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Water quality index assessment of Koudiat Medouar Reservoir, northeast Algeria using weighted arithmetic index method

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Abstract

Water quality index (*WQI*) is a mathematical tool used to transform large quantities of water quality data into a single number which present water quality level. The aim of the present study is to evaluate the quality of Koudiat Medouar Dam in Batna (Algeria) to assess its suitability for drinking purposes. Samples were assessed for ten (10) physicochemical settings namely pH, electrical conductivity, total hardness, nitrate, sulphate, chloride, calcium, magnesium, dissolved oxygen and turbidity. The calculation of *WQI* was done via weighted arithmetic index method. The *WQI* values ranged from 99.097 to 174.92 during 2015. It reflected that the water samples were in February in the range of very poor quality and ranged to be in unsuitable for drinking rang in the all other months. The *WQI* of the present study reveals dam water is contaminated and not suitable for drinking purpose without giving treatment.

Key words: *assessment, Koudiat Medouar Reservoir, physicochemical parameters, water quality index, weighted arithmetic index*

INTRODUCTION

Water is necessary and one of the precious natural resources of our planet. Water plays a vital role in the existence of life and various sector of the economy such as agriculture, livestock production, forestry, industrial power generation, fisheries and other creative activities [TYAGI *et al.* 2013].

The increasing urbanization, industrialization, the modernization of agriculture, the increase in traffic contribute to global pollution, which requires accurate monitoring and information about the quality of water resources. Water quality is used to describe the condition of the water, including its chemical, physical and biological characteristics, usually with respect to its suitability for a particular purpose (i.e., drinking, swimming or fishing) [DIERSING 2009; KHAN *et al.* 2003; SARGAONKAR *et al.* 2003].

The surface water bodies are the abundant and important sources of biological life. These are unfortunately under lots of environmental stress and getting polluted as consequence of manmade activities. There is a fact about the water bodies as they are the mirror of their environment as well as they reflect the society exists around surface water bodies and collect all Sins of humanity [ROOPSHAH 2016]. The World Health Organization (WHO) estimated that in developing countries about 80% of water pollution is a result of domestic waste. More ever the inadequate management of water systems can cause serious problems in the availability and quality of water [KRISHNAN *et al.* 2007].

Surface water is the most common source of consumers in most of the cities through the municipal water supply. In this manner, more stringent treatments would be required to make the surface water potable [ROOPSHAH 2016]. There is an importance and need to study about surface water bodies. In Algeria Surface water is generally used for drinking and irrigation. Therefore, we carried out studies of physicochemical parameters of surface water in Koudiat Medouar Reservoir whether it is fit for drinking and some other purposes. Universal access to safe drinking water and sanitation has been promoted as an essential step in reducing the preventable diseases [PRÜSS-USTEN, CORVALAN 2006; WHO 1992].

The provision of portable water to the rural and urban population is necessary to prevent health hazards. Before water can be described as available, it has to comply with certain physical, chemical and microbiological standards, which are designed to ensure that the water is potable and safe for drinking [TEBUTT 1983]. Hence it is very important to analyse the physicochemical properties to assess the quality of ground/ surface water in rural or urban areas that influence the suitability of water for domestic, irrigation and industrial needs [SHIVAYOGIMATH *et al*. 2012]. Monitoring of drinking water quality is an important component of water management, while data analysis is necessary for the identification and characterization of water quality problems. The levels of detected contaminants are used to determine compliance with a maximum contaminant level (*MCL*). Therefore, water quality monitoring of various water variables through water quality index (*WQI*) forms the foundation of water quality management [BARTRAM, BALANCE 1996].

Assessment of surface water quality can be a complex process undertaking multiple parameters capable of causing various stresses on overall water quality. To evaluate water quality from a large number of samples, each containing concentrations for many parameters is difficult [ALMEIDA 2007]. To analyze water quality, different approaches like statistical analyses of an individual parameter, multi-stressors water quality indices, etc. have been considered [VENKATESHARAJU *et al*. 2010]. Numerous water quality indices have been formulated all over the world which can easily judge out the overall water quality within a particular area promptly and efficiently. The general *WQI* was developed by [BROWN *et al.* 1970] and improved by for the Scottish Development Department. HORTON [1965] suggested that the various water quality data could be aggregated into an overall index.

These indices are based on the comparison of the water quality parameters to regulatory standards and give a single value to the water quality of a source [ABBASI 2002; KHAN *et al*. 2003].

Water quality index is a well-known method as well as one of the most effective tools to expressing water quality that offers a simple, stable, reproducible unit of measure and–communicates information of water quality to the concerned citizens and policy makers. It, thus, becomes an important parameter for the assessment and management of surface water.

The quality of drinking water indicates water acceptability for human consumption. Water quality depends on water composition influenced by natural process and human activities. Water quality is characterised on the basis of water parameters (physical, chemical, and microbiological), and human health is at risk if values exceed acceptable limits [TAHERA *et al.* 2016].

Water quality index (*WQI*) of water can tell us whether the overall quality of water bodies possess a potential threat to various uses of water, such as habitat for aquatic life, irrigation water for agriculture and livestock, recreation and aesthetics, and drinking water supplies. *WQI* is a single value indicator to the water quality. It integrates the data pool generated after collecting due weights to the different parameters.

The present study is based on the analyses of physiochemical characteristics of reservoir water as samples of water collected from various locations of Koudiat Medouar Reservoir. The advantages of an index include its ability to single number, its ability to combine various measurements in a variety of different measurement units in a single metric and its effectiveness as a communication tool. A water quality index is a means to summarize a large amounts of water quality data into simple terms (ex: excellent, good, poor, very poor, unsuitable for drinking) for reporting to management and public in a consistent manner.

STUDY AREA

The Koudiat Medouar watershed is located northeast of the city of Batna in the eastern part of Algeria. It has an area of 590 km^2 and controlled by a reservoir bearing the same name with a capacity of 62 million m^3. The flow goes south to north and supplied by storms or by sewage disposal of bordering cities and villages. The area lies between the longitude of 35°30′57″ N and latitude 6°30′48″ E (Fig. 1). Koudiat Medouar watershed is subjected to a semi-arid climate, characterized by a cold and wet winter, a warm and dry summer, and rainfall between 300 and 450 mm per year. The extreme is marked by a climate known as mountain climate with abundant rainfall (over 600 mm per year), especially in spring and late fall [TIRI 2010]. It is sometimes characterized by violent storms. Generally, the regional rainfall exhibits three maxima during the year: January, May and November. The annual average temperature is between 12 and 13°C, with January as the coldest month and August as the hottest month (average between 26 and 34°C).

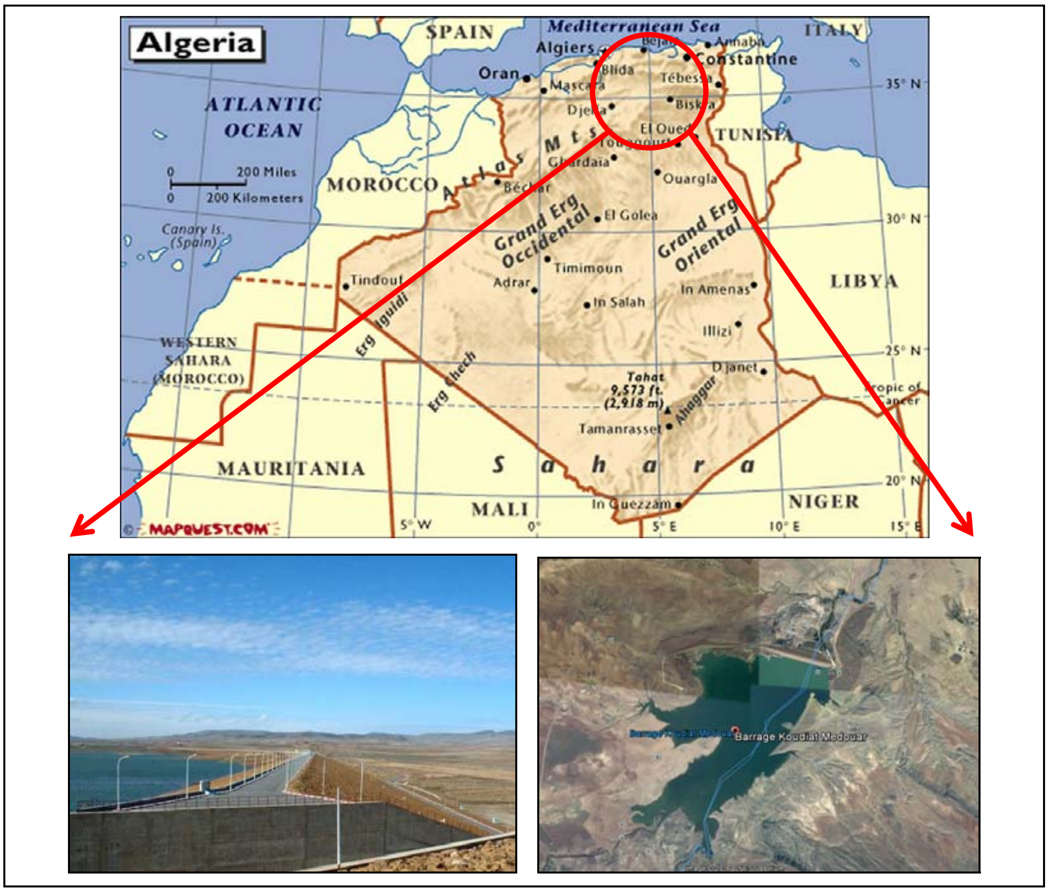

Fig. 1. Localization of the study area; source: own elaboration

In the southern part of the area, limestone and malicious calcareon formations of the cretaceous crop out where the Miocene and the Pliocene, not distinguished, occupy the central part. It concerns the alternation of ferruginous red and gypseous clay which alternated with fine to course sandstone occupying an area of nearly 50 km^2. A conglomeratic marly and limestone series, with limited extension, is added to this assemblage. The quaternary is represented by sheets of screens of limestone or gritty origin, from recent alluvial deposits, and by limestone crust which crops out in many places [VILA 1980].

This reservoir is intended for the supply of drinking water to Batna, Aris, Khenchela, Barika, additionally, industrial water supply to Batna and irrigation of the plain of Chemora, Batna and Taoufana.

MATERIALS AND METHODS

The water samples were collected at monthly interval, for a period of one year during January/ December 2015 at different sampling stations in the lake. One litre of surface water samples was collected from these different stations of the dam.

Water quality samples were collected. All water samples are carried out in glass bottles by filling subsurface. Samples stored at 4°C, transported to the laboratory for analysis. The physico-chemical parameters: temperature, dissolved oxygen, turbidity, hydrogen potential, is measured directly in situ using multi WTWMULTI 340I/SET device parameters. Determining the contents of the elements is performed by spectrophotometry. *WQI* was calculated using weighted arithmetic index method.

In this study, Excel is used to describe statistics of water quality parameters (minimum, maximum and mean) of the ten selected physic-chemical parameters of water body of the reservoir.

WQI COMPUTATION EQUATIONS

Water quality index (*WQI*) is defined as a rating reflecting the composite influence of different water quality parameters [RAMAKRISHNALAH *et al.* 2009]. *WQI* is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water**.** The study for the calculation of water quality index (*WQI*), ten important parameters were chosen. The *WQI* has been calculated by using the standards of the drinking water quality recommended by the WHO. The calculation of *WQI*, selection of parameters has great value. The water quality index will widen if too many parameters are used. An importance of various parameters depends on the intended use of water. Therefore, several steps of the weighted arithmetic index method are given [BROWN *et al.* 1972] in the following steps.

Calculation of sub index of quality rating (q_n)

Let (n) there be the water quality parameters and (q_n) the quality rating or sub-index corresponding to n^{th} parameter is a number reflecting the relative value of this parameter in the polluted water with respect to its standards permissible value). The q_n value of is calculated using the following expression.

$$q_n = 100\ [(V_n - V_{i0}) / (S_n - V_{i0})] \quad (1)$$

where: q_n = quality rating for the n^{th} water quality parameter; V_n = estimated value of the n^{th} parameter at a given sampling station; S_n = standard permissible value of the n^{th} parameter; V_{i0} = ideal value of n^{th} parameter in pure water.

All the ideal (V_{i0}) values are taken as zero (0) for drinking water for all other parameters except the parameter pH, where it is 7.0 and dissolved oxygen = 16.6 mg·dm^{-3} [TRIPATY, SAHU 2005].

Calculation of unit weight (W_n)

Calculation of unit weight (W_n) for various water quality parameters is inversely proportional to the recommended standards S_n for the corresponding parameters.

$$W_n = K/S_n \quad (2)$$

where: W_n = unit weight for the n^{th} parameters; S_n = standard value for n^{th} parameter; K = constant for proportionality.

Calculation of *WQI*

WQI is calculated from the following equation:

$$WQI = \Sigma q_n W_n / \Sigma W_n \quad (3)$$

The overall water quality index was calculated by aggregating the quality rating with unit weight linearly.

Assessment of water quality

WQI has been classified into 5 classes. Table 1 represents the 5 classes of water quality based on *WQI* of arithmetic *WQI* method.

Table 1. Water quality index (*WQI*) range, status and possible usage of the water sample

WQI range	Water quality status	Possible usage
0–5	excellent water quality	drinking, irrigation and industrial
26–50	good water quality	drinking, irrigation and industrial
51–75	poor water quality	irrigation and industrial
76–100	very poor water quality	irrigation
Above 100	unsuitable for drinking and propagation of fish culture	proper treatment required before use

Source: BROWN *et al.* [1972], CHATTERJI and RAZIUDDIN [2002].

In this study, different water quality parameters have been analysed and ten important parameters were taken to determine *WQI* of Koudiat Medouar Reservoir. Standards limit of parameters introduced according to World Health Organization [WHO 1993].

The first step in the calculation of *WQI* following 'weighted arithmetic index' method involves the estimation of 'unit weight' assigned to each physico-chemical parameter considered for the calculation. By assigning unit-weights, all the concerned parameters of different units and dimensions are transformed to a common scale. Table 2 shows the drinking water quality standards and the unit weights assigned to each parameter used for calculating the *WQI*. Maximum weight, i.e., 0.333 is assigned to both dissolved oxygen and turbidity, thus suggesting the key significance of these two parameters in water quality assessment and their considerable impact on the index.

Table 2. Standards for drinking water and relative weight of parameters

No.	Parameter[1)]	Standards WHO[2)] S_n	$1/S_n$	K	Relative weight W_n
1	pH	6.5–8.5	0.1176	1.6667	0.1961
2	electrical conductivity (*EC*)	300	0.0033		0.0056
3	total hardness	300	0.0033		0.0056
4	calcium	75	0.0133		0.0222
5	magnesium	30	0.0333		0.0556
6	chloride	250	0.004		0.0067
7	nitrate	50	0.02		0.0333
8	sulphate	200	0.005		0.0083
9	dissolved oxygen	5	0.2		0.3333
10	turbidity	5	0.2		0.3333

1) All values are in mg·dm^{-3}, except pH, *EC* (µS·cm^{-1}) and turbidity (NTU).
2) PRÜSS-USTEN, CORVALAN [2006].
Source: own elaboration.

RESULTS AND DISCUSSION

The analytical results obtained for different study parameters summarised in Table 3 are discussed below.

Table 3. Summary of basic statistics for different water quality parameters

Parameter[1)]	Minimum	Mean	Maximum	Standard
pH	7.73	8.09	8.38	8.5
Electrical conductivity (*EC*)	952	1039	1156	300
Total hardness	32	36.6	40	300
Calcium	51.3	76.35	97.79	75
Magnesium	26.24	41.63	54.43	30
Chloride	72.31	90.04	107.92	250
Nitrate	0.35	2.18	4.02	50
Sulphate	159.27	244.81	320	200
Dissolved oxygen	5.26	6.13	6.7	5
Turbidity	5.7	11.00	17.5	5

1) As in Tab. 2.
Source: own study.

pH. pH is one of the most important factors that serves as an index for the pollution. The measurement of the pH of surface waters is important because many pollutants increase in toxicity with changes in pH. The experimental water bodies were found to be approximately neutral or slightly alkaline. In the present study pH in all the sampling varied between 7.73 to 8.38. The permissible limit of pH value of drinking water specified as 6.5 to 8.5 as per WHO standards. This approves that the nature of surface water samples varies from slightly acidic to slightly alkaline.

Electrical conductivity (*EC*). The importance of *EC* is due to its measure of cations which greatly affects the taste and thus has significant impact on the user acceptance of the water as potable [PRADEEP 1998]. It is an indirect measure of total dissolved salts. High conductivity may arise through natural weathering of certain sedimentary rocks or may have an anthropogenic source, e.g. industrial and sewage effluent [WHO 2004]. The results showed that *EC* values were slightly higher than the permissible level recommended by the WHO for drinking water.

Turbidity. Turbidity indicates clarity of the water and is caused by organic and mineral suspended matter and colour producing substances. The mean turbidity readings of the samples were in the range 5.7 to 17.5 NTU. A value of 17.5 was recorded in June, were above the WHO standards. The presence of suspended particles and other materials are usually responsible for high turbidity values; similarly, higher turbidity values were reported by [MEDUDHULA *et al.* 2012]. The soil particles may have found their way into the waters from the unstable sides thereby increasing the turbidity of the water [GARG *et al.* 2006]. Turbidity also affects the temperature of surface waters, where the bottom temperatures are lower in turbid waters than in clear waters.

Hardness. Hardness in water is mostly caused by calcium and magnesium ions, with all other divalent cations also contributing to the concentration. The rocks surrounding the water body is largely the source of hardness, although some industrial wastes and irrigation drainage contribute. The hardness value ranged between 32 to 40 mg·dm^{-3}. The samples water having hardness below 300 mg·dm^{-3} is considered portable, but beyond this limits cause gastro-intestinal irritation.

Calcium and magnesium. The calcium concentration is ranged from 51.3 to 97.79 mg·dm^{-3} and magnesium concentration is ranged from 26.24 to 54.43 mg·dm^{-3}.

Nitrate varied between 0.35 to 4.02 mg·dm^{-3}. The tolerance range for Nitrate is 50 mg·dm^{-3} [WHO 1993] and the values were found well within the prescribed limit. They are found in surface waters as a result of wastewater discharge, runoff from land application of fertilisers, and ground water polluted by fertilizers. Nitrate concentrations in surface waters tend to be higher than nitrite because nitrite rapidly oxidises to nitrate.

Dissolved oxygen (DO) is the measurement of the amount of oxygen dissolved in water and is considered a direct indicator of water quality. The concentration depends on the physical, chemical and biological characteristics of the water body. Warm temperatures reduce the amount of DO a water body can store. Turbulence, photosynthesis and decreases in temperature increase the concentration of DO in the water. The analysis results reveal exceeding the value of DO with the standard value during 12 months.

Chloride. Dissolved chloride in surface waters occurs naturally from the geology but high concentrations typically result from runoff of de-icing salts applied to road surfaces. Chloride is a good conservative element to use for quality assurance in a mass balance model because no natural biological or chemical processes remove or add chloride to the surface water. Therefore, the mass of dissolved chloride remains constant in the surface water unless there is a discharge to or withdrawal from the water body. The drinking water standard and surface water criterion for dissolved chloride is 250 mg·dm^{-3}, in the present study chloride ranged 72.31 to 107.92 mg·dm^{-3}.

Sulphate. Sulphate in the reservoir was 159.27 to 320 mg·dm^{-3}. Sulphate occurs naturally in surface water as a result of the weathering of both igneous and sedimentary rocks. Other contributions of sulphates in surface water are leachate from abandoned mines, air deposition from the combustion of fuels, and industrial wastewater. The surface water criterion and drinking water standard for sulphates are 250 mg·dm^{-3}. Sulphates affect the taste of drinking water and are therefore a concern for water purveyors [EPA 2001].

Calculation of quality rating and water quality index has been determined. All important step of determination of *WQI* in different months are given in Tables 4 and 5. Water quality index of Koudiat Medouar Reservoir has been calculated for June 2015 and given in Table 5.

Values of *WQI* were illustrated in Figure 2 which ranged from 108.88 to 174.92 and rated as unfit for human consumption according to the classification of [BROWN *et al.* 1972; CHATTERJI, RAZIUDDIN 2002] as shown in Table 1 except for February with 99.08 which is classified as very poor. These values belong to high water salinity (*EC*), sulphate, dissolved oxygen (DO) and turbidity of the water body (Tab. 3) comparable with other parameters.

The water quality index for Koudiat Medouar Reservoir was registered to be 99.08 in the very poor category (*WQI* – 76–100) in February and under the category (*WQI* ≥ 100) of unsuitable for drinking range for the remainder of the monthly values. However, this water can be used for drinking purpose after purification treatment followed by disinfection before consumption and is also need to be protected from the perils and contaminations. A very poor category of water quality index (*WQI*) may be due to excessive flow of agricultural and domestic waste. Thus, high priority should be given to water quality monitoring and advanced technologies should be adopted to make water fit for, domestic and drinking use. The water quality index value of this study exhibits that, the water body contains high organic matter and eutrophic conditions.

Table 4. Water quality index calculation of Koudiat Medouar Reservoir in February 2015

No.	Parameter[1)]	Observed value	Standard value	*Wn*	Quality rating *Qn*	Weighted value *Wn* · *Qn*
1	pH	8.34	8.5	0.1961	89.33	17.52
2	electrical conductivity (*EC*)	1146	300	0.0056	382.00	2.12
3	total hardness	38.4	300	0.0056	12.80	0.07
4	calcium	65.73	75	0.0222	87.64	1.95
5	magnesium	53.46	30	0.0556	178.20	9.90
6	chloride	91.59	250	0.0067	36.64	0.24
7	nitrate	1.93	50	0.0333	3.86	0.13
8	sulphate	320	200	0.0083	160.00	1.33
9	dissolved oxygen	6.59	5	0.3333	83.44	27.81
10	turbidity	5.7	5	0.3333	114.00	38.00
				∑*Wn* = 1	**∑*Qn* 1147.91**	**∑*Wn*·*Qn* = 99.08**
WQI = Σ*QnWn* / Σ*Wn* = 99.079 / 1 = **99.08**						

[1)] As in Tab. 2.
Source: own study.

Table 5. Water quality index calculation of Koudiat Medouar Reservoir in June 2015

No.	Parameter[1)]	Observed value	Standard value	*Wn*	Quality rating *Qn*	Weighted value *Wn* · *Qn*
1	pH	8.01	8.5	0.1961	67.33	13.20
2	electrical conductivity (*EC*)	1046	300	0.0056	348.67	1.94
3	total hardness	36.8	300	0.0056	12.27	0.07
4	calcium	62.5	75	0.0222	83.33	1.85
5	magnesium	51.51	30	0.0556	171.70	9.54
6	chloride	98.16	250	0.0067	39.26	0.26
7	nitrate	4.02	50	0.0333	8.04	0.27
8	sulphate	226.5	200	0.0083	113.25	0.94
9	dissolved oxygen	5.91	5	0.3333	90.52	30.18
10	turbidity	17.5	5	0.3333	350.00	116.67
				∑*Wn* = 1	**∑*Qn* 1284.37**	**∑*Wn*·*Qn* = 174.92**
WQI = Σ*QnWn* / Σ*Wn* = 174.918 / 1 = **174.92**						

[1)] As in Tab. 2.
Source: own study.

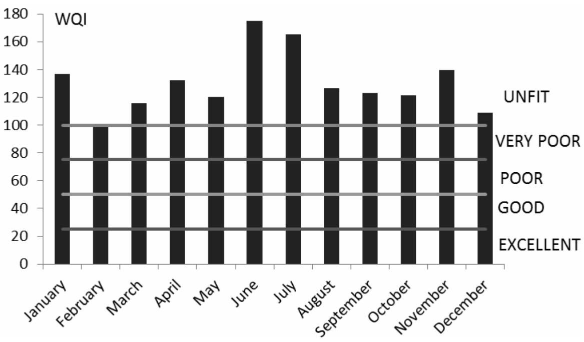

Fig. 2. Water quality index (*WQI*) and status of water quality; source: own study

The high *WQI* scores in all the above sites are contributed mainly by various anthropogenic activities like the inflow of direct sewerage from residential and commercial establishments, lack of proper sanitation system, agricultural run-off, direct disposal of untreated effluents from small scale industries and factories and unabated dumping of solid wastes by the communities residing in the catchment area, etc.

CONCLUSIONS

The protection and management of surface water, one of the most valuable natural resources is emerging as a major public concern in Algeria. Human population growth has significantly altered the environment of many natural water bodies.

The water quality varies according to the type of use. Furthermore, the criterion of an 'acceptable water quality' varies from region to region and from time to time depending upon the prevailing conditions. Water quality indices are necessary for resolving lengthy, multi-parameter, water analysis reports into single digit scores.

The results obtained from physiochemical parameters which were analysed to calculate *WQI*, the reservoir is having an organic load which comes through Koudiat Medouar Reservoir.

On the basis of the above discussions, it may be concluded that the *WQI* for all samples were found in the range of 99.08 to 174.72 in 2015.

The *WQI* values of Koudiat Medouar Reservoir clearly show the unsuitability of water of human being. The comparatively high level of electrical conductivity and sulphate indicates the water is not suitable for domestic use without giving treatment. The Reservoir can be used for boating or other recreational activities because of the good dissolved oxygen concentration. Water quality of water body is an important and significant technique for complete assessment of water body. It is an important tool and can summarise the water quality status in a single number from which users can find out about the water body.

Hence highest priority should be given to water quality monitoring and indigenous technologies should be adopted to make water fit for domestic and drinking purpose after treatment.

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Ocena indeksu jakości wody w zbiorniku Koudiat Medouar (północnowschodnia Algieria) z użyciem ważonego indeksu arytmetycznego

STRESZCZENIE

Indeks jakości wody (*WQI*) jest matematycznym narzędziem używanym do transformacji dużej liczby danych o jakości wody w jedną liczbę, która charakteryzuje poziom jakości wody. Celem przedstawionych badań było określenie jakości wody w zbiorniku zaporowym Koudiat Medouar w Batna (Algieria), aby ustalić jej przydatność do celów spożywczych. W próbkach oceniano 10 parametrów fizycznych i chemicznych: pH, przewodność elektrolityczną, całkowitą twardość, stężenie azotanów, siarczanów, chlorków, wapnia, magnezu, rozpuszczonego tlenu i mętność. Obliczenia indeksu *WQI* wykonano metodą ważonego indeksu arytmetycznego. Wartości *WQI* zmieniały się od 99,097 do 174,92 w 2015 r. W lutym próbki wody cechowała bardzo zła jakość, a w pozostałych miesiącach woda nie nadawała się do picia. Indeks ustalony w niniejszych badaniach dowodzi, że woda w zbiorniku zaporowym jest zanieczyszczona i nie nadaje się do celów spożywczych bez uprzedniego uzdatniania.

Key words: *indeks jakości wody, ocena, parametry fizyczne i chemiczne, ważony indeks arytmetyczny, zbiornik zaporowy Koudiat Medouar*