26,4
16,3
20,5
18,6
22,6
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8
(h)
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8
(i)
217 261
1 886 719
8937
82 896
44 883
6 590
6 384
7 168
4 084
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8
(j)
114
158
1 938
373
315
81
187
222
220
262
R1 R2 B1 B2 S1 S2 LR3 LR5 LR6 LR8

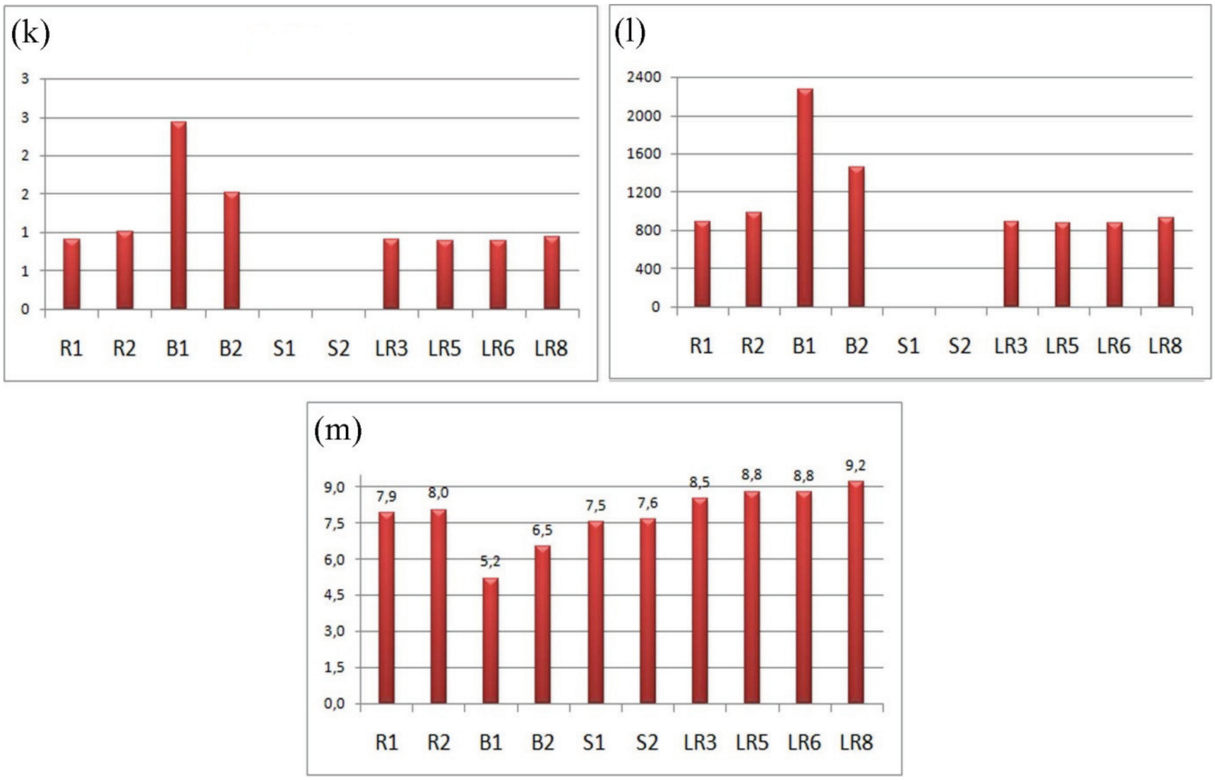


Fig. 3. Spatial variations; (a) BOD5, (b) COD, (c) SS, (d) NO3, (e) PO4, (f) NO2, (g) MH4, (h) EC, (i) WQI with Fecal Coliforms, (j) WQI without Fecal Coliforms, (k) Salinity, (l) TDS and (m) pH.

4. Conclusion

This study assesses temporal and spatial evolution of water quality using a traditional approach based on a comparison of parameters values with existing guidelines and water quality indices which translate several values of parameters into a single value.

The principal results can be summarized as follows:

Firstly:

- The lake has presented excessive pollution since the 1970s with a very low biodegradability of its waters.
- The values of WQI indicate poor and unsuitable water quality for irrigation purposes.
- Hypertrophy was identified in Réghaïa Lake by the TSI method and was confirmed by the international classification of OECD (1982).
- The Réghaïa River and ElBiar River are the most important pollution sources.
- A slight decrease in organic pollution and remarkable improvement in microbiological quality were recorded in the outlet of the lake.
- The lake discharges into the Mediterranean Sea waters with very bad quality.
- The Réghaïa wastewater treatment plant contributes to the dilution of pollution.

Secondly:

- The traditional approach is very important to give a global idea about pollution and to visualize the individual effects of each parameter.
- The use of different indices such as WQI TSI OPI and MQI helps in the interpretation of data matrices to better understand the water quality and offers valid proof and valuable tools for reliable management of water resources as well as rapid solution to pollution problems.

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References

Abbasi, T., & Abbasi, S.A. (2012). Water Quality Indices. Amsterdam: Elsevier Science. Pp. 362.

Abukila, A.F. (2015). Assessing the drain estuaries' water quality in response to pollution abatement. Water Science **29**(1):1-18.

Adjerid A.S. (2000). Evaluation de la qualité des eaux du lac de Réghaïa. ing. thesis, Higher National Agronomic School (ENSA), Algiers, Algeria.

Bilotta, G.S. & Brazier, R.E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. Water research **42**(12):2849-2861.

Bouam, A. (1989). Contribution a la connaissance de la pollution du marais de Réghaïa. ing. thesis, Higher National Agronomic School (ENSA), Algiers, Algeria.

Bouhezila, F., Hariti, M., Lounici, H. & Mameri, N. (2011). Treatment of the OUED SMAR town landfill leachate by an electrochemical reactor. Desalination **280**(1-3):347-353.

Carlson, R.E. (1977). A trophic state index for lakes. Limnology and Oceanography **22**(2):361-369.

CCME, (Canadian Council of Ministers of the Environment) (2001). Canadian Environmental Quality Guidelines. Hull, QC: CCME.

Chun, H. & Yizhong, W. (1999). Decolorization and biodegradability of photocatalytic treated azo dyes and wool textile wastewater. Chemosphere **39**(12):2107-2115.

Diamantini, E., Lutz, S.R., Mallucci, S., Majone, B., Merz, R. & Bellin, A. (2018). Driver detection of water quality trends in three large European river basins. Science of The Total Environment **612**:49-62.

Dunalska, J.A., Grochowska, J., Wiśniewski, G. & Napiórkowska-Krzebietke, A. (2015). Can we restore badly degraded urban lakes? Ecological Engineering **82**:432-441.

El-Serehy, H.A., Abdallah, H.S., Al-Misned, F.A., Irshad, R., Al-Farraj, S.A. *et. al.* (2018). Aquatic ecosystem health and trophic status classification of the Bitter Lakes along the main connecting link between the Red Sea and the Mediterranean. Saudi Journal of Biological Sciences **25**(2):204-212.

Ewaid, S.H. & Abed, S.A. (2017). Water quality index for Al-Gharraf River, southern Iraq. The Egyptian Journal of Aquatic Research **43**(2):117-122.

Guasmi, I., Kherici-Bousnoubra, H., Kherici, N. & Hadji, F. (2010). Assessing the organic pollution of surface water of Medjerda watershed (NE Algeria). Environmental Earth Sciences **60**(5):985-992.

Haddoum, M.O. (1978). Etude de la pollution de l'oued et du lac de Réghaïa. ing. thesis, Higher National Agronomic School (ENSA), Algiers, Algeria.

Howell, J.M., Coyne, M.S. & Cornelius, P.L. (1996). Effect of Sediment Particle Size and Temperature on Fecal Bacteria Mortality Rates and the Fecal Coliform/ Fecal Streptococci Ratio. Journal of Environment Quality **25**(6):1216.

ISO 11923 (1997). Water quality -Determination of suspended solids by filtration through glass-fibre filters.

ISO 5815-1 (2003). Water quality - Determination of biochemical oxygen demand after n days (BODn) - Part 1: Dilution and seeding method with allylthiourea addition.

ISO 6060 (1989). Water quality -Determination of the chemical oxygen demand.

ISO 6777 (1984). Water quality - Determination of nitrite - Molecular absorption spectrometric method.

ISO 6878 (2004). Water quality — Determination of phosphorus — Ammonium molybdate spectrometric method.

ISO 7150-1 (1984). Water quality - Determination of ammonium - Part 1: Manual spectrometric method.

ISO 7890-3 (1988). Water quality - Determination of nitrate - Part 3: Spectrometric method using sulfosalicylic acid.

ISO 7899-2 (2000). Water quality — Detection and enumeration of intestinal enterococci — Part 2: Membrane filtration method.

ISO 9308-1 (2014). Water quality — Enumeration of *Escherichia coli* and coliform bacteria — Part 1: Membrane filtration method for waters with low bacterial background flora.

Khattabi, H., Belle, É., Servais, P. & Aleya, L. (2007). Variations spatiale et temporelle des abondances bactériennes dans quatre bassins de traitement du lixiviat de la décharge d'Étueffont (Belfort, France). Comptes Rendus Biologies **330**(5):429-438.

Leclercq, L. (2001). Intérêt et Limites Des Méthodes d'estimation de La Qualité de l'eau. Station Scientifique Des Hautes-Fagnes,. Available at: https://inforef.be/

projets/eureau/brochure/partie1/sommaire.htm

Lumb, A., Sharma, T.C. & Bibeault, J.-F. (2011). A Review of Genesis and Evolution of Water Quality Index (WQI) and Some Future Directions. Water Quality, Exposure and Health **3**(1):11-24.

Leonard, L.A., & Reed, D.j. (2002). Hydrodynamics and Sediment Transport Through Tidal Marsh Canopies. Journal of Coastal Research:459-469.

MEDD & Agences de l'eau (2003). Système d'évaluation de la qualité de l'eau des cours d'eau SEQ-Eau. Grilles d'évaluation version **2**:40.

Misaghi, F., Delgosha, F., Razzaghmanesh, M. & Myers, B. (2017). Introducing a water quality index for assessing water for irrigation purposes: A case study of the Ghezel Ozan River. Science of The Total Environment **589**:107-116.

OECD (1982). Eutrophication of Waters: Monitoring, Assessment and Control. Organization for Economic and Co-operative Development, Paris, France.

Olaseeni, O.G., Sanuade, O.A., Adebayo, S.S. & Oladapo, M.I. (2018). Integrated geoelectric and hydrochemical assessment of Ilokun dumpsite, Ado Ekiti, in southwestern Nigeria. Kuwait J. Sci. **45 (4)** pp 82 - 92

Ostroumov, S.A. (2005). On some issues of maintaining water quality and self-purification. Water Resources **32**(3):305-313.

Prasad, M.N.V. (ed.) (2016). Bioremediation and Bioeconomy. Amsterdam ; Boston: Elsevier. Pp. 698.

Seghouani, H., & Allia, L. (1986). Contribution a l'étude de la pollution engendrée par l'ENAD et son impact sur le lac de Réghaïa. ing.thesis, Higher Polytechnic School (ENP), Algiers, Algeria.

Şener, Ş., Şener, E. & Davraz, A. (2017). Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). Science of The Total Environment **584–585**:131-144.

Tyagi, S., Sharma, B., Singh, P. & Dobhal, R. (2013). Water quality assessment in terms of water quality index. American Journal of Water Resources **1**(3):34-38.

Ubogu M. & Odokuma L.O. (2019). Growth and lolerance evaluation of selected plants to crude oil contamination for rhizoremediation potentials in the Niger Delta. Kuwait J. Sci. **46 (4)** pp. 93-103.

Vagnetti, R., Miana, P., Fabris, M. & Pavoni, B. (2003). Self-purification ability of a resurgence stream. Chemosphere **52**(10):1781-1795.

Varol, M., Gökot, B., Bekleyen, A. & Şen, B. (2012). Water quality assessment and apportionment of pollution sources of tigris river (turkey) using multivariate statistical techniques-a case study: water quality assessment. River Research and Applications **28**(9):1428-1438.

Yaşar Korkanç, S., Kayıkçı, S. & Korkanç, M. (2017). Evaluation of spatial and temporal water quality in the Akkaya dam watershed (Niğde, Turkey) and management implications. Journal of African Earth Sciences **129**:481-491.

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