

ASSESSMENT OF DAMS' TROPHIC STATUS AS A TOOL FOR WATER RESOURCES' SUSTAINABLE MANAGEMENT IN MOROCCO: CASE OF THE BOUHOUDA TAOUNATE DAM (MOROCCO)

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ABSTRACT

The Bouhouda's dam was built on Oued Sra, a tributary on the right bank of Ouergha wadi, about 18 km in the north of Taounate town. The waters of this dam are mainly intended for irrigation and drinking water supply (Ministry of town planning and urban planning, 2014). The aim of this paper is to study the quality and the spatio-temporal evolution of the physicochemical of this dam waters parameters of over a period of eight years (2000/2008) in order to have a better knowledge of the mechanisms and the factors that condition the eutrophication of this lake. A classification has been established based on the Carlson index (1977) (Trophic State Index or TSI) and the Vollenweider index (1968), to identify the trophic state of the reservoir waters. Accordingly, these results can be used for decision support in the context of sustainable development of several nearby dams in the Sbou Basin.

Key words: Bouhouda dam, physiochemistry, eutrophication, trophic state, Carlson index, Vollenweider index, Sebou basin.

Cite this Article: Aicha HAMID, Oussama BENABBI and Mohammed FEKHAOUI, Assessment of Dams' Trophic Status as a Tool for Water Resources' Sustainable Management in Morocco: Case of the Bouhouda Taounate Dam (Morocco), *International Journal of Advanced Research in Engineering and Technology*, 10(5), 2019, pp. 111-125.

<http://www.iaeme.com/IJARET/issues.asp?JType=IJARET&VType=10&IType=5>

1. INTRODUCTION

Since the beginning of this century, the socio-economic conditions of water use have changed considerably in Morocco, a country with a semi-arid climate, the development of urban agglomerations, the demographic pressure and the limitation of groundwater resources [1] mean that the country has more and more recourse to the superficial waters to satisfy in sufficient quantity, the needs of the populations in drinking and industrial water built [2]. The

Table 1. Morphometric and hydrological characteristics of the dam lake Bouhouda [13]

Date of impoundment	1999
Watercourse	Sra
Province	Taounate
The nearest town	Bouhouda
function	Irrigation / Drinking water supply
Overall capacity of the reservoir	55Mm3
Average annual contributions	303Mm3
Characteristics of the book: Type:	BCR
Heights: Volume:	55m 220.000m3
Works duration	48 month

2.2. Sampling and analysis methods

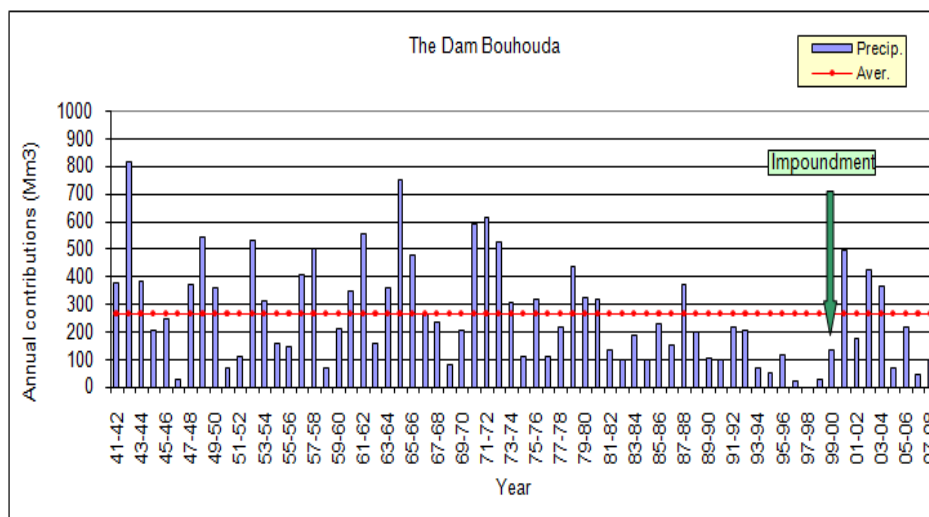
The lake was sampled between 09/03/2000 and 06/08/2008 with a sampling frequency of once a month at the catchment level of ONEP [14] in order to study the majority of its physicochemical characteristics (temperature, dissolved oxygen, conductivity, pH, chlorophyll a, transparency, nitrogen elements, orthophosphates and total phosphorus, cations, etc.).

In order to determine the degree of the lake stratification, a profile of temperature, pH and oxygen was made only twice during 2003 because of the difficulty of access. Therefore, the month June represents the summer season and the month October represents the fall season.

3. RESULT AND DISCUSSION

3.1. Water Balance

For water supplies, a series of records made from 1942 until 2008, to compare the average inputs in millions of m³ before and after the impoundment of the Bouhouda dam, are presented below.



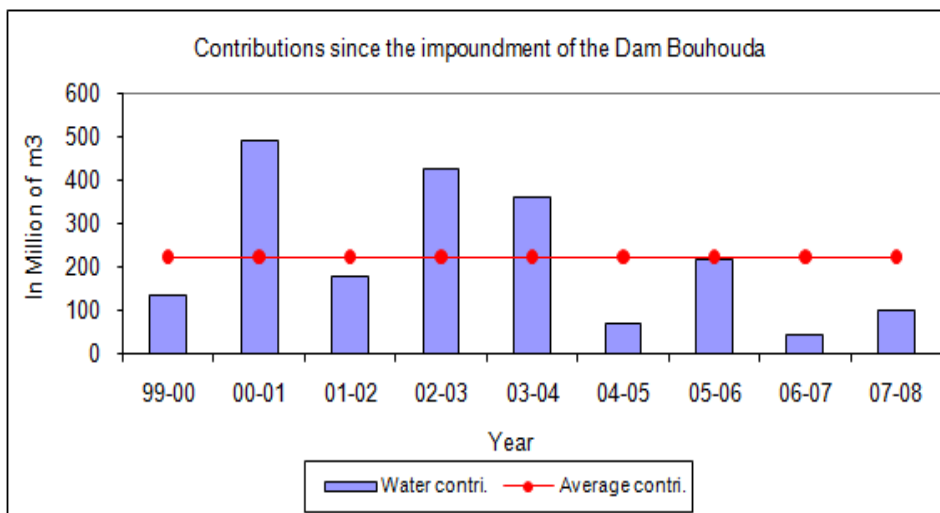


Figure 2 Water supply before and after the Bouhouda dam impoundment

Contributions were irregular from a year to another. The minimum was recorded during 1996-97 and the maximum during 1942-43, respectively 21.1 and 814.1 Mm³. However, the global analysis of these fluctuations since 1999 permit to distinguish that the inputs are much more sustained after the dam impoundment with an average of 225.2 Mm³.

3.2. Temperatures

3.2.1. Seasonal variations

Considered among the most important ecological factors, water temperature is closely related to a whole set of parameters, its alteration can lead to various ecological consequences [15]. The lake water temperature variations depend on the ambient atmospheric temperature variations, which is as well subject to seasonal variations ($R^2 = 0.6687$) (Figure 3). The presence of a seasonal cycle in this data series is perceptible. This cycle shows that the water temperature is minimal during the cold season and maximal during the hot season, which certainly favors, in the summer period, the development of plankton, an important factor in water purification [16].

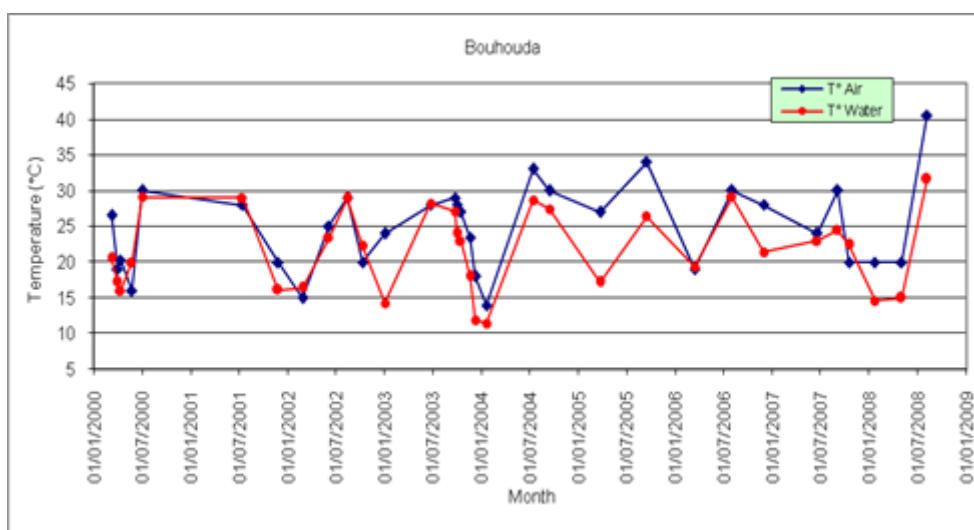


Figure 3 Inter-annual evolution and correlation of Lake Bouhouda water and air temperatures.

3.2.2. Stratification and mixing waters cycle

A Sudden thermal stratification of the temperature was detected in autumn. The reservoir appears subdivided into a low part called cold hypolimnion and a high part called hot epilimnion, separated by a thermocline located at a depth of 7-9 m, these periods are associated with wet periods (rainfall). Unlike the summer season, there is a less pronounced and progressive thermal stratification to be diffused beyond 15 m until the total mixing at depth.

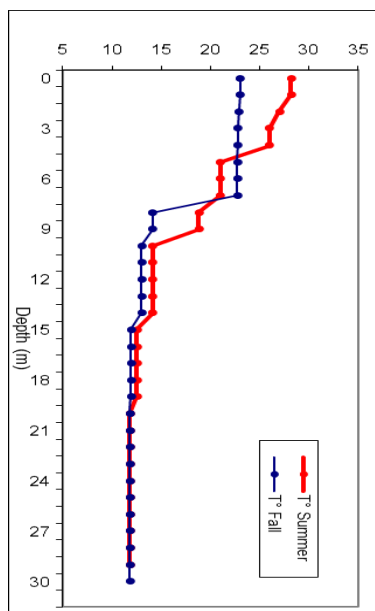


Figure 4 Vertical profiles of seasonal temperature variation in Bouhouda Lake

3.3. pH

3.3.1. Seasonal variations

The pH has shown relatively high values between 7.8 and 10.20. These values are all situated in the VMR range [14] (Figure 5), with a pH that is above the alkalinity threshold (8.2). This allows us to deduce that the dam water is alkaline. This alkalinity could be due, on one hand, to the biological activity of the aquatic ecosystems (photosynthesis and mineralization of organic matter), on the other hand to the land crossed nature and/or to the Sra wadi water inputs.

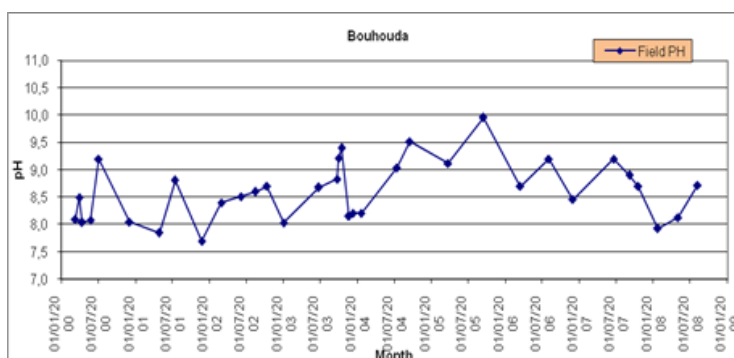


Figure 5 Inter-annual evolution of Bouhouda Lake PH.

3.3.2. pH stratification state

Seasonal variations show a very strong and brutal stratification during the wet period (autumn) with the highest values at the surface, unlike the summer period where the stratification is less pronounced and settles progressively. The pH content decreases considerably between the

surface, where the activity of photosynthesis is very important (intense light, strong heat), and the depth that is characterised by a lack of light and a lower temperature (reduction of photosynthesis) during the summer and the autumn.

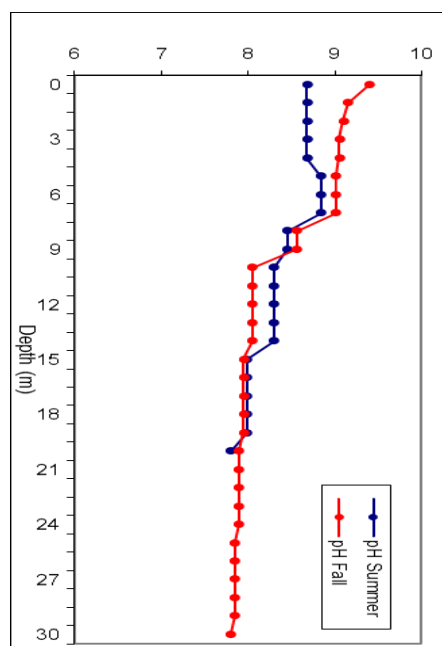


Figure 6. Vertical profiles of pH seasonal variation in Bouhouda Lake

3.4. Dissolved oxygen and oxydability

3.4.1. Seasonal variations

Dissolved oxygen is one of the most sensitive parameters to pollution. Its value gives us information on the degree of pollution and consequently on the degree of self-purification of a watercourse [17]. Except the low value founded in 2007 (4.7 mg / l), the dissolved oxygen levels reveal that Bouhouda Lake waters are sufficiently oxygenated. Values vary between 6.1 mg/l and 11.5 mg/l.

The oxydability measured values are low (good results according to the surface water quality standards). The maximum recorded is 5.1 (05/2000) (figure 9). The minima are in the order of 0.66 and 0.84mg/l.

The inter-annual evolution is very irregular due to the hydrological conditions instability that characterizes this environment. The average high values would probably coincide with the autumnal photosynthesis of the highly active algal and zooplanktonic biomasses.

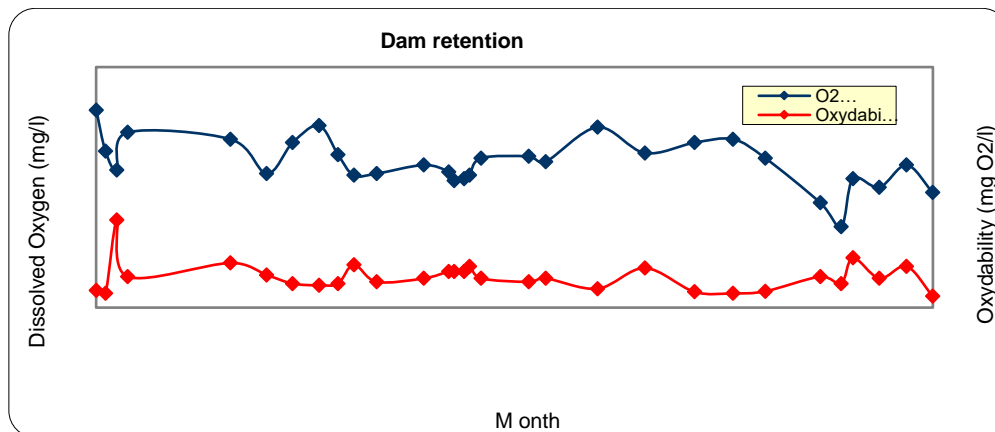


Figure 7 Dissolved oxygen variation and oxydability of Bouhouda Lake.

3.4.2. Stratification state of dissolved oxygen

The oxygen vertical profile shows that the summer mixing, even incomplete, has allowed a low reoxygenation of the bottom, however higher concentrations of dissolved oxygen are observed at the surface (8.3 and 8.5 mgO₂/l). Lower in the column, the partial reoxygenation reaches 3.6 mgO₂/l at the bottom; this observation demonstrates that the hypolimnion has a sufficient amount of dissolved oxygen in the summertime.

However the lack of oxygen present in autumn shows a significant deep biodegradation. The average difference in surface-bottom oxygenation is important (figure 8).

The availability of light in the water column is a major physical factor, since that the water transparency plays a dominant role in the dissolved oxygen stratification. Indeed, there is a depth of compensation in terms of dissolved oxygen, defined as the depth where photosynthetic production rates are equal to organisms' respiration rates.

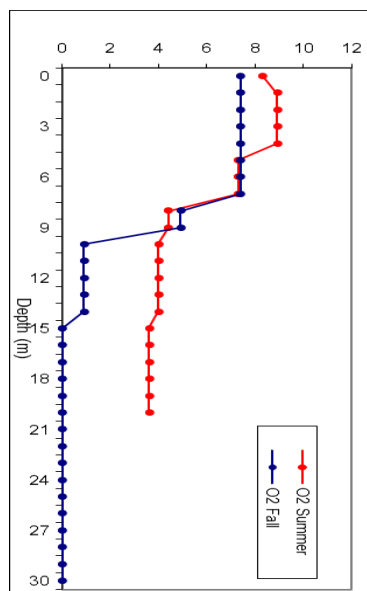


Figure 8 Vertical profiles of seasonal variation Dissolved oxygen in Bouhouda Lake

3.5. Water Turbidity, Suspended Materials and Dry Residues

A similarity and a correlation between Bouhouda Lake's turbidity and suspended material (SM) are noticed.

In fact, turbidity measures the degree of light penetration in the water column. The most important values were recorded in 08/2002 and 01/2004.

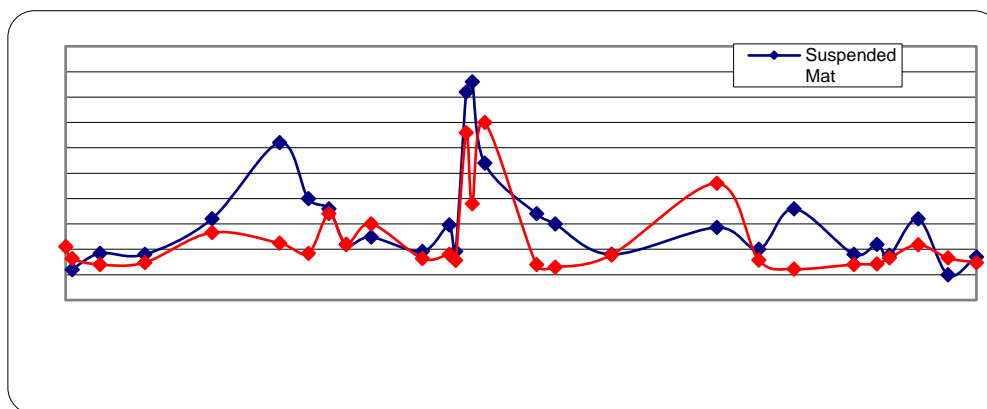


Figure 9 Variation and correlation of Bouhouda Lake's turbidity and SM.

For dry residues, all the recorded values do not exceed 300 mg/l, then the lake water remains weakly mineralized.

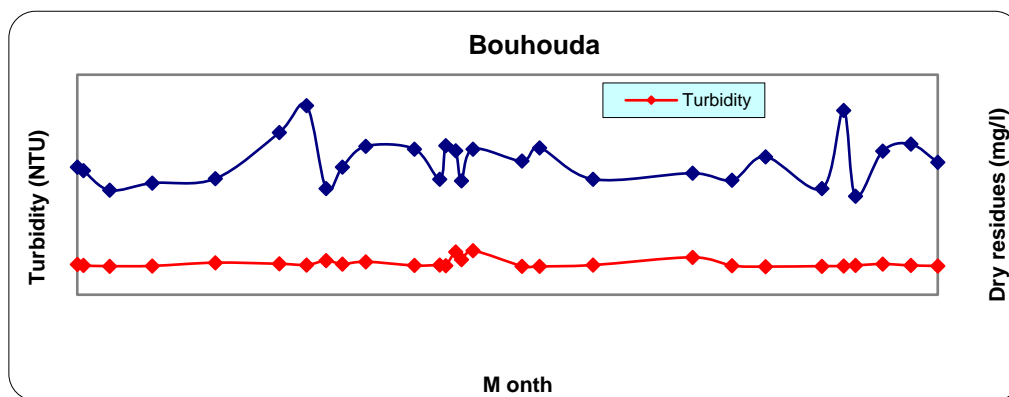


Figure 10 The variation and correlation of Bouhouda Lake turbidity and dry residues.

3.6. Conductivity

The lake's conductivity data remains moderate ($<300 \mu\text{S} / \text{cm}$) during the entire sampling period, which indicates that the mineralization and the release of minerals by the decomposition of organic matter are quite low in the lake.

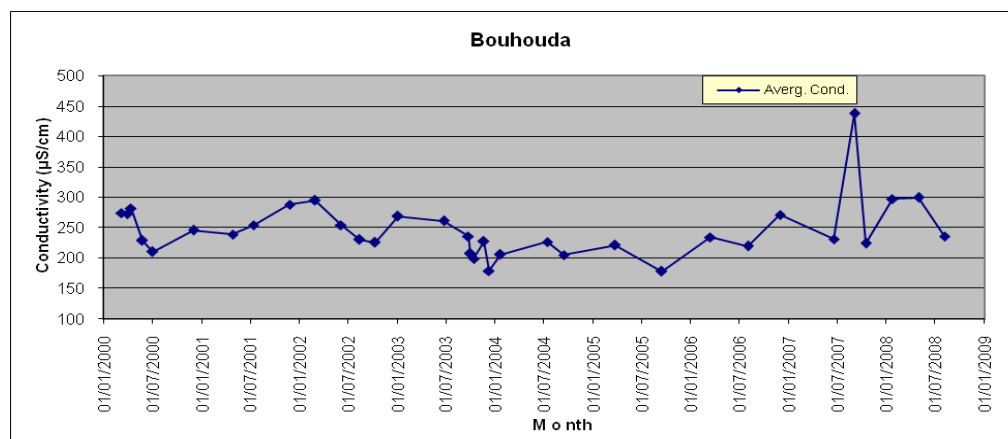


Figure 11 Evolution of the conductivity in $\mu\text{S} / \text{cm}$ in Bouhouda Lake.

3.7. Chlorophyll a

Chlorophyll (a) is marked by a very high seasonal variability during the study period. The highest concentration 13 mg/m³; was recorded in 2001, 2002 and 2004 (Figure 12). This fairly important level of chlorophyll (a) reflects the presence of a large phytoplankton biomass; therefore, the water column is quite rich in nutrients.

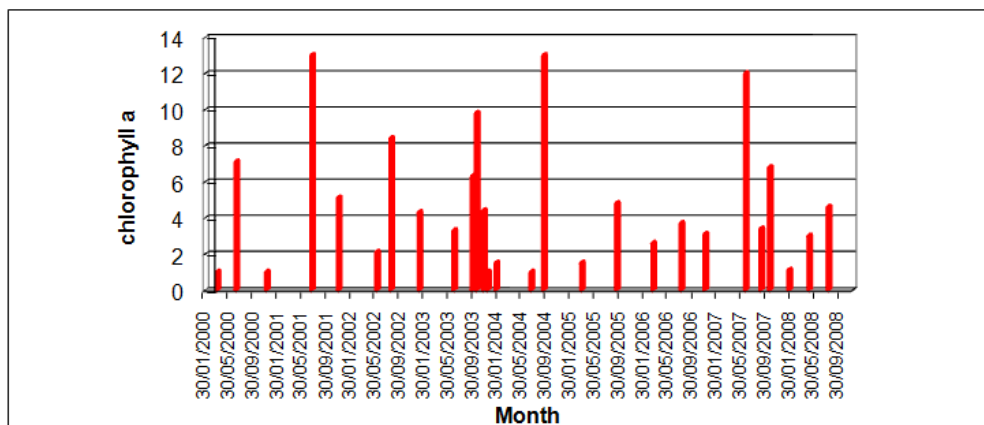


Figure 12 Inter-annual evolution of chlorophyll (a) in Bouhouda Lake

3.8. Transparency

The water's transparency varies irregularly and depends on the hydrological cycles, especially on the phytoplankton and algal productivity. In fact, seasonal variations show that the dam waters are poorly transparent, especially in winter, and relatively transparent in summer and autumn.

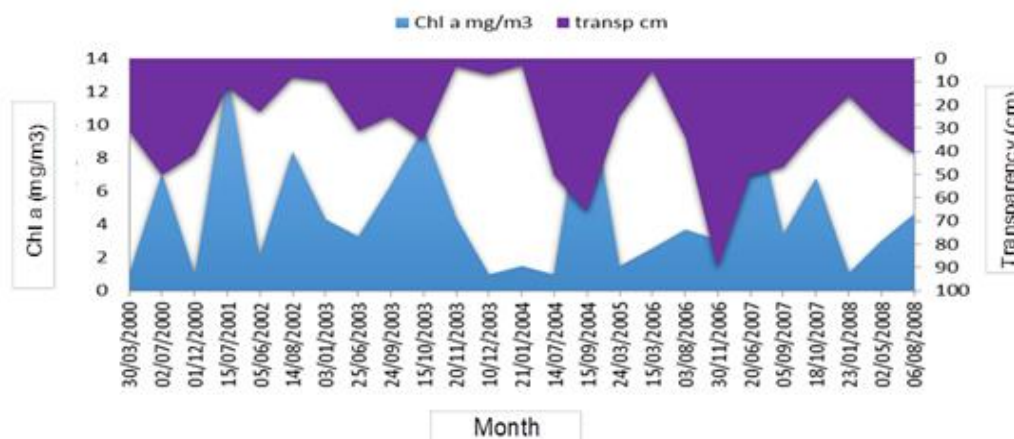


Figure 13 Inter-annual variations in transparency and chlorophyll (a).

The comparison of the chlorophyll (a) and transparency variation profiles (Figure 13) shows some correlation except for few points. This suggests that the lake productivity is the main responsible factor of this state, and not the winter and autumn inflows water (which are heavily loaded with suspended matter).

3.9. Nutritional elements

3.9.1. Orthophosphates and Phosphorus Total

Orthophosphates have low variability except a peak in 2001, where a value of 0.43 mg/l is recorded (Figure 14). The maximum records of total phosphorus concentrations (PT-P) are 1.6 and 1.9 mg/l, registered respectively in 2002 and 2004. The other values recorded do not exceed the maximum value of 1 mg /l. However, according to the lake water quality grid, the recorded values classify these waters as medium to poor waters.

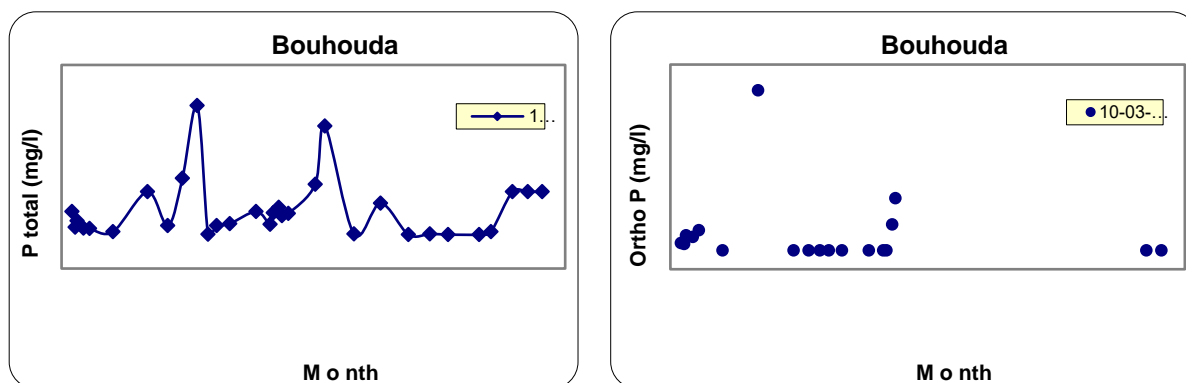


Figure 14 Inter-annual evolution of orthophosphates and total phosphorus.

3.9.2. Nitrogen salts

Nitrate contents (NO₃⁻), which represent the essential of the total nitrogen, show significant seasonal variations. They are relatively high in the winter-spring period due to the good water oxygenation combined with the importance of liquid inputs (Figure.15). These grades respect water quality standards (excellent class) (<10 mg / l), except few peaks where maximum values between 13.2 and 14.8 mg/l are recorded.

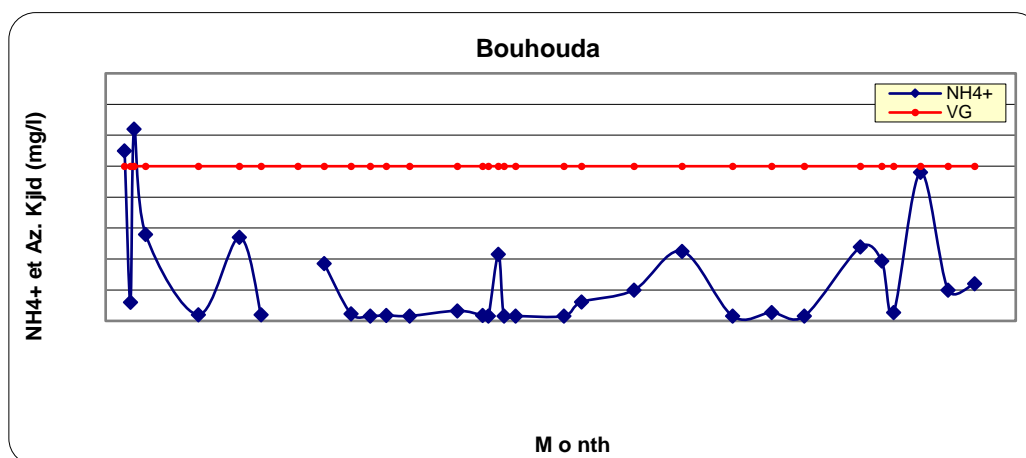


Figure 15 Inter-annual evolution of nitrates.

The contents of N-NH₄ are low especially in winter. The highest values are recorded in summer (0.55 and 0.48 mg/l recorded in 04/2000, 05/2008 respectively).

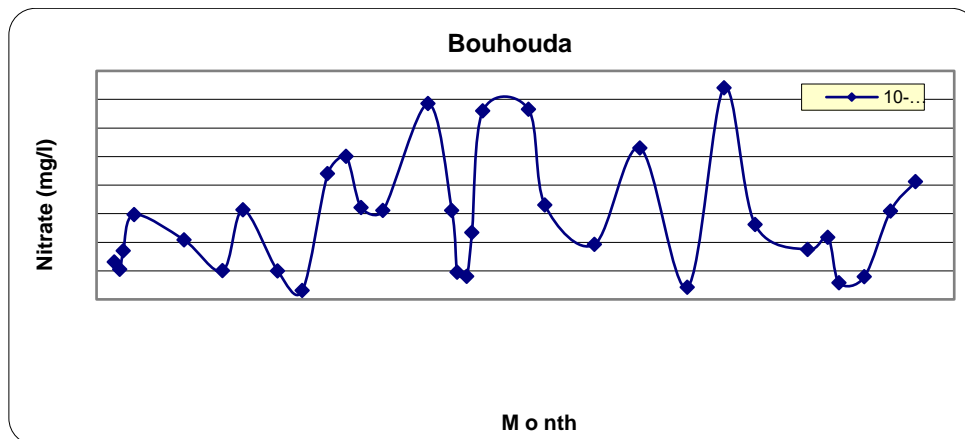


Figure 16 Inter-annual evolution of ammoniacal nitrogen.

Kjeldahl total nitrogen contents (Figure 17) remain very low and fluctuate between 0 and 3 mg/l in the water reservoir.

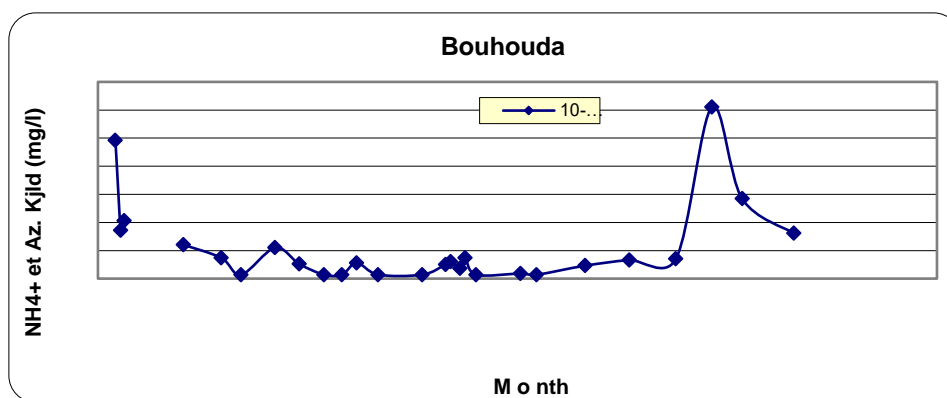


Figure 17 Interannual evolution of Kjeldal Nitrogen

3.10. Iron and Manganese

The average iron content varies from 0 to 2.9 mg/l; all values recorded do not exceed the guideline values, except for a few values observed during wet periods in 2000; 2001 and 2003. Concerning manganese, the majority of the values do not exceed the guide values. They vary between 0.01 mg/l to 0.19 mg /l except for the years 2007 and 2008 where the recorded contents are respectively 0.19 and 0.12 mg /l.

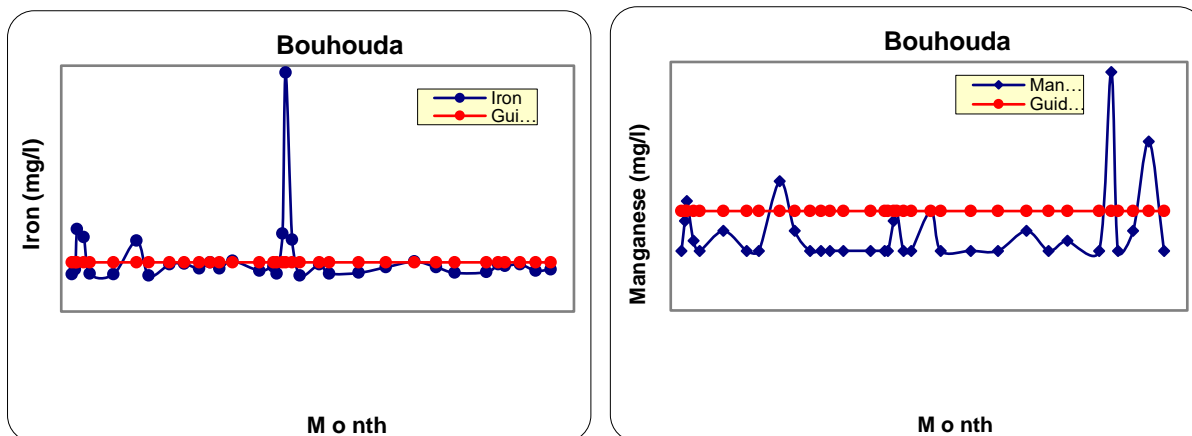


Figure 18 Evolution of manganese and iron in Bouhouda Lake waters.

3.11. Trophic state of Lake Bouhouda

Used by several authors to identify the trophic state of lakes, the Carlson index [18] (Trophic State Index or TSI) is based on the fact that the degree of a lake eutrophication depends on the nutrients' increased concentration, including phosphorus. Generally, the increase in phosphorus concentration results in a microscopic algae increase; as evidenced by the chlorophyll (a) parameter measurements and the transparency decrease.

High values above 50 on the TSI scale are typical of eutrophic lakes with high biological productivity, whereas the values below 40 on the same scale are usually representative of oligotrophic lakes, where the water detains low biological productivity. Intermediate values correspond to mesotrophic lakes.

In the following table the average values of the three considered parameters are reported with their index namely transparency TSI (Secchi), chlorophyll a, PT and their average TSI:

	Transparency (m)	Total phosphorus (µg/L)	Chlorophyll (µg/L)	Average TSI
Average values	0,19	377,78	4,91	
TSI	83 ,93	89,72	46,21	73,28

Based on these TSI indices, Bouhouda lake can be classified as eutrophic hypertrophic.

The same observation is noted by the calculation according to the following diagram.

The transparency index, the total phosphorus index and the chlorophyll (a) index of Bouhouda Lake correspond to the trophic eutrophic to hyper-eutrophic status (according to the diagram in figure 19).

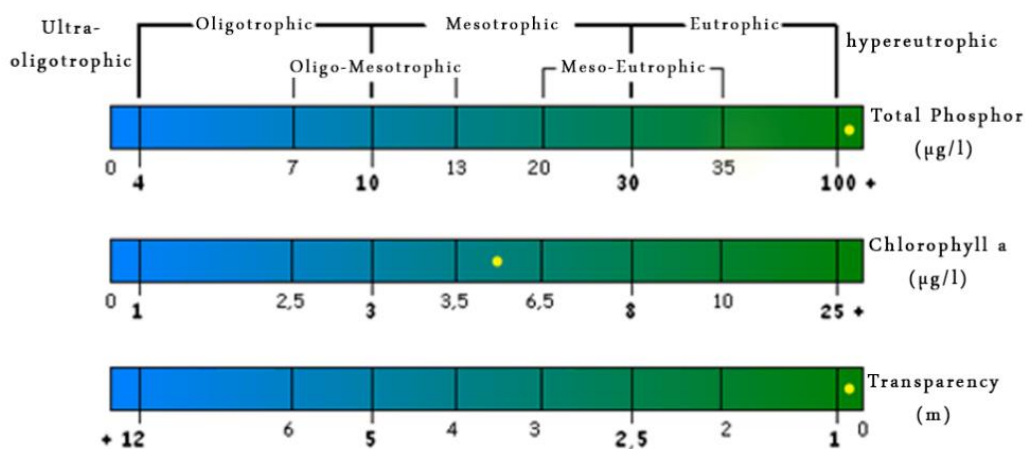


Figure 19 Lake Trophic Level Rank Diagram [19]

In summary, the trophic status of the lake corresponds to a eutrophic hypereutrophic stage. This conclusion is based on the three indices which reveal low water transparency, high phytoplankton biomass and high levels of total phosphorus.

Table 2. Lakes classification according to Vollenweider [20]

Trophic category	Chlorophyll a
Ultra-oligotrophic	< 1
Oligotrophic	< 2,5
Mesotrophic	2,5-8
Eutrophic	8-25
hypereutrophic	> 25

Thus, the trophic status of the Bouhouda reservoir-lake, based on the general average of chlorophyll (a) and the Vollenweider's classification (1968), is also classified as hyper-eutrophic lakes (Table 1).

4. CONCLUSIONS

The limnological diagnosis of the Bouhouda dam allowed us to note several particularities:

- The body water stratification and mixing regime is a monomictic body of water with a thermal stratification that usually extends during the cold wet season of the year.

The thermocline created forms a barrier which prevents the well-oxygenated water transport from the epilimnion to the hypolimnion. The production of microscopic algae in the superficial layers is due to the light penetration which, in the presence of nutrients, causes an excessive sedimentation of detritus. This sedimentation produces deoxygenation of the hypolimnion where the anaerobic conditions are established and tend to rise very high in the water column particularly in the summer season.

- Due to the presence of sufficient nitrates, which act as additional oxidizing material, bacteria do not need to use the sulphates in the organic material decomposition processes, and therefore there is no Hydrogen sulphide release, however iron, manganese, and ammonium are presents.

- The Bouhouda dam water has a relatively high concentration on total phosphorus, a very low transparency and a significant deficit in oxygen at the level of the hypolimnion. The Bouhouda dam is classified in a eutrophic state to a hyper-eutrophic situation.

- If total phosphorus concentrations in the lake are maintained around the current load, and as long as there are no long periods with poor water mixing and a prolonged anoxia in the bottom waters of the lake, a strong release of phosphorus sediment would certainly be caused. This would maintain the lake in a hyper-eutrophic state.

These results could contribute to establish specific programs and actions to reduce phosphorus inputs according to the use of water, and to improve the water quality management in terms of trophic response as part of a sustainable development program. It would be interesting to complete this study with future work based on the mathematical modeling of the lakes trophic states in order to carry out prevention procedures capable of curbing the eutrophication phenomenon of the other Mediterranean water reservoirs.

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