Water quality analysis of reservoirs within Western Algeria catchment areas using water quality index CCME WQI

Abdelkader Hamlat, Abdellatif El-Bari Tidjani, Djillali Yebdri, Mohamed Errih and Azeddine Guidoum

ABSTRACT

The present paper aims at determining the status and trends in water quality at Western Algeria reservoirs. The method consists of the computation of Water Quality Index (WQI) on the basis of the physical–chemical quality parameters that were registered at the monitoring stations placed at the reservoirs. This WQI was applied to water quality data collected from 2001 to 2010. Results revealed that the overall surface water quality mainly fell into the marginal class in all reservoirs, expect Hammam Boughrara reservoir where water quality fell into the poor category. This implies that the water quality of this reservoir is almost always threatened or impaired; conditions usually depart from natural or desirable levels. The low value of the index was registered in 2005 at the following monitoring stations: Hammam Boughrara – 26.5%, Sikkak – 33.5%, and Cheurfa – 41.2%. This low level of WQI can be attributed to a number of variables and tests that exceed or are less than the objectives. This study showed that the Canadian Council of Ministers of the Environment's WQI (CCME WQI) may assist water managers to integrate and interpret the picture of overall water quality in the study area.

Key words | CCME WQI, Hammam Boughrara reservoir, physical–chemical parameter, water quality index, Western Algeria reservoirs

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INTRODUCTION

Water is one of the most important natural resources to sustain life. Ascertaining its quality is very crucial before use for water drinking, agricultural, aquatic life, recreational, or industrial purposes. However, all available water bodies are not suitable for all different uses. The scale of socio-economic activities such as urbanization, industrial operations, and agricultural production, has reached a level where they interfere not only with natural processes within the same watershed, but also have a world-wide impact on water resources (Helmer 1994). At the present time, to safeguard freshwater resources, it is important to develop a comprehensive river water quality monitoring program all over the world.

Maintaining or improving the water quality of reservoirs is of particular concern. In fact, it is considered now as one of the key factors in the operation and water quality management of reservoirs, particularly in regions that are exposed to high variations of climatology. Algeria had for over 20 years a severe and persistent drought where its spectrum began to be felt in the west of the country especially (Meddi & Hubert 2003). In addition, and, according to a report of the European Economic Community (EEC) on the situation of wastewater treatment plants (WWTPs) in Algeria, treatment plants have a 'bad reputation', being structural units intended to fall into disuse because of a high degree of technical sophistication, lack of management skills, and/or a lack of funding (CNES 2000). Studies show that there is a significant amount of wastewater that continues to spread into the environment without treatment, although the treatment plant has sufficient capacity (MRE 2010). Remedial proposals from previous studies in the field

doi: 10.2166/aqua.2013.226

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of water quality in Algeria have excessive costs, and cannot be used because they do not eliminate the causes of pollution.

In the western region of Algeria, different kinds of environmental problems, caused by disordered economic growth and the excessive water use associated with it, are affecting both the availability and the quality of freshwater. For the main wadis of the region such as, Tafna Wadi, Mekkerra Wadi, El Hammam Wadi, and Mouilah Wadi, located in the Macta and Tafna basins, each wadi drains its own agricultural catchment. The wadis also receive discharges of urban wastewater from settlement areas (cities/towns); some of the urban wastewater has been discharged without any previous treatment. The wastewater flow rate discharged from the cities of wilayas (provinces) situated in Macta basin (wilayas of Mascara, Saida, and Sidi Bel Abbes) is about 126,916 m^3/d (ABHOCC 2006a). For Tafna basin, the flow rate disharged is about 85,927.2 m^3/d (ABHOCC 2006b), the volume discharged from the cities of wilayas Ain Temouchent and Tlemcen. This volume reached the wadis and reservoirs of Tafna basin, particularly Sikkak and Hammam Boughrara reservoirs, causing excessive pollution (Djediai 2004) (cf. Figures 1 and 2).

One of the difficult tasks facing environmental managers is how to transfer their interpretation of complex environmental data into information that is understandable and useful to technical and policy individuals as well as the general public (Pauzi *et al*. 2008). This is particularly important in reporting the state of the environment. Internationally, there have been a number of attempts to produce a method that meaningfully integrates the datasets and converts them into information (Nagels *et al*. 2001). Traditionally, water quality has been assessed by comparison of experimentally determined parameter values with existing guidelines. In many cases, the use of this methodology allows proper identification of contamination sources and may be essential for checking legal compliance. However, it does not readily give an overall view of the spatial and temporal trends in the overall water quality in a watershed (Debels *et al*. 2005). Thus, modern techniques such as water quality indices (WQIs) and water quality modeling were developed.

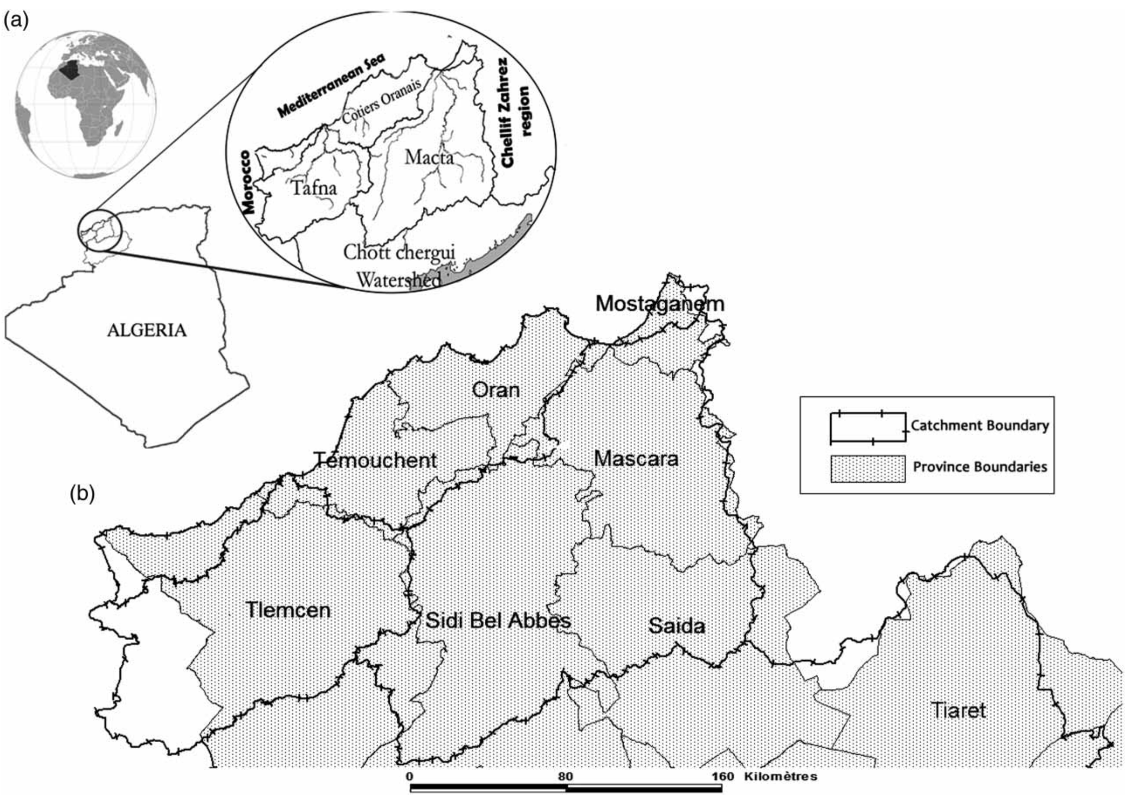

Figure 1 | Description of the study area: (a) location of the study area; (b) location of the wilayas situated in the study area.

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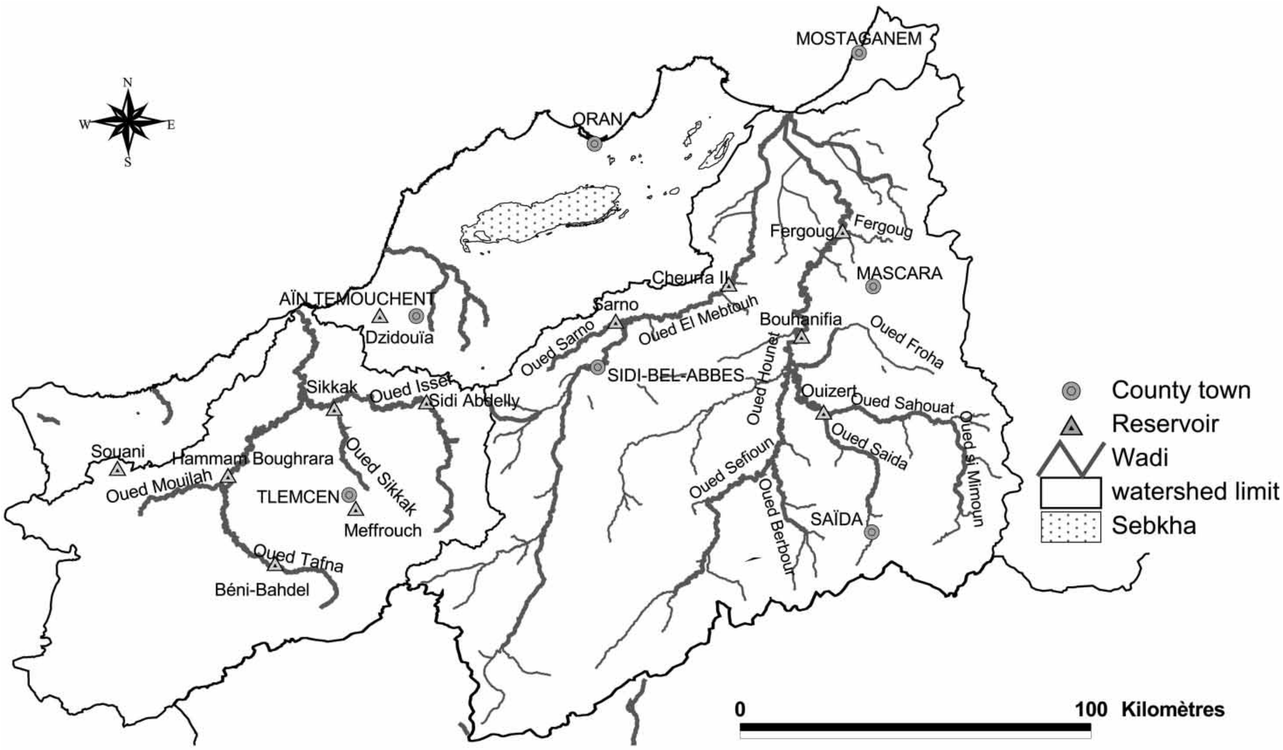

Figure 2 | The geographical location of the studied reservoirs.

The use of a WQI was initially proposed by Horton (1965) and Brown *et al.* (1970). Since then, many different methods for the calculation of WQIs have been developed; for example, US National Sanitation Foundation's Water Quality Index (NSF-WQI), Canadian Council of Ministers of the Environment's WQI (CCME WQI), British Columbia WQI, Oregon WQI, Florida Stream WQI (Debels *et al.* 2005; Nikoo *et al.* 2011), Bhargava WQI method (Bhargava 1983), Harmonic Mean WQI method (Dojlido *et al.* 1994), etc. In general, they all consider similar physical and chemical parameters but differ in the way the parameter values are statistically integrated and interpreted (Nives 1999). The CCME WQI is the most suitable index because of its flexibility for selecting parameters as well as the possibility of modifying the objectives to be met by each variable according to the specific end use of the water (Terrado *et al.* 2010).

Previous studies on the use of a WQI in the study area are nonexistent. The evaluation of water quality has been assessed only by comparing the values with the local norms (ABHOCC 2006c, 2006d). Current monitoring is temporally and spatially fragmented and there is inadequate use of data and information generated by monitoring activities. As a result, water quality managers are unable to provide a comprehensive, national picture of the status and trends of water quality.

In the present study, the Canadian Council of Ministers of the Environment WQI 1.2 (CCME WQI) was used, which is a well-accepted and universally applicable computer model for evaluating the WQI (CCME 2001; Khan *et al.* 2003; Al-Heety *et al.* 2011; Sharma & Kansal 2011; Damodhar & Reddy 2013; Munna *et al.* 2013). It can combine a variety of different measurement units in a single metric and is effective as a communication tool. The index has the ability to convey relative differences in water quality between sites even when the same objectives and variables are used (CCME 2001).

STUDY AREA AND SAMPLING SITES

Oranie Chott Chergui hydrographic region is located in the northernmost part of Algeria. This region comprises four major catchments areas: Tafna, Macta, the coastal Oranais (le côtiers Oranais), and Chott Chergui (Hamlat *et al.* 2013) (cf. Figure 1).

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The territory has several dams that are concentrated in Tafna and Macta basins. These dams were constructed to fulfill multiple purposes, such as water reservoirs for potabilization, generation of electricity, irrigation and recreation.

The Tafna basin (7,245 km^2), is a transboundary catchment area; there are several dams within this catchment area but the quality of its surface water has continued to deteriorate in recent decades (Tidjani *et al.* 2006). This basin has been considered one of the main water towers of all hydrographic regions due to its important water resources. It covers most of the wilaya of Tlemcen and Ain Temouchent (ABHOCC 2006a; Hamlat *et al.* 2013) (cf. Figure 1).

The Macta basin (14,389 km^2) plays an important role in the supply of coastal Oranais after the Tafna basin because of its important water resources and soil potentialities. As well, this basin is a factor influencing the perspectives of the development of the Oranais metropolis; it partially covers the following wilayas: Mascara, Sidi Bel Abbes, Saida, Tlemcen, Mostaghanem, and Oran (ABHOCC 2006a) (cf. Figure 1).

In both catchments (Tafna and Macta), the general rainfall regime is similar to that of the semiarid Mediterranean areas of northern Algeria, and is characterized by winter precipitation with the maximum in December, January, and February, and a long period of drought from June to September. These systems are also characterized by high spatial and temporal variability of total rainfall; rainfall during the wettest years may be three to four times higher than during the driest years.

The mean annual precipitation in the whole Tafna basin is 394 mm, with a monthly maximum of 45 mm during November to December, 54 mm during February to March, and a monthly minimum of between 1 and 2 mm in July (UNEP & WRC 2008). In the Macta basin, annual rainfall varies from 280 mm in the south to 600 mm in the Beni Chougrane Mountains in the north (Meddi *et al.* 2010).

The region's population and wastewater domestic characteristics are briefly summarized in Table 1.

The following 10 sampling sites within Western Algeria catchment areas were chosen for the study (cf. Figure 2): Site 1, Beni-Bahdel reservoir; Site 2, Meffrouch reservoir; Site 3, Sidi Abdelli reservoir; Site 4, Hammam Boughrara reservoir; Site 5, Sikkak reservoir; Site 6, Cheurfa reservoir; Site 7, Ouizert reservoir; Site 8, Bouhanifia reservoir; Site 9, Fergoug reservoir, and Site 10, Sarno reservoir. Characteristics of these dams are briefly summarized in Table 2.

MATERIALS AND METHODS

The WQI concept is based on the comparison of the water quality parameter with respective regulatory standards (Khan *et al.* 2003). The WQI reflects the status of water quality in lakes, streams, rivers, and reservoirs. The WQI improves understanding of water quality issues by integrating complex data and generating a score that describes water quality status and evaluates water quality trends (Hülya 2007). The WQI includes the ability to represent measurements of a variety of variables in a single number, the ability to combine various measurements in a variety of different measurement units in a single metric. The WQI makes the information more easily and rapidly interpretable than a list of numerical values. Consequently, a WQI is a communication tool for transmitting information.

The application of the CCME WQI provides a measure of the deviation of water quality from water quality guidelines or objectives. Therefore, for each site and water use, different sets of parameters can be used depending upon the availability of data and regulatory standards.

In order to analyze water quality trends and characterize the spatial and temporal variability of surface water

Table 1 | The region's population and wastewater domestic characteristics (ABHOCC 2006a, b)

Basin	Wilaya	Population (2005)	Wastewater flow rate (m^3/d)	Point of release
Macta	Mascara	499,263	53,637	Fergoug Wadi, Froha Wadi, Ain Fekan Wadi
	Sidi Bel Abbes	508,475	46,095	Mekerra Wadi, Sarno Wadi
	Saida	220,997	27,184	Saida Wadi
Tafna	Tlemcen	707,171	83,404	Sikkak Wadi, Mouilah Wadi, Isser Wadi, Ouerdefou Wadi
	Ain Temouchent	29,223	2,523.2	El Malah Wadi, Chabaat Wadi

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Table 2 | Characteristics of the studied reservoirs (MRE 2009)

Site	Station ID	Name and location of reservoir	Wadi	Latitude (N)	Longitude (W)	Basin area (km²)	Year put into service	Initial capacity (MCM)
Site 1	160403	Beni-Bahdel dam, Tlemcen	Tafna	34° 41′ 49.5084″	– 1° 30′ 32.7165″	1,016	1945	63
Site 2	160701	Meffrouche dam, Tlemcen	Meffrouche	34° 50′ 23.64″	– 1° 17′ 49.92″	90	1962	15
Site 3	160613	Sidi-Abdelli dam, Tlemcen	Isser	35° 5′ 31.56″	– 1° 7′ 26.76″	1,137	1988	110
Site 4	160520	H. Boughrara dam, Tlemcen	Tafna	34° 52′ 17.8212″	– 1° 38′ 52.098″	4,000	1999	177
Site 5	160728	Sikkak dam, Tlemcen	Sikkak	35° 2′ 36.8484″	– 1° 20′ 22.8696″	326	2004	27
Site 6	110304	Sarno dam, Sidi Bel Abbes	Sarno	35° 17′ 45.906″	– 0° 34′ 34.32″	263	1954	22
Site 7	110402	Cheurfa dam, Mascara	Mebtouh	35° 24′ 9.36″	– 0° 15′ 4.68″	4,190	1992	82
Site 8	111303	Ouizert dam, Mascara	Taria	35° 6′ 30.7584″	0° 0′ 5.1372″	2,100	1985	100
Site 9	111503	Bouhnaifia dam, Mascara	El-Hammam	35° 16′ 54.7068″	– 0° 4′ 25.4316″	7,850	1948	73
Site 10	111506	Fergoug dam, Mascara	El-Hammam	35° 30′ 48.96″	0° 2′ 36.24″	420	1987	18

quality, important reservoirs located within Oranie Chott Chergui hydrographic region were studied (cf. Figure 1). The Canadian Council of Ministers of the Environment's WQI (CCME WQI 1.2) was used in the present study. This WQI was calculated from eight physical–chemical parameters: temperature, pH, and chemical elements of water such as nitrate, nitrite, ammoniac, total hardness, dissolved oxygen (DO) and phosphate periodically measured at 10 sampling sites (January 2001–December 2010). Therefore, this research work will contribute to the development of cause–effect relationships which can be very useful for remediation programs to minimize the risk promoted by hazardous substances in the studied reservoirs.

Conceptual framework of CCME water quality index

The CCME WQI consists of three measures of variance from selected water quality objectives (scope, frequency, amplitude), each of which has been scaled between 0 and 100.

After the body of water, the period of time, the variables, and the objectives have been defined, each of the three factors that make up the index must be calculated as follows (CCME 2001):

F1 (Scope) represents the percentage of variables whose objectives are not met in terms of 'failed variables':

$$F1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) * 100 \tag{1}$$

F2 (Frequency) represents the percentage of individual tests that do not meet objectives in terms of 'failed tests':

$$F2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right) * 100 \tag{2}$$

F3 (Amplitude) represents the amount by which failed test values do not meet their objectives. F3 is calculated in three steps:

1. The number of times, by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective, is termed an 'excursion' and is expressed as follows.

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When the test value must not exceed the objective:

$$\text{excursions}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_j}\right) - 1 \tag{3}$$

For the cases in which the test value must not fall below the objective:

$$\text{excursions}_i = \left(\frac{\text{Objective}_j}{\text{Failed test value}_i}\right) - 1 \tag{4}$$

2. The collective amount by which individual tests are out of compliance. This variable, referred to as the normalized sum of excursions, or nse, is calculated as:

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Number of tests}} \tag{5}$$

3. F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$\text{F3} = \left(\frac{\text{nse}}{0.01\ \text{nse} + 0.01}\right) \tag{6}$$

The CCME WQI is then calculated as:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) \tag{7}$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the 'worst' water quality and 100 represents the 'best' water quality. Once the CCME WQI value has been determined, water quality is ranked by relating it to one of the following categories (cf. Table 3).

The WQI software has been prepared in Visual Basic by CCME, which can be implemented in MS Excel for computational purposes. Instructions for the implementation are well described in the Calculator Version 1.2; CCME WQI calculators are available from CCME (http://www.ccme.ca/ourwork/water.html?category_id=102) and the Newfoundland and Labrador Department of Environment and Conservation (http://www.env.gov.nl.ca/env/waterres/quality/background/cwqi.html) websites.

In addition to being a communications and summarizing tool, the CCME WQI has also proven to be very useful for analysis and communication of ambient water quality data. This stems from its ability to convert raw water quality data into insightful and meaningful information. When analyzing any water quality dataset the usual analysis requires understanding which parameters exceeded guidelines, how frequently and by how much. This information is captured in the F1, F2, and F3 factors of the CCME WQI and a review of F1, F2, and F3 values for any dataset provides valuable insights into issues with the dataset (Khan 2005).

Data for CCME WQI calculation

For each site, different sets of parameters (also known as variables) have been used depending upon the availability of data and regulatory standards. The comprehensive list

Table 3 | CCME WQI categorization schema (CCME 2001)

Rank	WQI value	Description
Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels; these index values can only be obtained if all measurements are within objectives virtually all of the time.
Good	80–94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45–64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

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of all parameters used in the present study is given in Tables 4 and 5. Based on the preliminary evaluation of the data, the data processing was not straightforward due to the following variability and inconsistency in the raw data (Khan *et al.* 2003):

1. A large number of parameters (variables) have been sampled.
2. The majority of parameters (variables) have very few data.
3. Several parameters (variables) have been analyzed by different methods over time and space.

The physical and chemical factors investigated in this research have been used to assess the water quality; furthermore, the data limitations (i.e., low record length) significantly impact the WQI analysis. In this study, only sets of data with a minimum of four parameters and sampled at least four times were used in the WQI analysis (Husain *et al.* 1999). The use of statistically large sample size ($n > 30$) further improves the accuracy and precision of the WQI analysis results. The exploration of a series of instantaneous samples were collected with at least monthly frequency over a period of 10 years (January 2001–December 2010).

Tables 4 and 5 give an overview of the parameters determined during this study. Statistical calculations were performed using Kyplot 2.0 for Windows.

RESULTS AND DISCUSSION

The nitrite, nitrates, and ammonium concentrations are important properties for monitoring surface water quality and are essential properties to evaluate for better water management (Bliefert & Perraud 2001). The values of nitrates appear particularly significant in Sikkak, Ouizert, and Cheurfa reservoirs. This sudden increase in specific periods of the year generally corresponds to periods of fertilizer applications to agricultural land. In the case of rain, the nitrate ions that are not assimilated by plants are leached into the reservoirs. The increase of nitrates in these reservoirs leads to a rapid increase of aquatic plants and algae on the surface and can lead to eutrophication of water bodies.

Like the 'standard' freshwater in which calcium is the dominating cation (Golterman & Kouwe 1980), the ionic composition of the water of Western Algeria reservoirs was also dominated by calcium followed by magnesium.

DO is an important indicator of water quality, ecological status, productivity, and the health of a reservoir. This is due to its importance as a respiratory gas, and its use in biological and chemical reactions. Higher DO recorded in the rains could be as a result of low temperature and increased mixing of water (Mustapha 2008). The increase in DO in the studied reservoirs is due to high run-offs occurring during the rainy season. The highest DO concentration recorded in all reservoirs was a good pointer to the fact that all the studied reservoirs are the most productive, with the highest water quality parameters and will support diverse organisms.

According to the assessments performed by the analysis of the laboratory of National Water Resources Agency (ANRH), in 2008, on the pollution of Sarno reservoir, it registered an excess of the following parameters compared to the limit values of Algerian standards: biochemical oxygen demand (BOD_5) = 336, 4 mg/L and chemical oxygen demand (COD) = 2,800 mg/L. This pollution is mainly due to addition of domestic effluents, and untreated industrial wastewater discharges from the industries located within the catchment area of Sarno reservoir.

The computation of WQI for Western Algeria reservoirs was realized through the introduction of the monthly mean values of each quality parameter being taken into account; the values were registered at the 10 monitoring stations (cf. Table 2). The variation of the water quality for the studied reservoirs is presented in Figures 3 and 4. Due to the increase of human impact on water resources, the values of WQI show obvious annual oscillations (cf. Figures 3 and 4). Thus, between 2001 and 2010, the figures show important variations registered during the 10 years, especially in 2005, 2007, and 2008. It was observed that the range of CCME WQI for Western Algeria reservoirs is under the good category except for 2005, where it is under the marginal category for Hammam Boughrara, Sikkak, and Cheurfa reservoirs, mainly due to addition of domestic effluents and untreated industrial wastewater discharges from industries located in the catchment area of these reservoirs. The figures also show a decrease in water quality in all reservoirs in 2007, even in 2008 for Hammam Boughrara and Sarno reservoirs and for Hammam Boughrara and Cheurfa reservoirs in 2010.

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Table 4 | Mean, standard deviation, and range of physical and chemical properties of water quality of Western Algeria reservoirs – Tafna basin – 2001–2010 period

Variables/maximum admissible value				**Site**				
Parameters	**Symbol**	**Unity**	**Maximum value admissible (Algerian standards[a])**	**Beni Bahdel reservoir**	**Sikkak reservoir**	**S. Abdelli reservoir**	**Boughrara reservoir**	**Mefrouche reservoir**
Calcium	Ca	mg/L	75–200	48.86 ± 14.64 (21–107)	49.71 ± 17.34 (20–93)	59.38 ± 13.1 (29–100)	71.04 ± 17.84 (25–115)	44.08 ± 14.53 (14–101)
Magnesium	Mg	mg/L	150	39.86 ± 11.55 (13–78)	50.5 ± 12.05 (18–85)	43.92 ± 11.97 (9–77)	54.89 ± 14.94 (16–109)	19.99 ± 8.02 (5–48)
Temp	Temp	°C	25	18.5 ± 6.04 (8–28)	19.87 ± 5.96 (8–31)	19.18 ± 5.92 (9–30)	19.47 ± 5.45 (10–31)	16.24 ± 6.71 (4–30)
Hardness	Hardness	mg/L	100–500	288.22 ± 52.76 (182.5–563.33)	334.69 ± 73.11 (160–550)	331.44 ± 51.96 (177.5–483.33)	406.31 ± 77.88 (231.67–664.17)	193.5 ± 48.86 (100–362.5)
pH	pH	pH	6.5–8.5	8.02 ± 0.59 (7.13–13)	8.07 ± 0.37 (7.31–8.8)	7.91 ± 0.34 (7.13–8.9)	8.29 ± 1.37 (7–17.7)	8.11 ± 0.42 (7.16–10)
Total suspended solids	TSS	mg/L	n/a	522.86 ± 103.12 (140–900)	815.33 ± 103.97 (620–1,080)	787.85 ± 159.12 (500–1,360)	1,124.39 ± 222.97 (660–1,680)	330.2 ± 95.83 (140–660)
DO	DO	%	n/a	67.07 ± 28.21 (5.4–125.25)	80.3 ± 36.33 (5.7–171.8)	84.21 ± 16.12 (27.8–154.1)	67.25 ± 46.22 (4.1–290.7)	70.81 ± 28.68 (6–112.2)
Nitrate	NO_3	mg/L	50	6.17 ± 3.57 (1–24)	9.59 ± 8.31 (1–48)	6.4 ± 4.32 (1–26)	6.05 ± 3.92 (1–18)	5.13 ± 3.71 (1–16)
Nitrite	NO_2	mg/L	0.1	0.11 ± 0.07 (0.01–0.4)	0.44 ± 0.57 (0.02–2.8)	0.09 ± 0.11 (0.01–1)	0.84 ± 1.24 (0.01–7)	0.06 ± 0.05 (0.01–0.28)
Ammonium	NH_4^+	mg/L	0.5	0.1 ± 0.12 (0.01–0.68)	1.09 ± 2.3 (0.02–13.4)	0.24 ± 1.07 (0.01–9.85)	2.95 ± 3.13 (0.01–14.8)	0.08 ± 0.08 (0.01–0.38)
Phosphate	PO_4^-	mg/L	10[b]	0.09 ± 0.08 (0.01–0.5)	0.62 ± 0.91 (0.06–4.4)	0.15 ± 0.54 (0.01–4.87)	2.08 ± 1.5 (0.1–6.05)	0.07 ± 0.07 (0.01–0.28)
Biochemical oxygen demand	BOD_5	mg O_2/L	7[b]	5.93 ± 5.4 (1.6–47)	8.28 ± 4.59 (2.7–25)	7.13 ± 4.47 (1.6–22.8)	12.01 ± 6.68 (2–38.9)	6 ± 3.83 (1.1–23.1)
Chemical oxygen demand	COD	mg O_2/L	30[b]	24.15 ± 15 (4–90)	36.79 ± 18.99 (20–130)	33.02 ± 19.06 (10–110)	57.68 ± 29.16 (19–160)	25.57 ± 15.73 (10–80)

n/a = not applicable or not available.
[a]Algerian standards (NA 6360-1992).
[b]Official Journal of the Algerian Republic (OJAR) 2011.

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Table 5 | Mean, standard deviation, and range of physical and chemical properties of water quality of Western Algeria reservoirs – Macta basin – 2001–2010 period

Variables/maximum admissible value				Site				
Parameters	**Symbol**	**Unity**	**Maximum value admissible (Algerian standards[a])**	**Fergoug reservoir**	**Ouizert reservoir**	**Cheurfa reservoir**	**Sarno reservoir**	**Bouhanifia reservoir**
Calcium	Ca	mg/L	75–200	93.05 ± 42.4 (28–226)	62.77 ± 15.56 (22–99)	87.72 ± 22.79 (31–179)	123 ± 40.08 (36–233)	61.02 ± 14.57 (24–104)
Magnesium	Mg	mg/L	150	79.46 ± 22.66 (32–155)	49.59 ± 16.33 (17–97)	72.56 ± 18.75 (27–118)	72.71 ± 25.57 (20–132)	60.45 ± 19.62 (24–124)
Temp	Temp	°C	25	19.42 ± 6.82 (7–31)	19.61 ± 6.29 (9–30)	20.28 ± 5.95 (8–32)	17.51 ± 6.05 (5–28)	19.32 ± 6.04 (7.5–30)
Hardness	Hardness	mg/ L	100–500	563.72 ± 141.61 (233.33–968.33)	366.55 ± 73.19 (205–575.83)	521.65 ± 106.54 (322.5–835)	612.32 ± 181.87 (220.83–1,057.5)	404.42 ± 82.37 (239.17–669.17)
pH	pH	pH	6.5–8.5	7.82 ± 0.3 (7.05–8.5)	7.94 ± 0.34 (7.25–8.9)	8.59 ± 3.34 (6.9–33)	7.75 ± 0.35 (6.75–8.6)	7.94 ± 0.33 (6.8–8.67)
Total suspended solids	TSS	mg/ L	n/a	1,520 ± 480.04 (700–2,860)	796.14 ± 230.7 (400–1,380)	1,484.17 ± 291.11 (860–2,080)	2,093.92 ± 1,126 (400–9,260)	901.74 ± 233.1 (80–1,480)
DO	DO	%	n/a	83.95 ± 34.56 (5.7–178.6)	81.02 ± 36.02 (5.5–197.4)	92.69 ± 54.36 (9.5–333)	67.57 ± 21.39 (6.7–114.2)	73.11 ± 31.71 (3.9–167.4)
Nitrate	NO_3	mg/L	50	6.47 ± 4.14 (1–20)	8.27 ± 5.73 (1–31)	8.32 ± 7.01 (1–36)	4.56 ± 2.5 (1–13)	4.91 ± 3.1 (1–16)
Nitrite	NO_2	mg/ L	0.1	0.27 ± 0.34 (0.02–2.61)	0.32 ± 0.36 (0.01–2.4)	0.49 ± 0.9 (0.01–5.16)	0.09 ± 0.06 (0.01–0.28)	0.18 ± .38 (0.02–4)
Ammonium	NH_4^+	mg/L	0.5	0.37 ± 0.6 (0.01-3.62)	0.27 ± 0.42 (0.01–3.15)	0.24 ± 0.42 (0.01–2.56)	0.5 ± 1.3 (0.01–10)	0.19 ± 0.24 (0.01–1.82)
Phosphate	PO_4^-	mg/ L	10[b]	0.16 ± 0.19 (0.01–1.48)	0.14 ± 0.16 (0.01–1.3)	0.53 ± 0.5 (0.02–2.1)	0.21 ± 0.26 (0.02–1.83)	0.11 ± 0.15 (0.01–1.43)
Biochemical oxygen demand	BOD_5	mg O_2/L	7[b]	11.55 ± 8.38 (1.9–70)	8.11 ± 4.48 (1.3–31.4)	19.06 ± 13.44 (4.9–100)	31.98 ± 60.56 (3.9–-336.4)	9.3 ± 6.04 (2–42.3)
Chemical oxygen demand	COD	mg O_2/L	30[b]	47.54 ± 24.41 (10–140)	35.37 ± 19.77 (5–130)	76.39 ± 39.74 (20–280)	158.47 ± 351.42 (20–2,800)	40.57 ± 21.69 (10–140)

n/a = not applicable or not available.
[a]Algerian standards (NA 6360-1992).
[b]Official Journal of the Algerian Republic (OJAR) 2011.

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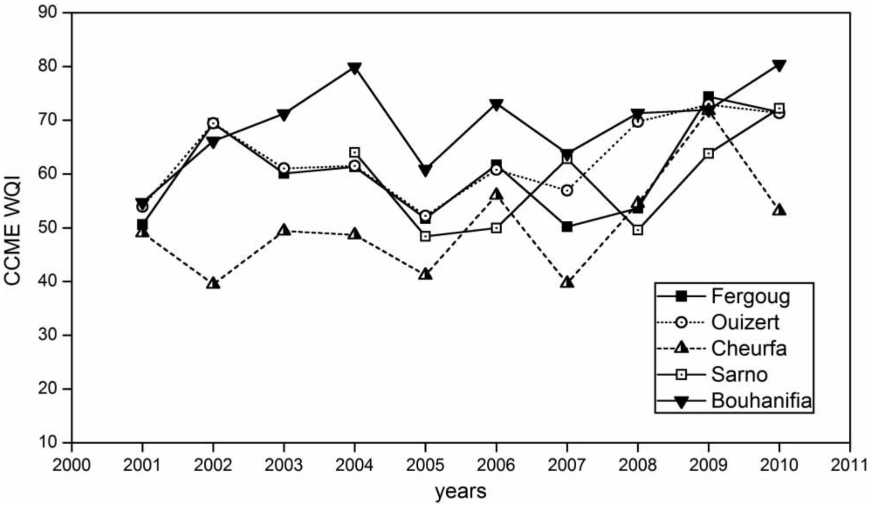

Figure 3 | Variation of the WQI in the Western Algeria reservoirs, in the period 2001–2010 (Macta basin).

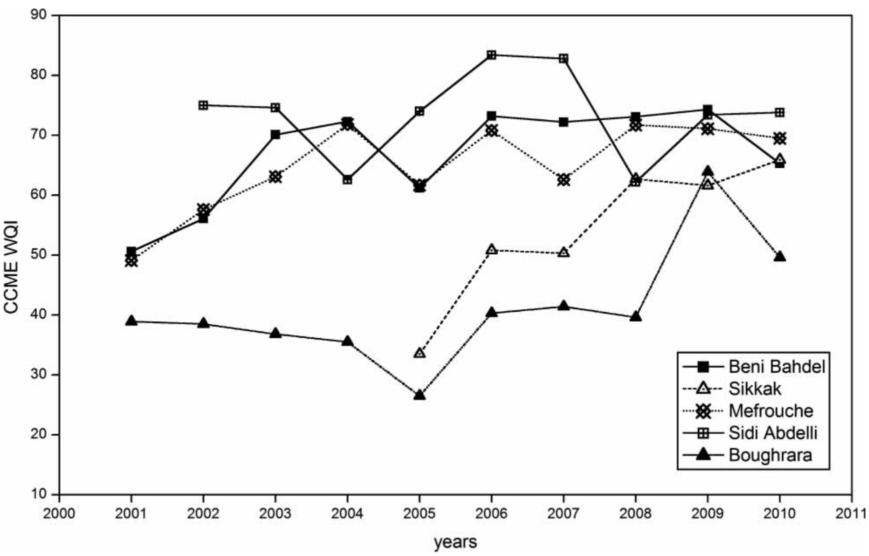

Figure 4 | Variation of the WQI in the Western Algeria reservoirs, in the period 2001–2010 (Tafna basin).

The low value of the index was registered in 2005 at the following monitoring stations: Hammam Boughrara – 26.5%; Sikkak – 33.5%, and Cheurfa – 41.2%. This low level of WQI can be attributed to the number of variables and tests that exceed or are less than the objectives. The nutrients, respectively the values of the nitrates, are also responsible in this case for influencing the quality category. The water quality of Sikkak reservoir reflects the impact of domestic and industrial discharges of Tlemcen town.

It should be noted that the water of Ouizert, Bouhanifia, and Fergoug reservoirs, which are situated in the same catchment area 'El-Hammam Wadi', are threatened with pollution from the industrial area of Saida. Indeed, it was found that the water of Saida Wadi had a blackish color indicating the presence of pollution.

Histograms for three factors for the Hammam Boughrara reservoir (Tafna basin) and Cheurfa reservoir (Macta basin), in the period 2001–2010, are shown in Figures 5 and 6

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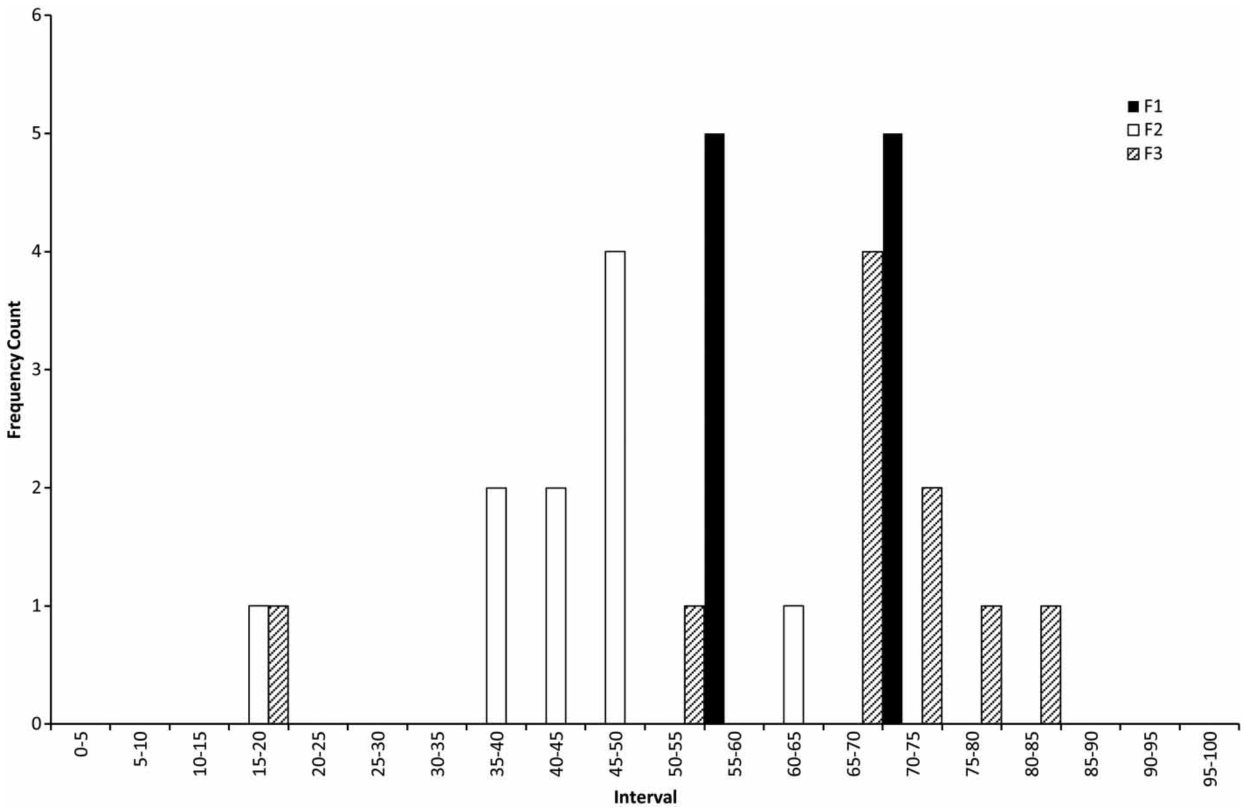

Figure 5 | Histogram of F1, F2, and F3 parameters distribution for the Hammam Boughrara reservoir (Tafna basin).

representing scope, frequency, and amplitude. For Hammam Boughrara reservoir, the maximum number of variables whose objectives are not met lie in the range of 70–75. The frequency with which the objectives are not met is highest between the range of 45–50 and the amount by which the objectives are not met is highest between 65 and 70 (cf. Figure 5). The low level of WQI of Hammam Boughrara reservoir can be attributed to the number of variables and tests that exceed or are less than the objectives. For Cheurfa reservoir, the maximum number of variables whose objectives are not met lie in the range of 70–75. The frequency with which the objectives are not met is highest between the range of 30–35 and the amount by which the objectives are not met is highest between 55 and 60 (cf. Figure 6).

WQI of Hammam Boughrara reservoir – case study

The site of Hammam Boughrara reservoir is the main outflow of the Bounaim Wadi, stretching from Morocco to Algeria as the Mouilah Wadi, with a catchment area of 4,000 km^2. The hydrological basin shared between Morocco and Algeria (2,100 km^2 of the area lies in Algeria, whereas the rest of the area, i.e., 1,900 km^2 lies in the state of Morocco) is an example of the politics of silence and non-cooperation (Zarhloule *et al.* 2010). In the whole catchment area of Mouilah Wadi, pollution spreads to finally reach Hammam Boughrara reservoir which is the receiver of solid and liquid wastes of all activities contained in the perimeter. At Hammam Boughrara monitoring station, the water quality in this reservoir falls into the poor category for the entire study period. It was found that the water quality has been annually threatened and rarely reaches the desired value. However, since 2009 and 2010, WQI fell into the marginal category (WQI 63.9 in 2009 and 49.6 in 2010) (cf. Figure 4).

The water quality conditions were critical: first, due to the effects of the urban wastewater discharge of Ouajda (Morocco) and industrial wastewater discharge of Maghnia (Tlemcen); and second, due to the effects of drought that significantly reduced the natural process of self-purification of

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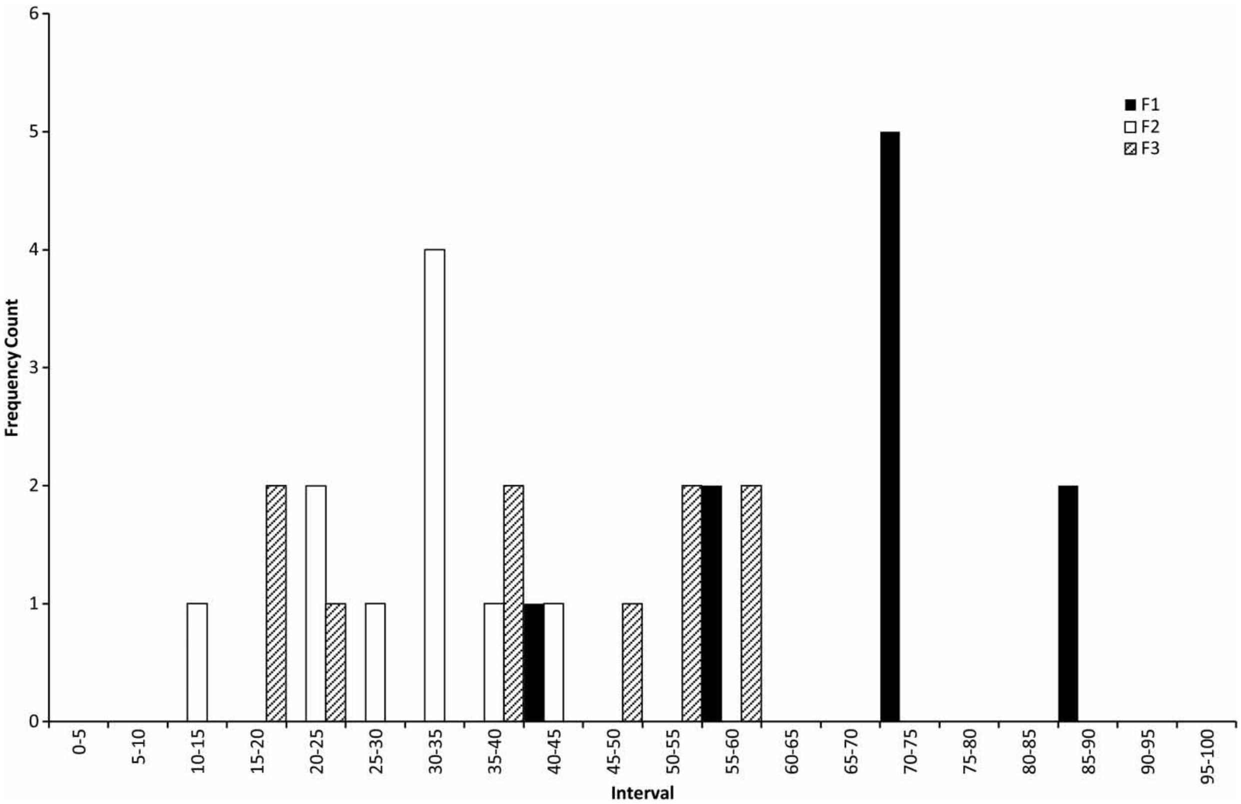

Figure 6 | Histogram of F1, F2, and F3 parameters distribution for the Cheurfa reservoir (Macta basin).

Mouilah Wadi. The irrigated area of Maghnia, especially areas used within the plain of Maghnia, is among the sources of pollution caused by fertilizer and pesticide misuse.

This transboundary catchment area (catchment area of Hammam Boughrara) should be subjected to assessment and monitoring to ensure sustainable, equitable management of scarce water. The new WWTP implented in the city of Ouajda (Morocco), which will treat around 40,000 m^3 of wastewater per day (Kharroubi 2011), should contribute significantly in the treatment of wastewater discharged into Bounaim Wadi and, consequently, a reduction of pollution that enters the Hammam Boughrara reservoir.

CONCLUSION

The results obtained from the application of CCME WQI to all reservoirs located within catchment areas of Western Algeria based on observed water quality data, revealed that the overall surface water quality mainly fell into the marginal class (i.e., the water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels) in all reservoirs expect for Hammam Boughrara reservoir whose water quality fell into the poor category where its hydrological basin is shared between Morocco and Algeria. This implies that the water quality of this reservoir is almost always threatened or impaired; conditions usually depart from natural or desirable levels. The low value of the index was registered in 2005 at the following monitoring stations: Hammam Boughrara – 26.5%; Sikkak – 33.5%; and Cheurfa – 41.2%. This low level of WQI can be attributed to the number of variables and tests that exceed or are less than the objectives.

The situation of water quality is critical within the catchment areas of the region. It is very important to accelerate protective measures to reduce pollution of reservoirs into the study area. The management and protection of lakes

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and reservoirs is primarily a function of the local, state, or federal government. Algeria has made considerable efforts to protect the water resources, adopting a number of water resources protection initiatives and establishing a comprehensive legislation and institutional set-up. Lake and reservoir protection measures often may consider solutions to pollution problems; such options are constructing treatment plants to treat polluted water prior to its discharge to lakes and reservoirs, as well as recycling or reusing wastewaters.

This is in accordance with the Ministry priorities in the field of construction of the WWTPs, particularly that relating to the preservation of surface water and groundwater resources. The priority criteria for the realization of WWTPs are primarily granted to agglomerations located in water exploitation fields or in the drainage basins of such fields, and secondly to agglomerations located upstream from water exploitation dams under construction.

In order to remedy this situation, there is a plan to achieve more than 115 WWTPs up to 2030 in the whole of the region, and these will be capable of treating up to 7,000,000 population equivalent when at full capacity by 2030. Forty-two WWTPs are planned to be constructed up to 2020 and will treat 3,961,251 population equivalent. The amount of treated wastewater by 2020 should reach 815,184 m^3/d (293.47 Hm^3/yr) (MRE 2009).

Finally, raising environmental awareness among the public and the key stakeholders, as well as the establishment of a participatory methodology on the decision-making process for environmental issues, are considered very important priorities for the successful planning and implementation of the environmental policies in the country. The results from the WQI study will help environmental planners to design, formulate, and implement the pollution abatement strategies.

ACKNOWLEDGEMENTS

The authors express their special thanks to members of the hydrographical basin agencies (ABH OCC) and National Water Resources Agency (ANRH) for their assistance in providing necessary data for the study.

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First received 30 June 2013; accepted in revised form 22 September 2013. Available online 21 November 2013

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