

Status and trends of water quality in the Tafna catchment: a comparative study using water quality indices

Abdelkader Hamlat, Azeddine Guidoum and Imen Koulala

ABSTRACT

Water quality indices (WQIs) are necessary for resolving lengthy, multi-parameter, water analysis reports into single digit scores; different WQIs have been developed worldwide which are greatly differing in terms of mathematical structures, the numbers and types of variables included, etc. The aim of this paper is to evaluate trends of water quality in Tafna basin with a comparison of 10 WQIs perceived as the most important indices for water quality assessment. The results show that there is an appreciable difference between indices values for the same water sample. The results also show that water quality categorization for sampling stations in the Canadian Council of Ministers of the Environment WQI (CCMEWQI) and British Columbia WQI (BCWQI) was found to be 'marginal' for all sampling stations, except Hammam Boughrara reservoir and Mouillah wadi where it was found to be 'poor'. For the Aquatic Toxicity Index, it was found to be 'totally unsuitable for normal fish life' for all stations and 'suitable only for hardy fish species' for Mouillah wadi and Boughrara reservoir. The results show that this transboundary catchment always needs strategies for more effective pollution control management. Future use of WQIs in this way should prove a valuable tool for environmental planning decision-makers in tracking water quality change.

Key words | CCMEWQI, Hammam Boughrara, Mouillah wadi, Tafna catchment, transboundary, water quality indices

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INTRODUCTION

Water is a dynamic renewable resource. Its availability with good quality and adequate quantity is very important for human life and other purposes (Ibraheem *et al.* 2013). Algeria is characterized by misallocation of water resources and irregular temporal distribution of water flow in wadis. Rainfall varies considerably from the west to the east of the country (450 mm annually at Oran, over 1,000 mm at Annaba); this longitudinal gradient is due to the effect of the Sierra Nevada in the south of Spain and High Atlas mountains of Morocco in the west that act as a screen eliminating the Atlantic influence on the north-west of Algeria (Djellouli

1990). Furthermore, in the last two decades, climate change and hydric stress have affected remarkably the availability of water in the region (Meddi & Hubert 2003).

The problem of water quality is another factor that affects the availability of water resources in north-western Algeria especially in the Tafna basin. Studies show that there is a significant amount of wastewater that continues to spread into the water reservoirs without treatment.

The Tafna basin is a transboundary basin between Algeria and Morocco with roughly a third of its surface area located in Morocco; the water quality of this basin is affected by both natural processes and anthropogenic influences. Municipal and industrial wastewater discharges from Oujda City (Morocco) and its vicinity, and dumping of waste and industrial effluents of Tlemcen, Maghnia into wadis and streams running close to the cities are becoming major sources of basin water

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pollution (Taleb *et al.* 2004; Tidjani *et al.* 2006; Boumediene 2010a, 2010b; Hadji *et al.* 2012; Derrag & Dali 2014).

The reporting of results to both managers and to the general public is an integral part of any environmental monitoring program. This poses a problem in water quality monitoring due to the complexity associated with analyzing a large number of measured variables (Canadian Council of Ministers of the Environment (CCME) 2001). Traditional approaches to assessing water quality are based on the comparison of experimentally determined parameter values with existing guidelines (Debels *et al.* 2005; Boyacioglu 2007). This type of assessment is simple and detailed, but not capable of providing a whole and interpreted picture of water quality especially for managers and decision-makers who require concise information about water bodies (Mohebbi *et al.* 2013).

The possible solution for this problem is to reduce the multivariate nature of water quality data by employing a dimensionless number that combines multiple water-quality factors into a single number and gives efficiently the overall water quality (Miller *et al.* 1986; CCME 2001).

The use of water quality indices (WQIs) was introduced in the 1960s as a tool to evaluate the status of water quality in rivers. Furthermore, a new WQI similar to Horton's index was also developed by Brown's group in 1970 (Tyagi *et al.* 2013). In 1982 Steinhart *et al.* applied a novel environmental quality index to sum up technical information on the status and trends in the Great Lakes ecosystem (as cited in Poonam *et al.* 2013). In the mid-1990s, the WQI was introduced in Canada by the water quality guidelines task group of the Canadian Council of Ministers of the Environment (CCME) (Sharma & Kansal 2011). Various indices have been formulated and developed by many researchers as tools for simplifying the representation of data (Bhargava 1983; Smith 1990; Pesce & Wunderlin 2000; Cude 2001; Liou *et al.* 2004; Said *et al.* 2004; Boyacioglu 2007, etc.). Most WQIs are based on the first WQI developed by the National Sanitation Foundation (NSF) (Said *et al.* 2002). 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). A wide range of WQIs has been developed and applied to provide a general assessment of the river water quality status, whereas a few WQIs also consider specific uses (suitability

for drinking water supply, irrigation, aquaculture, etc.; Smith 1990). Usually a higher score of WQI alludes to better water quality (excellent, good) and a lower score to degraded quality (bad, poor) (Lumb *et al.* 2011).

A number of comparative evaluations of the various indices in use are available (Landwehr & Deininger 1976; Ott 1978; Gupta *et al.* 2003; Stambuk-Giljanovic 2003; Fernandez *et al.* 2004; Avvannavar *et al.* 2007; Jiménez *et al.* 2007; Beamonte Córdoba *et al.* 2010; Terrado *et al.* 2010; Katyal & Bharti 2011; Lumb *et al.* 2011; Abbasi & Abbasi 2012; Rekha *et al.* 2013; Sarala Thambavani & Uma Mageswari 2013; Tunc Dede *et al.* 2013; Tyagi *et al.* 2013, etc.).

Actually, the evaluation of water quality in Algeria has been carried out by National Agency of Water Resources 'Agence Nationale des Ressources Hydriques' (ANRH), where the water quality has been assessed only by comparing experimentally determined parameter values with existing guidelines, the process is lengthy, complex, and labor intensive (Agence de Bassin Hydrographique Oranais Chott Chergui (ABHOCC) 2006). 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.

The purpose of this paper is to evaluate trends of water quality in Tafna catchment and to compare several WQIs perceived as simple, basic and the most important indices for water quality assessment. Their mathematical structure, set of parameters, calculation, aggregation formula and flaws have also been detailed using the same set of data, with the objective of observing the performance of each one in water quality assessment; a comparison has been made using 10 WQIs (Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), National Sanitation Foundation WQI (NSFWQI), Dinius WQI (DWQI), Oregon WQI (OWQI), Department of Environment WQI (DOEWQI), British Columbia WQI (BCWQI), Universal WQI (UWQI), ISQA (the Catalan water agency WQI), Overall Index of pollution (OIP) and Aquatic Toxicity Index (ATI)). These WQIs have been implemented on some wadis and reservoirs within the Tafna catchment.

The results presented in this paper are based on physico-chemical water quality parameters, such as temperature, pH, conductivity, turbidity, dissolved oxygen (DO), total

suspended solids (TSS), total dissolved solids (TDS), calcium, magnesium, hardness, sodium, potassium, chlorides, sulfates, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total organic carbon (TOC), nitrate, nitrite, ammonium, ammonia, phosphate, total phosphorus, iron, manganese, zinc, etc.

Study area and sampling sites

This study was undertaken in the Tafna basin which is located in north-western Algeria (Figure 1).

The transboundary Tafna river basin has a total area of 7,245 km² (5,340 km² of the area lies in Algeria, whereas the rest of the area, i.e., 1,905 km² lies in the state of Morocco).

The Tafna basin can be divided into two zones of different geological nature: the upstream sector where the river runs in a canyon through Jurassic rocks rich in limestone and dolomite; and the downstream sector where it runs in a tertiary basin characterized by marls covered by recent alluvium (Taleb *et al.* 2008).

The general rainfall regime in this catchment is similar to semi-arid Mediterranean areas, with maxima in winter and minima in late summer. This system is also characterized by winter rainfall that is at least three times the amount that falls during the summer. Indeed, over much of the Mediterranean summer rainfall is virtually zero (Meddi *et al.* 2010).

The Tafna basin has been considered one of the main water towers of all hydrographic regions due to its important water resources. The demand and competition for water is high in the basin. Two-thirds of the groundwater is used for irrigation, and one-third for potable and industrial use (United Nations Environment Programme (UNEP) & Water Research Commission (WRC) 2008).

The basin's water resources are already being extensively exploited. Further, the projections indicate that, the available water resources will not be able to fully meet the water demand by 2030 (Hamlat *et al.* 2013).

Five different sites were studied (cf. Figure 2). The first site is Beni Bahdel reservoir (its code is 160403), located in the wilaya (province) of Tlemcen at 34° 41' 49" N, -1° 30' 32" W, it was



Figure 1 | Location of study area.

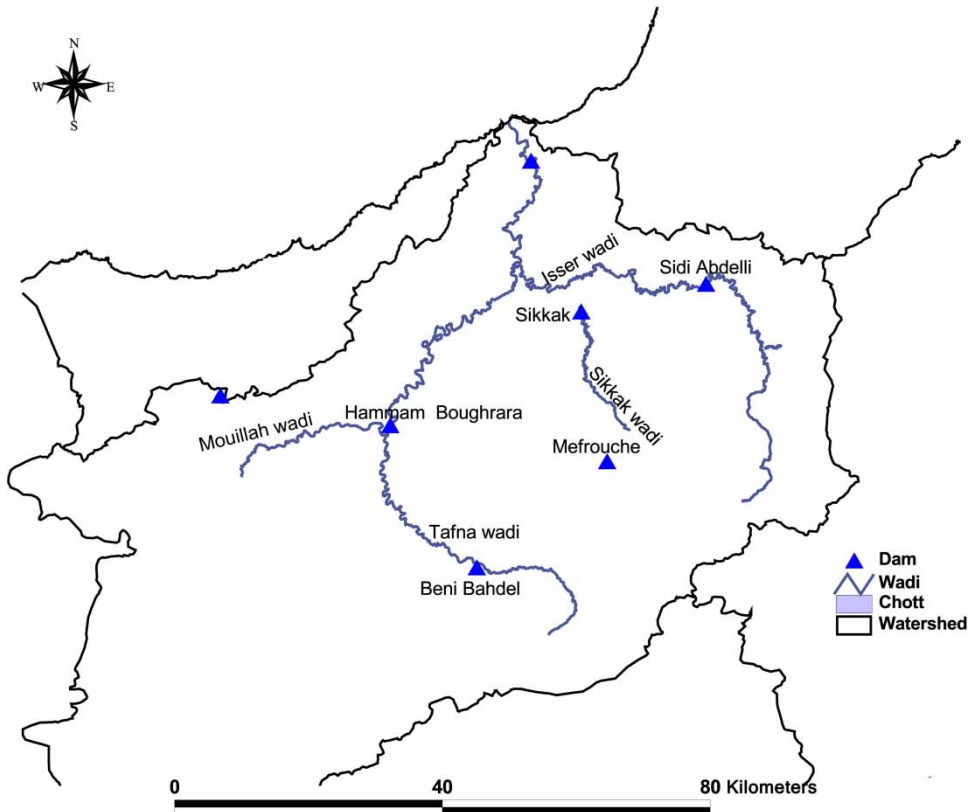


Figure 2 | The geographical location of the studied reservoirs and wadis.

initially designed to ensure irrigation of Maghnia irrigated perimeter; it was decided later to use it to supply water to the wilaya of Oran.

The second site is Tafna wadi (160402), located in the Upper-Tafna sub-basin in the wilaya of Tlemcen at $34^{\circ} 41' 38''$ N, $-1^{\circ} 27' 48''$ W. The gauging station is located at the outlet of the basin and approximately 1,000 m upstream of the inlet of the Beni Bahdel dam (Megnounif et al. 2013). The wadi also receives discharge of urban and industrial wastewater from Sebdu, Aïn Ghoraba, Azail and Beni Bahdel; some of the urban wastewater has been discharged without any previous treatment (Boume-diene 2010a, 2010b).

The third site is Sikkak reservoir (160728), located in Tafna catchment in the wilaya of Tlemcen at $35^{\circ} 2' 36''$ N, $-1^{\circ} 20' 22''$ W. The dam was constructed to help alleviate the water problems of the Sikkak basin. The quality of this ecosystem has been degrading due to agriculture and human activities (Derrag & Dali 2014).

The fourth site is Mouillah wadi (160202), located at $34^{\circ} 51' 3''$ N, $-1^{\circ} 51' 28''$ W. It is over a length of 124 km, it enters in Morocco taking the name of Isly wadi and follows an intermittent course, it becomes permanent downstream near Oujda (Morocco) where it is called Bounaim wadi, and penetrates Algeria near to Maghnia city (wilaya of Tlemcen) under the name of Mouillah wadi.

The last site is Hammam Boughrara reservoir (160520), located in Tafna catchment, and built about 8 km north-east of Maghnia at $34^{\circ} 52' 17''$ N, $-1^{\circ} 38' 52''$ W. The site of this reservoir is the main outflow of the Bounaim Wadi, stretching from Morocco to Algeria as the Mouillah Wadi, with a catchment area of 4,000 km². In the whole catchment area of Mouillah wadi, pollution spreads to finally reach Hammam Boughrara reservoir which is the receiver of solid and liquid waste of all activities contained in the perimeter.

MATERIAL AND METHODS

Water quality index

According to [Stambuk-Giljanovic \(2003\)](#), the WQI is a mathematical instrument used to transform large quantities of water quality data into a single number; which improves understanding of water quality issues. This is done by integrating relevant water quality data, to generate a score that describes water quality status and can also be used to evaluate water quality trends.

There are generally four basic steps involved in the development of WQIs. They are: (a) the selection of water quality variables; (b) transformation or the comparison of variables on a common scale through the development of rating curves; (c) weighting of variables based on their importance to overall water quality; and (d) formulating and computing of the overall index ([Wepener et al. 2006](#)).

In this section, a detailed description of various WQIs perceived as simple, basic and the most important indices for water quality assessment is presented. Their mathematical structure, set of parameters, calculation, aggregation formula and flaws have also been detailed.

CCMEWQI

The CCMEWQI has been developed by the CCME; it is based primarily on the water index formula developed by the British Columbia Ministry of Environment, Lands and Parks in the mid-1990s, refined with inputs from the Alberta Environment. The CCME recommends that a minimum of four variables sampled at least four times should be used for index calculation. It should also be ascertained that the variables chosen provide relevant information about a particular site ([CCME 2001](#)). The CCMEWQI is calculated as follows:

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

where:

F_1 (Scope) represents the percentage of variables that do not meet their objectives at least once during the time period

under consideration ('failed variables'), relative to the total number of variables measured.

F_2 (Frequency) represents the percentage of individual tests that do not meet objectives ('failed tests').

F_3 (Amplitude) represents the amount by which failed test values do not meet their objectives. Water quality can be ranked as poor (0–44), marginal (45–64), fair (65–79), good (80–94.9), or excellent (95–100), according to the CCMEWQI scale (for more details, see [CCME \(2001\)](#)).

BCWQI

The BCWQI was developed by the Canadian Ministry of Environment in 1995 as an increasing index (the index numbers increase with the increasing degree of pollution) to evaluate water quality. This index is similar to the CCMEWQI where water quality parameters are measured and their violation is determined by comparison with a predefined limit. It provides the possibility to make a classification on the basis of all existing measurement parameters.

To calculate the final index value, the following equation is used:

$$\text{BCWQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + \left(\frac{F_3}{3}\right)^2}}{1.453} \right) \quad (2)$$

The number 1.453 was selected to give assurance to the scale index number from zero to 100. It is important to note that repeated samplings and increasing stations increase the accuracy of the British Columbia index ([Salim et al. 2009](#)). The WQI is a number ranging from 0 to 100 divided into one of five categories: excellent (0–3), good (4–17), fair (18–43), borderline (44–59) and poor (60–100).

NSFWQI

The NSFWQI was developed by the NSF in 1970. This WQI has been widely field tested and applied to data from a number of different geographical areas all over the world in order to calculate the WQI of various water bodies ([Akkoyunlu & Akiner 2012](#)). The WQI is a 100-point scale

that summarizes results from a total of nine different parameters. Water quality can be ranked as very bad (0–25), bad (26–50), medium (51–70), good (71–90), or excellent (91–100), according to the NSFQWI scale.

The formula used for calculating the NSFQWI is given by:

$$\text{NSFQWI} = \sum_{i=1}^p W_i I_i \quad (3)$$

where I_i is the sub-index for i th water quality parameters, W_i is the weight (in terms of importance) associated with the i th water quality parameter, and p is the number of water quality parameters.

OWQI

The OWQI is a single number that expresses water quality by taking eight water quality variables (temperature, DO, pH, BOD, total phosphorus, total solids, fecal coliform, ammonia and nitrate nitrogen) into account. The original OWQI was designed after the NSFQWI where the Delphi method was used for variable selection. Both indices used logarithmic transforms to convert water quality variable results into sub-index (SI) values. Logarithmic transforms take advantage of the fact that a change in magnitude at lower levels of impairment has a greater impact than an equal change in magnitude at higher levels of impairment.

$$\text{OWQI} = \sqrt{\frac{n}{\sum_{i=1}^n \frac{1}{SI_i^2}}} \quad (4)$$

where n is the number of sub-indices, and SI is the sub-index of each parameter.

OWQI scores that are less than 60 are considered very poor, 60–79 poor, 80–84 fair, 85–89 good, and 90–100 excellent (see Cude (2001) for details).

ATI

The ATI was developed by Wepener *et al.* (1992) to assess the health of aquatic ecosystems. Since extensive toxicity databases are available for fishes, the toxic effects of different

water quality on fishes have been employed as health indicators of the aquatic ecosystem. The physical water quality parameters employed were pH, DO and turbidity while the chemical determinants included ammonium, total dissolved salts, fluoride, potassium and orthophosphates, and the potentially hazardous metals chosen were total zinc, manganese, chromium, copper, lead and nickel concentrations. For the ATI, the aggregation technique employed was the Solway Modified Unweighted Additive Aggregation function (Wepener *et al.* 1992; Sarkar & Abbasi 2006).

$$\text{ATI} = \frac{1}{100} \cdot \left(\frac{1}{n} \sum_{i=1}^n q_i \right)^2 \quad (5)$$

where q_i is the quality of the i th parameter (a value between 0–100) and n is the number of determinants in the indexing system.

Water quality can be ranked as totally unsuitable for normal fish life (0–50), suitable only for hardy fish species (51–59), or suitable for all fish life (60–100) (for more details, see Wepener *et al.* (1992)).

DWQI

It is a multiplicative WQI developed by Dinius (1987) for six categories of water uses: public water supply, recreation, fish, shellfish, agriculture and industry. He employed the liberal use of Delphi for decision making. The index included 12 parameters: DO, BOD5, coliform count, *Escherichia coli* count, pH, alkalinity, hardness, chloride, specific conductivity, temperature, color and nitrate. The weightage of each parameter was assigned based on the evaluation of importance by the Delphi panel members. Water quality can be ranked as not acceptable (0–40), doubtful (40–50), necessary treatment becoming more expensive (50–80), minor purification required (80–90), or purification not necessary (90–100), according to the DWQI scale (Ott 1978; Poonam *et al.* 2013). The individual SI functions were combined with the help of a multiplicative aggregation function as follows:

$$\text{DWQI} = \prod_{i=1}^n I_i W_i \quad (6)$$

where I_i is the sub-index function of the pollutant parameter, W_i is the unit weight of the pollutant parameter whose value ranges from 0–1 and n is the number of pollutant parameters (see Dinius (1987) for details).

OIP

The OIP is a single number that expresses the overall water quality by integrating measurements of 14 different physico-chemical, toxicological, and bacteriological water quality parameters. It was developed by Sargaonkar and Deshpande (2003) at the National Environmental Engineering Research Institute, Nagpur, India in order to assess the status of surface waters. OIP values range from 0 to 16. A high OIP value signals poor water quality, while a low value signals good water quality based on the classification scheme developed for India (Sargaonkar & Deshpande 2003; Sharma et al. 2013). Water quality can be ranked as heavily polluted (8–16), polluted (4–8), slightly polluted (2–4), acceptable (1–2), or excellent (0–1), according to the OIP scale (Sarkar & Abbasi 2006).

The OIP is calculated as the average of each index value given by the following mathematical expression:

$$OIP = \frac{\sum_{i=1}^n P_i}{n} \quad (7)$$

where P_i = pollution index for i th parameter and n = number of parameters.

UWQI

The UWQI was developed by Boyacioglu (2007) on the basis of water quality standards set by the Council of the European Communities, the Turkish water pollution control regulations and other scientific information to select 12 water-quality parameters as the most representative for drinking water quality.

To assign weights to the water-quality variables the following factors are taken into account:

- Chemical parameters had a lower weight than microbiological parameters, because microbial contaminants belong to the greatest health impact category.

- Higher weight was given to those parameters which are of known health concern.

The temporary weights ranged from 1 to 4 on a basic scale of importance. The index is given by:

$$UWQI = \sum_{i=1}^n W_i I_i \quad (8)$$

where W_i is the weight for i th parameter and I_i is the sub-index for i th parameter.

Water quality can be ranked as poor (0–24), marginal (25–49), fair (50–74), good (75–94), or excellent (95–100), according to the UWQI scale (for more details, see Boyacioglu (2007)).

DOEWQI

The DOEWQI is the WQI calculation method developed by the Department of Environment (DOE) Malaysia. This method has been successfully applied to measure water quality for 462 rivers in Malaysia. The calculation involved six water parameters which are DO, BOD, COD, ammoniacal nitrogen (AN), suspended solids (SS), and pH. The procedure of calculation consists of three steps: to identify the SI equation based on the value of parameters, to calculate the SI of every parameter, and to calculate the WQI (Susilo & Febrina 2011). Water quality can be ranked as polluted (0–59), slightly polluted (60–80), or excellent (81–100), according to the DOE scale (DOE 2013).

The formula used for calculating the DOEWQI is described as follows:

$$DOE\ WQI = 0.22\ SI_{DO} + 0.19\ SI_{BOD} + 0.16\ SI_{COD} + 0.16\ SI_{SS} + 0.15\ SI_{AN} + 0.12\ SI_{pH} \quad (9)$$

where $SIDO$ = Sub-index of DO, $SIBOD$ = Sub-index of BOD, $SICOD$ = Sub-index of COD, $SISS$ = Sub-index of SS, $SIAN$ = Sub-index of AN, and $SIpH$ = Sub-index of pH.

WQI of the Catalan water agency (ISQA)

The Simplified WQI (índice simplificado de calidad del agua: ISQA) is currently applied by the Catalan water

agency. It is mainly a correlation of DO, TOC, SS, and conductivity, with a weight vector of 0.30, 0.25, 0.25, and 0.20, respectively (Ocampo Duque 2008). Water quality can be ranked as very poor (0–25), poor (26–50), medium (51–70), good (71–90) or excellent (91–100) according to the ISQA scale (see Terrado et al. (2010) for details).

$$ISQA = SI_{Temp} (SI_{TOC} + SI_{SS} + SI_{DO} + SI_{Con}) \quad (10)$$

where SI_{Temp} = Sub-index temperature, SI_{TOC} = Sub-index TOC, SI_{SS} = Sub-index SS, SI_{DO} = Sub-index DO, and SI_{Con} = Sub-index conductivity.

The results presented in this paper are based on physico-chemical water quality parameters determined at five sampling sites in the Tafna basin, and the exploration of an analysis of a series of instantaneous samples performed at ANRH laboratory; measured at monthly frequency for a period of 4 years (January 2004–December 2008).

The complete study was conducted in two steps. The first step was to organize and process the data into a format compatible with WQIs analysis. The second was the calculation of WQIs after processing the input data, with the purpose of facilitating the simpler calculation of indices and their comparisons. The Excel spreadsheet software program was used for the calculation of WQIs and decision-making process (cf. Figure 3).

Table 1 gives an overview of the parameters determined during this study.

The main sources of surface water of Tafna basin are untreated sewage of Maghnia and Tlemcen cities, waste and industrial effluents of Maghnia and Oujda (Morocco) and pollution caused by fertilizer application and processing of soil and plants especially in areas exploited in the plain of Maghnia (cf. Figure 4).

Table 1 shows that ammonium concentration exceeds the guideline level at Hammam Boughrara and Mouillah wadi; we note that higher concentrations occur in water polluted by wastewater, fertilizers and agricultural wastes or industrial wastes containing organic nitrogen, free ammonia or ammonium salts (Bartram & Balance 1996).

The values of COD and BOD appear particularly significant in Sikkak and Hammam Boughrara reservoirs and Mouillah wadi as shown in Table 1. High BOD and COD concentration may cause the death of some aquatic

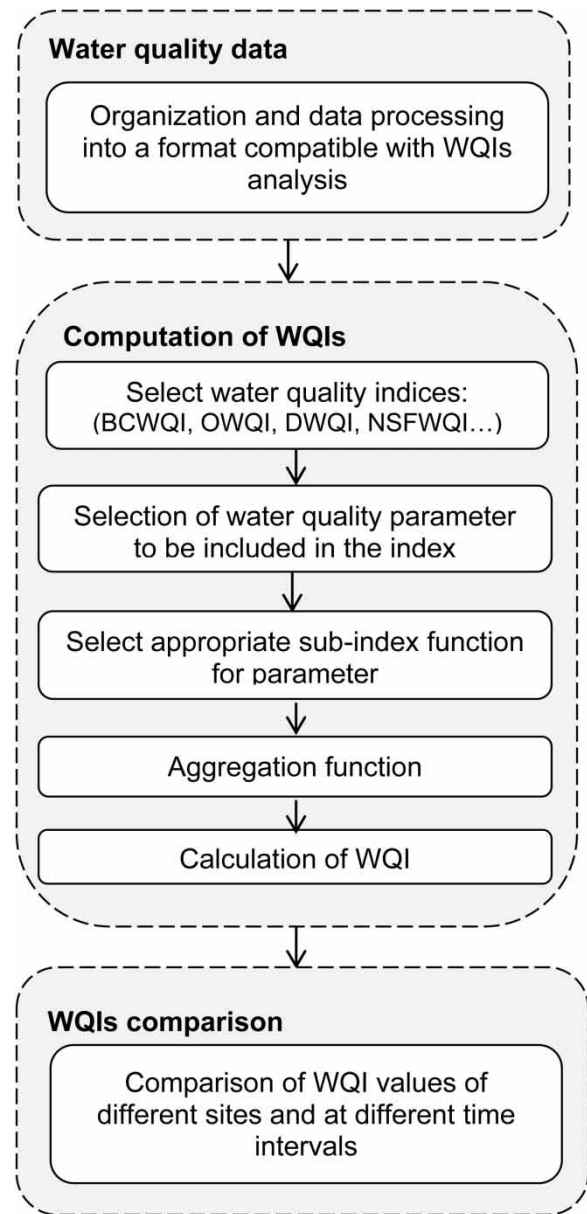


Figure 3 | Flow diagram showing the steps used in this work.

organisms such as fish; the high levels of these parameters in water often correlate with threats to human health including toxic algae bloom bacteria from organic wastes and seafood contamination, where high COD levels decrease the amount of DO available for aquatic organisms (Committee on Environment & Natural Resources (CENR) 2003). In Mouillah wadi, concentrations of phosphorus exceed the guideline level. Excess phosphorus is usually considered to be a pollutant because it can lead to eutrophication, the

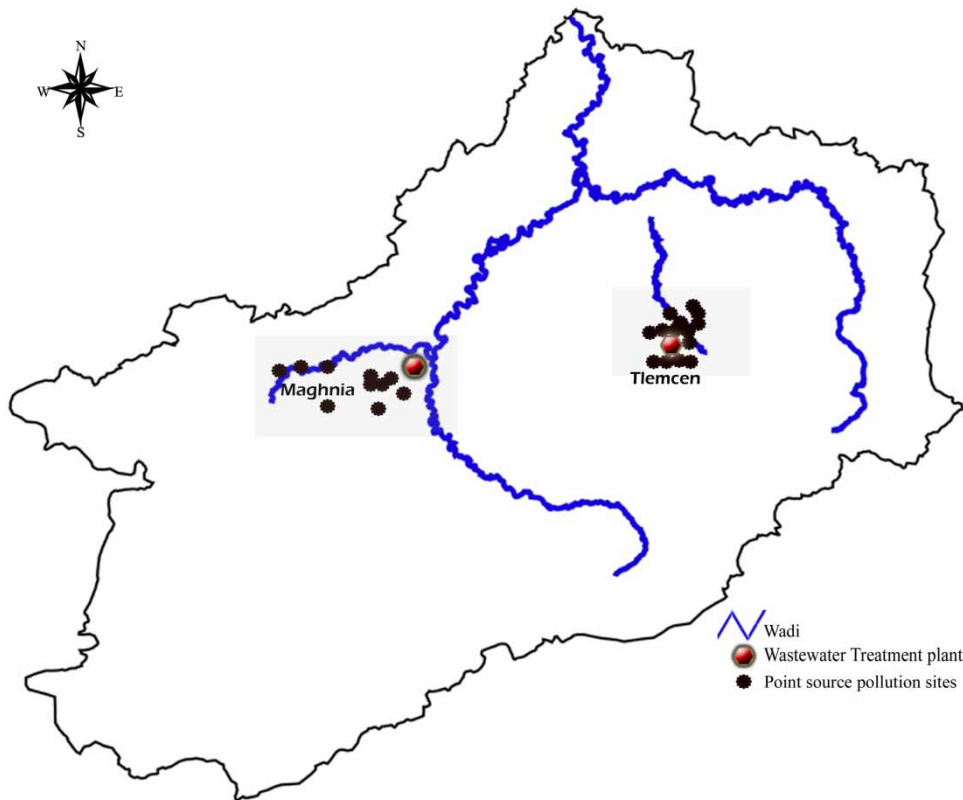


Figure 4 | Point source pollution sites in Tafna catchment (ABHOCC 2008).

latter can lower the levels of DO in the water and can render the water uninhabitable by many aquatic organisms.

RESULTS AND DISCUSSION

A comparison of different WQIs for Tafna and Mouillah wadis is shown in Figures 5 and 6, respectively; the figures indicate that there is an appreciable difference between classifications given by WQIs for the same water sample. The studied WQIs are greatly differing in terms of the numbers and types of variables included, weightage assignments, mathematical structures and aggregation formulae on which different indices are based (cf. Tables 2 and 3). The difference in the WQI values is due to disparity in selecting water quality parameters and preferred quality scales (Ott 1978; Akkoyunlu & Akiner 2012).

Figure 5 shows that the values of WQI for Tafna wadi range from 40.62 to 60.22 and from 3.96 to 4.90 for CCMEWQI and OIP, respectively.

The results show that the geographical variation in natural conditions is so important that each index should evolve from, and be adapted to, the specific characteristics of waters in the geographical area where it will be used. Results show again that ISQAWQI shows sensitivity to small changes in water quality.

The effective WQI methods in deriving the information from complex water quality data sets depends on various parameters, e.g. if it is important to consider low values, it is better to use the harmonic mean or its square (Cude 2001); the latter which is used in CCMEWQI and BCWQI is the most sensible method in a data set with low values, because these take more weight than those with high values (cf. Table 3). Both of them are interesting cases to consider, because of the integration of three factors, these factors are taken into account for the data and their relation to the objectives. With this concept focusing on the objectives, the agents must be more concerned more about improving the environmental conditions (Fernandez *et al.* 2004). Similarly, NSFWQI which uses the weighted

Table 1 | Descriptive statistics of water quality variables of sampling sites within Tafna Catchment 2004–2008 periods

Variables/maximum admissible value				Site				
Water quality parameters	Symbol	Unit	Maximum value admissible	H. Boughrara reservoir	Beni Bahdel reservoir	Sikkak reservoir	Mouillah wadi	Tafna wadi
Temp	Temp	°C	25	19.64 ± 5.81 (5–31)	18.25 ± 6.17 (8–28)	19.73 ± 5.97 (8–31)	19.5 ± 5.43 (9–28)	16.28 ± 4.52 (8–23)
pH	pH		6.5–8.5	8.05 ± 0.43 (7.2–9.1)	7.89 ± 0.34 (7.1–8.5)	8.04 ± 0.35 (7.3–8.8)	7.63 ± 0.33 (7–8.2)	7.66 ± 0.35 (7–8.5)
Conductivity	Cond	µS/cm at 20°c	2,800	1,667.6 ± 320.19 (977–2,750)	635.68 ± 80.2 (481–842)	1,002.12 ± 130.94 (774–1,330)	2,205.96 ± 234.79 (1,260–2,580)	924.03 ± 203.71(298–1,240)
Turbidity	Turb			31.72 ± 100.64 (2–779)	43.88 ± 136.43 (3–960)	17.95 ± 11.96 (3–55)	247.3 ± 330.24 (33–2,360)	92.2 ± 293.523(1,625–4,979)
DO saturation	Saturat	%O ₂	30	74.06 ± 38.7 (14.2–207.4)	80.21 ± 17.36 (37.6–142.7)	84.43 ± 34.33 (19.2–181.5)	7.44 ± 14.79 (0–57.4)	81.1 ± 14.87 (52.3–126.9)
Dissolved oxygen	DO	%		6.45 ± 3 (1.3–18)	8.54 ± 8.38 (3.1–70.5)	7.41 ± 2.57 (1.8–14.8)	0.67 ± 0.17 (1.32–1.74)	7.62 ± 1.88(0–12.8)
Total suspended solids	TSS	mg/l		40.97 ± 100.81 (6–771)	32.92 ± 52.73 (3–386)	25.6 ± 16.02 (6–98)	255.4 ± 187.14 (37–1,202)	74.91 ± 251.82(5–1,642)
Total dissolved solids	TDS	mg/l		1,269.85 ± 187.63 (680–1,680)	547.48 ± 99.81 (360–900)	829.17 ± 108.29 (620–1,080)	1,571.68 ± 208.47 (1,000–2,060)	713.56 ± 160.9(340–1,060)
Calcium	Ca	mg/l	75–200	79.3 ± 14.53 (43–115)	44.82 ± 12.9 (21–73)	51 ± 17.85 (20–93)	86.81 ± 25.03 (0–132)	66.35 ± 27.6(0–120)
Magnesium	Mg	mg/l	150	57.75 ± 14.25 (35–109)	40.48 ± 12.61 (13–78)	52.02 ± 12.51 (18–85)	86.05 ± 14.69 (42–124)	47.05 ± 17.14 (6–81)
Hardness	Hardness	mg/l	100–500	438.88 ± 62.92 (297.5–664.17)	280.72 ± 50.16 (182.5–466.67)	344.24 ± 74.91 (160–550)	569.4 ± 104.96 (0–754.17)	358.65 ± 102.05 (0–537.5)
Sodium	Na		200	256 ± 48.56 (127–416)	51.6 ± 8.73 (32–74)	126.6 ± 27.01 (23–184)	325.05 ± 62.73 (124–575)	67.63 ± 21.08(16–101)
Potassium	K			18.52 ± 3.58 (10–32)	5.58 ± 3.08 (4–23)	15.03 ± 2.62 (10–21)	32.77 ± 5.94 (18–68)	5.03 ± 3.38(3–24)
Chlorides	Cl		250	352.43 ± 57.4 (213–487)	76.67 ± 16.17 (27–109)	155.88 ± 31.48 (85–235)	345.91 ± 68.93 (153–562)	110.69 ± 59.22 (21–452)
Sulfates	So ₄	mg/l	400	189.12 ± 58.18 (47–364)	75.18 ± 23.77 (28–131)	142.38 ± 39.82 (55–217)	214.6 ± 68.76 (69–371)	82.98 ± 34.04 (4–177)

(continued)

Table 1 | continued

Variables/maximum admissible value				Site				
Water quality parameters	Symbol	Unit	Maximum value admissible	H. Boughrara reservoir	Beni Bahdel reservoir	Sikkak reservoir	Mouillah wadi	Tafna wadi
Chemical oxygen demand	COD	mg O ₂ /l	30	55.9 ± 30.67 (19–160)	23.73 ± 15.4 (10–90)	36.72 ± 20.02 (10–130)	266.23 ± 94.93 (20–500)	23.26 ± 19.98(10–130)
Biochemical oxygen demand	BOD ₅	mg O ₂ /l	7	11.21 ± 6.26 (3.7–35.8)	5.71 ± 6.38 (1.6–47)	8.65 ± 4.9 (2.2–25)	91.69 ± 41.34 (22.4–176.5)	5.12 ± 4.77(1.3–29)
Total organic carbon	TOC			19.33 ± 16.87 (6.52–84.99)	10.24 ± 5.65 (2.83–20.16)	14.65 ± 7.11 (8.69–30.66)	102.63 ± 101.11 (25.83–309.12)	14.03 ± 11.91(1.16–38.51)
Nitrate	NO ₃	mg/l	50	7.23 ± 4.03 (2–18)	4.97 ± 1.97 (1–11)	10.78 ± 9.06 (1–48)	6.32 ± 4.92 (1–32)	15.03 ± 6.88 (5–34)
Nitrite	NO ₂	mg/l	0.1	1.09 ± 1.07 (0.02–3.8)	0.1 ± 0.07 (0–0.34)	0.46 ± 0.58 (0.02–2.8)	0.23 ± 0.39 (0–2.5)	0.34 ± 0.51 (0.02–3)
Ammonium	NH ₄ ⁺	mg/l	0.5	5.43 ± 7.72 (0.03–57)	0.1 ± 0.12 (0–0.68)	1.29 ± 2.37 (0.01–13.4)	59.11 ± 20.5 (4.4–119)	0.26 ± 0.5(0–2.78)
Ammonia	NH ₃			5.12 ± 7.29 (0.03–53.81)	0.09 ± 0.11 (0–0.64)	1.22 ± 2.24 (0.01–12.65)	54.84 ± 20.54 (0–112.34)	0.24 ± 0.47 (0–2.62)
Phosphate	PO ₄ ⁻	mg/l	10	3.3 ± 1.51 (0.66–6.63)	0.09 ± 0.08 (0–0.43)	0.81 ± 1 (0.01–4.4)	27.22 ± 6.66 (7.45–41.27)	0.52 ± 0.63(0–2.8)
Total phosphorus	Ptot			4.03 ± 1.71 (0.88–7.5)	0.24 ± 0.15 (0.02–0.73)	1.29 ± 1.37 (0.05–5.35)	33.65 ± 7.56 (9.52–45.58)	0.74 ± 0.76(0.02–3.45)
Iron	Fe	mg/l	1	0.07 ± 0.04 (0–0.13)	0.11 ± 0.13 (0–0.5)	0.11 ± 0.08 (0.01–0.27)	0.37 ± 0.17 (0.14–0.64)	0.22 ± 0.22(0.07–0.47)
Manganese	Mn	mg/l	1	0.21 ± 0.15 (0.05–0.49)	0.05 ± 0.04 (0–0.14)	0.09 ± 0.1 (0.01–0.37)	0.2 ± 0.11 (0.11–0.47)	0.06 ± 0.02 (0.04–0.08)
Zinc	Zn	mg/l	5	0.06 ± 0.05 (0–0.15)	0.06 ± 0.06 (0.02–0.17)	0.08 ± 0.07 (0–0.2)	0.12 ± 0.11 (0.05–0.43)	0.1 ± 0.07 (0.02–0.15)

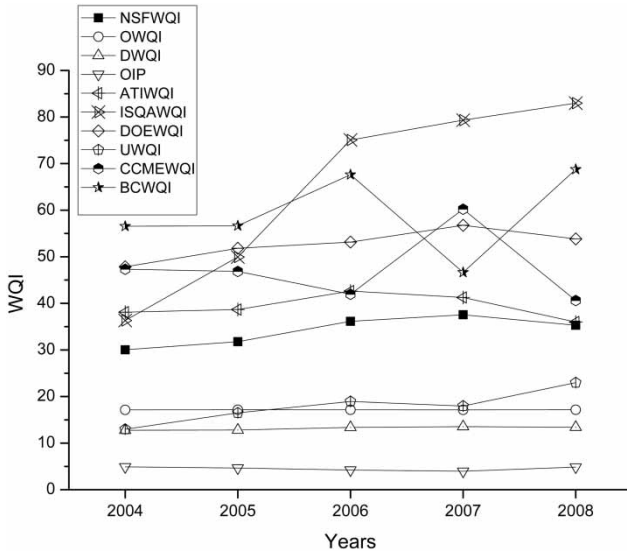


Figure 5 | Trend of water quality in Tafna wadi.

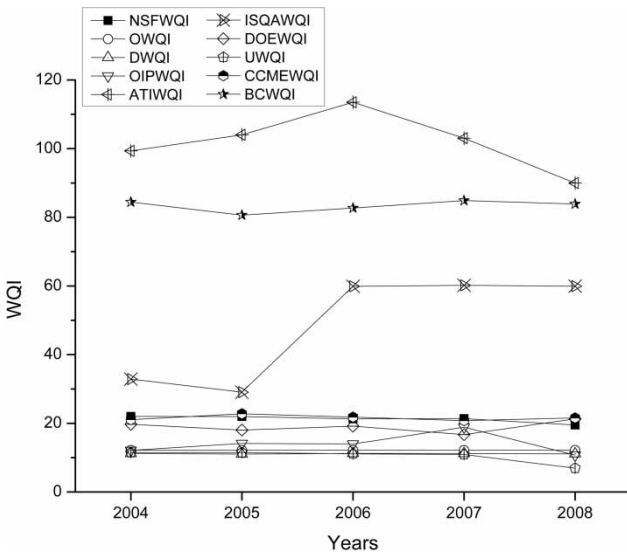


Figure 6 | Trend of water quality in Mouillah wadi.

geometrical sum has been widely used, especially where there is a great variability among samples.

Table 4 shows that the water quality categorization for sampling stations in CCMEWQI and BCWQI was found as ‘marginal’ for Beni Bahdel reservoir, Sikkak reservoir and Tafna wadi; and ‘poor’ for Hammam Boughrara reservoir and Mouillah wadi. For OWQI, the water quality categorization was found as ‘very poor’ for all sampling

Table 2 | Types of sub-indices, aggregation functions and flaws of studied WQIs (collected from several different sources)

Index	Sub-indices	Aggregation functions	Flaws
NSFWQI	Implicit non-linear	Weighted sum	Eclipsing region
OWQI	Non-linear	Unweighted Harmonic Square Mean	
DWQI	Non-linear	Weighted sum	Eclipsing region
OIP	Segmented linear	Weighted sum	
ATI		Solway modified unweighted	
ISQA		Weighted sum	
DOEWQI	Formula	Weighted average	
UWQI		Weighted sum	
CCMEWQI	Formula	Harmonic Square Sum	
BCWQI	Formula	Harmonic Square Sum	

stations. The results of the ATI give an idea about the suitability of water quality for aquatic life; it was found that the water quality categorization for all sampling stations was ‘totally unsuitable for normal fish life’ and ‘suitable only for hardy fish species’ for Mouillah wadi and Boughrara reservoir. We should note here that large amounts of fish were found dead in Tafna wadi near Ain Ghoraba (30 km south of Tlemcen) due to pollution by wastewater and industrial waste discharged from Sebdoou city into the wadi (Boumediene 2010a, 2010b). Even now, water quality of this wadi continues to deteriorate.

In the OIP, the water quality categorization for sampling stations was found as ‘heavily polluted’ for Mouillah wadi stations, and ‘polluted’ for the rest. It was found as ‘poor’ for all stations in the UWQI.

Figure 7 shows a comparison of WQIs in the studied sites within Tafna catchment, we note that OIP scale is adjusted from 0–16 to 0–100 for comparison purposes. The Tafna basin is at risk of pollution of its surface water resources (Mouillah wadi, Tafna wadi, Sikkak wadi) generated in large part by discharges from industrial areas in Maghnia and Tlemcen cities as well as Morocco’s discharges; this situation is causing a degradation of water

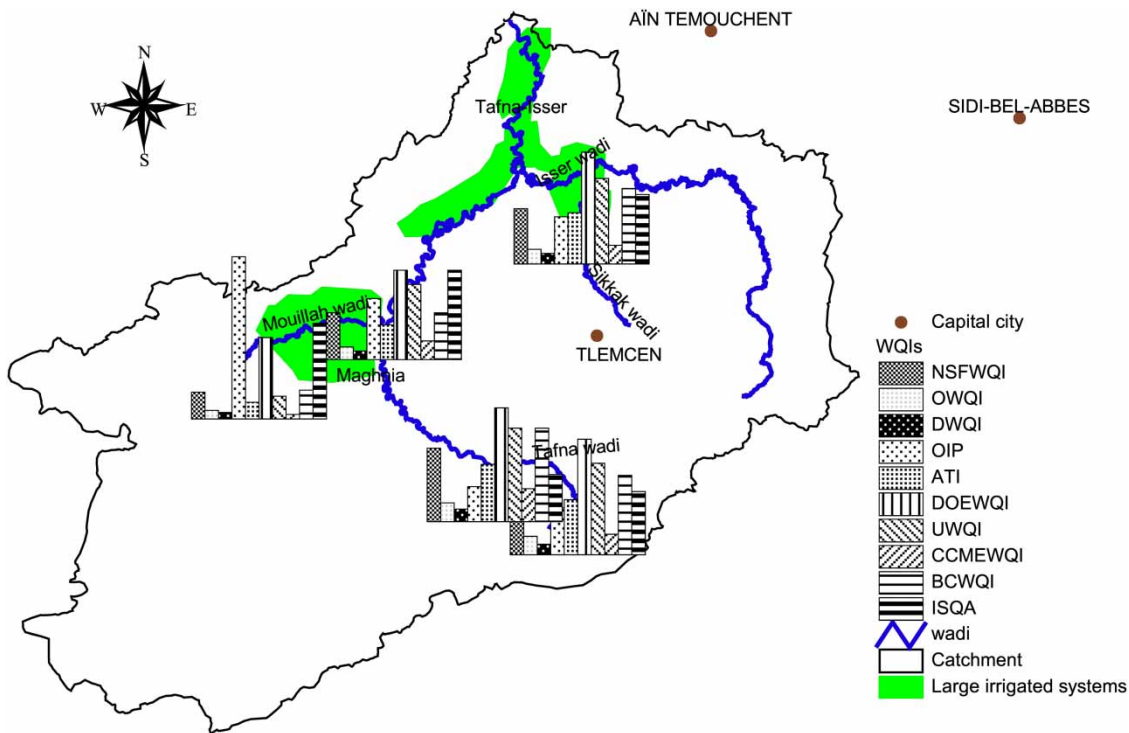
Table 3 | Importance rate and weight of the parameters of the studied WQIs

	NSF	DWQI	DOEWQI	UWQI	ISQA	CCME	OIP	BC	ATI	OWQI
pH	0.12	0.077	0.16	0.029		all variables are given the same weight	the model does not include any weight factors	all variables are given the same weight	the model does not include any weight factors	eliminates the use of weight factors
Temperature	0.11	0.077								
DO	0.18	0.109	0.22	0.114	0.30					
BOD	0.12	0.097	0.19	0.057						
Turbidity	0.09									
Phosphate	0.11									
Nitrate	0.10	0.09		0.086						
Coliform total	0.17	0.09		0.114						
Hardness		0.065								
Chloride		0.074								
Sp. Conductance		0.079			0.20					
COD			0.16							
SS			0.15		0.25					
NH ₃ -N			0.12							
F				0.086						
TP				0.057						
Hg				0.086						
Se				0.086						
Cyanide				0.086						
Cd				0.086						
As				0.113						
TOC					0.30					

Table 4 | Comparison of WQIs results

WQIs	Beni Bahdel		H. Boughrara		Sikkak		Mouillah wadi		Tafna wadi	
	WQI	Quality	WQI	Quality	WQI	Quality	WQI	Quality	WQI	Quality
NSFWQI	43.97	Bad	30.61	Bad	34.96	Bad	21.24	VB	34.16	Bad
OWQI	16.54	VP	14.03	VP	15.29	VP	12.21	VP	17.16	VP
DWQI	13.97	NA	12.4	NA	13.01	NA	11.17	NA	13.18	NA
OIP	4.16	Polluted	6	Polluted	4.67	Polluted	13.98	HP	4.52	Polluted
ATI	30.83	TUNFL	51.57	SHFS	41.56	TUNFL	56	SHFS	39.34	TUNFL
ISQA	63.5	Medium	51.88	Medium	63.13	Medium	48.41	poor	64.73	Medium
DOEWQI	53.94	Polluted	45.26	Polluted	50.19	Polluted	19	Polluted	52.68	Polluted
UWQI	24.22	Poor	16.74	Poor	17.23	Poor	10.4	Poor	17.87	Poor
CCMEWQI	54.2	Marginal	31.05	Poor	44.85	Marginal	21.61	Poor	47.4	Marginal
BCWQI	46.5	Borderline	73.92	Poor	58.06	Borderline	83.31	Poor	59.25	Borderline

TUNFL = totally unsuitable for normal fish life; SHFS = suitable only for hardy fish species; VB = very bad; VP = very poor; NA = not acceptable; HP = heavily polluted.

**Figure 7** | Summarized results of all applied WQI models.

quality of reservoirs such as Hammam Boughrara and Sikkak.

The identification and location of domestic and industrial waste discharges allowed the detection of 71 discharge

points, 14 of which are currently connected to a wastewater treatment plant (WWTP) with a flow rate of over 31,000 m³/d (cf. Table 5). There are 57 discharge points remaining, as 80% are not being easily connected; however,

Table 5 | Identification and location of domestic and industrial waste discharges within Tafna catchment

Name of city	Name of cities connected to WWTP	Number of discharge points	Number of discharge points connected to WWTP	Type of water discharge	x (m)	y (m)	Wastewater flow rate (m ³ /d)	Point of release
Tlemcen	Tlemcen; Chetouane	48	10	Domestic/ industrial	13,3033	183,861	30,550.176	Sikkak wadi
Maghnia	Maghnia	14	2	Domestic/ industrial	95,884	181,488	37.224	Ouderfou wadi
Sidi Abdelli	Sidi Snoussi	9	2	Domestic	15,2756	199,662	414.72	Snoussi wadi
Total		71	14				31,002.12	

the nearest of them from the WWTP requires the installation of a waste water pumping station (ABHOCC 2008).

Industrial releases of Tlemcen city are located at three discharge points, including one connected to the WWTP of Ain El Houtz. As for industrial releases from Maghnia city, they have been released into the natural environment except the dairy 'Halib Ennedjah' which is connected to Maghnia WWTP.

The pollution control strategy for Tafna catchment

The water quality in Tafna catchment was bad. Studies show that there is a significant amount of wastewater that continues to spill into the wild without treatment, while the WWTPs have sufficient capacity to provide treatment. Remedial proposals of studies already carried out in the field of water quality in Algeria, have excessive costs, and cannot be used because they do not eliminate the causes of pollution. The Tafna catchment should be the subject of an assessment and periodical surveillance, to ensure sustainable and equitable management; the pollution control strategy includes a combination of more than one pollution-reducing method. Methods could include the following:

- The removal of direct point-source discharges from wadis.
- Protecting the source water of the upstream Tafna wadi and Mouillah wadi (particularly from pollution from new, private rural industries) in order to guarantee the water quality for the new water supply intake and to avoid future pollution.

- The priority criteria for the realization of WWTP being primarily granted to cities located upstream of dams in operation and the second priority being given to the cities located upstream of dams under construction.
- Renovating the existing WWTPs and increasing the treatment capacity of industrial and domestic wastewater, giving priority to the removal of phosphorus and nitrogen.
- The current form of sewerage system and scattered aspect of Tlemcen requires rigorous management for collection of waste and implementation of new treatment systems. Three operating WWTPs located at the department of Tlemcen receive more than 31,000 m³/d of domestic and industrial waste (cf. Table 5). These stations have been designed for the treatment of urban wastewater, so the quality control of industrial waste is essential. Although some industrial units have a sewage system, it is still necessary and even urgent to establish a network of quality monitoring of industrial wastewater.
- Better management of fertilizer and manure.
- Protective agricultural practices such as the planting of vegetative buffer strips between cropland and wadis.
- Expanded levels of treatment of residential stormwater through the use of best management practices.

It is clear that the construction of WWTPs is not sufficient to solve the pollution problem if not accompanied by close monitoring and supervision of surface water quality and groundwater. There is a monitoring network operated by the ANRH, but it remains insufficient, especially with regard to the monitoring network for

groundwater that does not obey all the conditions for a good network.

To reduce the scope of the limiting factor of water resources in the region, an approach is feasible for waters affected by anthropogenic pollution. The healing of earlier proposals is exorbitantly expensive, and cannot be retained to the extent where they eliminate the causes of pollution. Moreover, for governments setting up of treatment units at the exit boreholes and reservoirs, is an investment in an unsustainable strategy. To solve the problem of sanitation, it is necessary to prevent pollution from spreading by treating the output of sewage or industrial complexes, increasing political connection to the sewerage system, and establishing WWTP and lagoons.

The hydrological Tafna basin shared between Morocco and Algeria is extensively stressed and impacted not only by the aridity of the climate, but also by anthropogenic activities. These impacts are felt on both sides of the border, but no action has so far been undertaken. This vulnerable zone represents an example of the politics of silence and non-cooperation (Zarhloule *et al.* 2010).

CONCLUSIONS

This research presents one of the WQIs applications in the transboundary Tafna river basin for the first time. Previous studies on the use of WQIs in the study area are non-existent. The previous evaluation of water quality has been assessed only by comparing the values with the local norms. 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.

The present research aims at determining the status and trends in water quality in the Tafna catchment with a comparison of 10 WQIs perceived as the most important indices for water quality assessment.

It has been concluded that CCMEWQI and BCWQI indices which use the harmonic mean or its square provided the best results for the indexation of the general water quality; studies show that the information provided by

CCMEWQI is a useful tool for describing the state of the drinking water quality and can be of great value for water users, suppliers, and planners, etc. (Damo & Icka 2013). Similarly, NSFQI which uses the weighted geometrical sum has been widely used, especially where there is a great variability among samples.

The results show that WQIs can vary from one region to another depending on local conditions and concerns. The development of a WQI corresponding with different conditions and characteristics of the relevant river or water body, such as geographical, hydrological, discharge rate and pollution sources, is necessary to represent the real water quality state and is very helpful for environmental planners to design, formulate, and implement pollution abatement strategies.

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