Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la Terre, 2022, n° 44, 01–12 ***e-ISSN : 2458-7184***

Stratification, trophic status and eutrophication in the El Kansra dam (Morocco)

Stratification, état trophique et eutrophisation de la retenue du barrage d'El Kansra (Maroc)

Allaa Elouahli*, Sayf El Islam Barcha, Rachid Sammoudi, Ilham Nassri & Mohammed Fekhaoui

Geo-Biodiversity and Natural Patrimony Laboratory (GEOBIO), Scientific Institute, Geophysics, Natural Patrimony and Green Chemistry Research Centre (GEOPAC), Mohammed V University in Rabat Morocco, Av. Ibn Batouta, B.P 703, 10106 Rabat, Morocco(allaa.elouahli@gmail.com).*

Abstract. The reservoir of the El Kansra dam contributes to the drinking water supply of the cities of Khemisset and Tiflet and also to the irrigation of more than 30,000 ha of cultivable land, as well as an annual electricity supply of approximately 13 million Kwh. This study aims to better understand the mechanisms and the factors that cause the eutrophication of this lake. 41 water samples (41 campaigns) per month were collected in the ONEP intake, from March 2005 to September 2015, in order to determine the degree of stratification, the trophic state and some trace elements (Iron and Magnesium) of this lake. Principal Component Analysis (PCA) was performed to process information on some of the most important physical and chemical tracers in dam eutrophication.

According to the Trophy State Index (TSI) and the Vollenweider classification, the lake of this dam is classified in the mesotrophic category. The stratification and mixing regime of the water mass presents a monomictic water body with a thermal stratification, generally extending between April and November. Physico-chemically, the water of the El Kansra dam contains a relatively high concentration of total phosphorus, with a much-reduced transparency by phase and a significant deficit in oxygen in the hypolimnion. As for nitrates (NO3-), they present relatively high levels during the winter-spring period in relation to the good oxygenation of the water, combined with the importance of liquid inputs. The PCA showed a state dominated by water rich in chlorophyll favored by a good oxygenation, leading to high water turbidity, and an opposite state, generally during the summer and autumn period, marked by a deficit of dissolved oxygen, but with a strong mineral load (Manganese, iron).

Keywords: Trophic state; Stratification; Trophy State Index; El Kansra Dam; Eutrophication.

Résumé. La retenue du barrage d'El Kansra contribue à l'approvisionnement en eau potable de deux villes (Khémisset et Tiflet) et à l'irrigation de plus de 30.000 ha de terres cultivables tout en apportant un appoint annuel d'électricité d'environ 13 millions de Kwh. Cette étude est effectuée sur le lac de ce barrage afin d'acquérir une meilleure connaissance des mécanismes qui entrent en jeu et les facteurs qui conditionnent l'eutrophisation de ce lac. Un échantillonnage mensuel de 41 prélèvements (41 campagnes) d'eau du lac a été effectué entre le mois de mars 2005 et le mois de septembre 2015 au niveau de la prise de l'ONEP pour déterminer le degré de stratification, l'état trophique, et quelques éléments traces (Fer et Magnésium). L'analyse en composantes principales (ACP) a été effectuée pour traiter les informations relatives à certains traceurs physiques et chimiques les plus importants dans l'eutrophisation du barrage.

Le statut trophique, selon Trophy State Index (TSI) et selon la classification de Vollenweider, ce lac est classée dans la catégorie Mésotrophe. Le régime de stratification et de mixage de la masse d'eau présente un plan d'eau monomictique avec une stratification thermique qui s'étend en général entre avril et novembre. Sur le plan physico-chimique, l'eau du barrage El Kansra a une concentration relativement importante en phosphore total, une transparence très réduite par phase et un déficit important en oxygène au niveau de l'hypolimnion. Quant aux nitrates (NO3-), ils présentent des teneurs relativement élevées en période hiverno- printanière en relation avec la bonne oxygénation de l'eau, conjuguée à l'importance des apports liquides. L'ACP a montré un état dominé par des eaux riches en chlorophylle du fait de la bonne oxygénation, entrainant une forte turbidité des eaux, et un état inverse, marqué par un déficit en oxygène dissous mais à forte charge minérale (Mn, fer) qui correspond généralement à la période estivale et automnale.

Mots-clés : Etat trophique, Stratification, Indice d'état trophique, Barrage d'El Kansra, Eutrophisation.

Introduction

The dynamics of a dam reservoir, considered as an artificial lake, is governed by physical (morphometry, temperature, light), chemical (nutrients, dissolved oxygen and acidity) and biological (fauna, flora, bacteria) characteristics. Thus, the greatest influence on the development of its water quality, and even on the eutrophication process, is the stratification and mixing regime of the water mass. The latter is strongly affected by anthropogenic, meteorological and hydrological processes in the watershed, which threaten the trophic status and ecological sustainability of the aquatic ecosystem. Indeed, stable stratification in reservoirs will lead to changes in the physicochemical properties of water (Liu *et al.* 2021) which can be accelerated by anthropogenic factors (urban development, domestic and hospital wastewater discharge, waste collection, polluting industrial activities, agricultural activities...) and climate change. Thus, eutrophication leads in changes in color, odor, and taste, as well as increased turbidity, water anoxia, and phytoplankton biomass (Dumitran *et al*. 2020, Halim *et al*. 2020).

The latter is a ubiquitous phenomenon that occurs in different types of climate, including equatorial (Galvez & Sanchez 2007), tropical (Janjua *et al.* 2009, Quevedo-Castro *et al.* 2019), arid (Abdelhay *et al.* 2018, Shekha *et* *al.* 2017), temperate (Zbierska *et al.* 2015, Dumitran *et al.* 2020) and polar climates (Kaup *et al.* 2005). Furthermore, the interactive impacts of warming and eutrophication have been widely known and documented in the literature (Binzer *et al.* 2016, Ansari *et al.* 2010). All of these impacts result in a deterioration of water quality. Thus, they can mutually reinforce the symptoms they express and the problems they cause, notably to biodiversity and biogeochemical cycles (Moss 2011). Indeed, the combination of these two factors (warming and eutrophication) should have antagonistic effects on the diversity and structure of natural communities (Binzer *et al.* 2016). There may be a more or less important break of species in the trophic chain having a variable impact on the survival of the other living beings. It therefore promotes the proliferation of species that are most adaptable to high organic loads (Herawati *et al.* 2020) and leads to composition species changes, species diversity declines, and loss of rare and uncommon species (Ansari *et al*. 2010). This also leads, over time, to more homogeneous community composition and degradation of the fundamental facet of biodiversity.

Another eutrophication-related phenomenon that exacerbates the decline in biodiversity is the recent increase in a variety of multi-host parasites of humans and wildlife. In addition, dam reservoirs can also become hotspots for greenhouse gas emissions (Maavara *et al.* 2020). Therefore, thermal stratification and trophic state coupled with anthropogenic activities and climate change make the management of a dam reservoir very complex and of great concern.

This study led us to assess, for the first time, the degree of stratification, trophic status and physico-chemical characteristics of the El kansra dam under a semi-arid climate. Previous studies with different aims have been conducted in the same reservoir (Derraz *et al.* 1995, Berrada *et al*. 1999).

Materials and methods

Study site

The El Kansra dam is one of the oldest dams in Morocco (1927 et 1935), located in the Beht basin (Fig. 1) in the province of Khemisset, Rabat-Salé-Kenitra region (northwestern Morocco). Its main functions are summarized in the production of energy, drinking water, irrigation and low water support and flood control of the Beht river, the last major tributary of the Sebou river. It was put into service in 1935 and its dike was raised in 1968 to compensate for the decrease in the volume of the reservoir, due to silting, and to increase the irrigated area downstream and the electrical productivity (ABH-Sebou, ...). The main characteristics of this river, at the entrance to the reservoir, are shown in Tab. 1. A significant deterioration of the reservoir water quality has been observed since the impounded of the dam (ONEP 1996). This situation is accentuated by the slow transit of the reservoir, where the average residence time of the water is 15.7 months (Derraz *et al.* 1995).

The catchment area of Beht River on which the El Kansra dam built, with an area of 4540 km2 and a reduced vegetation cover, is made up of Miocene marly hills, crossed by a valley exposed to the north.

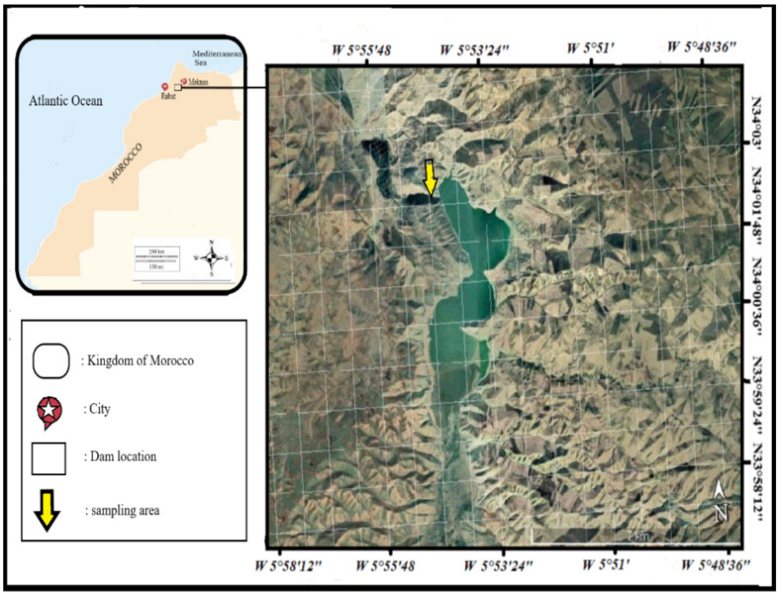

Figure 1. The geographical situation of the El Kansra dam reservoir.

Table 1. Characteristics of the El Kansra dam.

Commissioning	Retention (Mm^3)	H (m)	Goal	Regulated volume (Mm^3)	Irrigable area (ha)	Energy product. (KWh/year)
1935	230	68	Drinking water supply for two towns (Khemisset and Tiflet) and irrigation of 30,000 ha.	200	30.000	13 M

Water sampling and analysis

The temporal sampling plan for this study spans from March 2005 to September 2015. In the vertical of the water column, the water samples were taken at the ONEE outlet (Fig. 1) at the surface of the water body and vertically at a depth of 15 m. Thus, the sample size is of the order of 82 observations.

In order to calculate the trophic status index (TSI) of El Kansra Lake waters, physicochemical and biological parameters such as: pH, temperature (Tw), electrical conductivity (Ec), nitrates (NO3-), iron (Fe2+), manganese (Mn2+), dissolved oxygen (DO), total phosphorus (TP), transparency (Secchi disk), and chlorophyll-a were measured according to standard methods (Cooke *et al.* 2005; Le Moal *et al.* 2019).

Water samples are collected in a clean 1L polyethylene bottle at the above locations and were transferred to the ONEE laboratory at 4 °C for measurement of chemical (DO, PT, Iron, Mn, Nitrate) and biological (Chl(a) extraction) parameters. While physical parameters (T °C, pH, EC and transparency) were measured in situ.

Table 2. Methods and Techniques used in the physical-chemical parameters.

Measurements	Parameter	Method or technique
In situ	Temperature (T°C)	Thermometer
	pH	pH Philips 4014
	Electrical conductivity (Ec)	EC Philips 4025 counter
	Transparency	Secchi disk
Laboratory	dissolved oxygen (DO)	Nitrogen method in modification of the Winkler method
	Total Phosphate	Colorimetric (after mineralization of persulfate in an acid environment)
	Iron (Fe)	Atomic absorption spectrometry
	Manganese (Mn)	Atomic absorption spectrometry with flame
	Nitrate	Colorimetry
	Chl(a) Extraction	Using 80% acetone extraction procedure, which was determined at 663 and 645 nm

Statistical Analyzes

The parameters were assessed by Pearson correlation ($P<0.05$) using SPSS 20.0 software (Van Belle *et al.* 2006 & Kuperman *et al.* 2002). All data were tested for normality and homogeneity of variance prior to parametric statistical analysis. Variability between sampling sites was analyzed for each water parameter by one-way ANOVA. To detect differences between individual means, we used Duncan's test to analyze the relationships between the tested parameters.

The principal component analysis (PCA) allowed to classify and process the information related to some of the most important physical and chemical tracers in the dam eutrophication during the years 2005 and 2015. This was possible by establishing a typological structure, which is able to explain the quality water evolution during this period and to identify the correlations between the variables. This PCA is performed in data matrices, measured and carried out on data consisting of 41 samples (41 campaigns) in which the nine variables (Water Temperature, pH, OD, Ec., Chl(a), Transparency, TP, Iron and Mn).

Results and discussions

The degree of stratification

Temperature

The presence of a seasonal cycle in this data set is noticeable. This cycle shows that the surface water temperature is minimal in the cold season and maximal in the warm season (Fig. 2b).

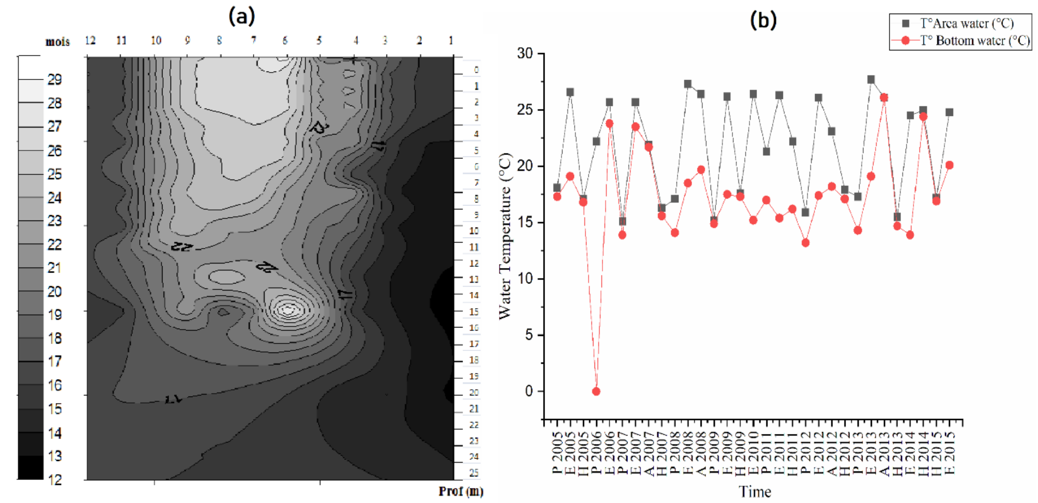

Figure 2. (a) The interannual temperature variation of the El Kansra reservoir; (b) The vertical profile and the diagram of the monthly variation of the El Kansra reservoir.

However, the bottom temperatures are lower than the surface temperatures, with a greater thermal difference during the summer and early autumn period (September). The thermal difference is significant between winter (minima and maxima of about 0.3 °C and 3 °C, respectively) and summer (minima and maxima of about 7.9 °C and 11.2 °C, respectively).

At the surface, the lowest value of 15.1 °C is observed in spring 2007, the maximum value of 27.7 °C was observed in summer 2013. However, at the bottom, the lowest value measured in winter 2007 is 13.9 °C, while the maximum value 26.1 °C was obtained in autumn 2013.

Thus, the importance of the seasonal variation in temperature in the purification process is remarkable in spring and summer. Indeed, these periods promote the development of the macrophytes, an important factor in water purification (Cheng *et al.* 2021).

The low minimum temperatures and the large temperature range observed on a seasonal scale in the reservoir induce significant changes of water column stability. Thermal stratification has been detected on a seasonal scale, and the duration and depth of temperature stratification can also affect the time and volume of water that is isolated during the summer (Dumitran *et al.* 2020). It begins to set in from April as a result of the increase in surface water temperatures followed by a decrease which begins in mid-September and is diffused until full mixing by the end of November. Similar results were reported in an arid climate (Asadian *et al.* 2020) in a humid sub-tropical climate (Jin *et al.* 2019).

Indeed, deep lakes, in the absence of significant water movements, exhibit thermal stratification, favoring the formation of water strata and thus preventing the homogeneity of temperature, oxygen and nutrients. Therefore, climate change and air temperature increase will lead to the extension of the thermal stratification period (Firoozi *et al.* 2020). Commonly, stratification tends to lead to deoxygenation of deep reservoir waters, due to heterotrophic consumption and lack of replenishment from oxic surface layers (Yan *et al.* 2015).

However, an episode of homothermy was recorded during the December-February period (Fig. 2a), the winter mixing phase. The figure 2 shows the presence of several phases where significant temperature differences between the surface and the bottom were maintained continuously (stratification period). The reservoir is divided into a lower part called cold hypolimnion and an upper part called warm epilimnion, which are separated by a thermocline located at a depth of 6–11 m. From November onwards, the lake begins its late autumn-winter mixing. These periods are all associated with wet periods (precipitation).

It is worth noting the disruption of the thermal structure of the water column noted in April and May and marked by a sudden shift of warm surface water to the bottom. This phenomenon can only be related to a large-scale mechanical action, namely the opening of the reservoir gates (Zbierska *et al.* 2015) or a very strong wind (Firoozi *et al.* 2020).

Thus, the thermal and dynamic stratification pattern observed at the El Kansera dam lake is typical of a reservoir that can be classified as warm monomictic. In particular, many studies have highlighted that increased air temperature has led to rapid warming and stronger thermal stratification (O'Reilly *et al.* 2015, Yin *et al.* 2018, Woolway & Merchant 2019, Valerio *et al.* 2021).

Some studies show that stratification is largely affected by the amount of precipitation (Chen *et al.* 2020) others have shown that air temperature (AT) and water level (WL) are the two dominant variables affecting it (Jin *et al.* 2019).

It is important to note that there is a close relationship between the thermal stratification of a lake, the oxygenation of the water, and eutrophication insofar as, for deep waters, the decomposition of the organic matter that accumulated on the bottom consumes oxygen (Yan *et al.* 2015).

pH

In general, the pH of surface waters is always alkaline (between 7.84 and 8.98) (Fig 3b). At the surface, the lowest value 7.84 is observed in winter 2005, the maximum value 8.78 was observed in summer 2006. However, the pH decreases from the surface to the bottom to reach 7.45, the lowest value measured in summer 2007, while the maximum value 8.16 is obtained in spring 2013. These values are all in the V.m.r range (ONEP 1989). The differences between surface and bottom are higher in summer and winter than in autumn and spring. This pH distribution could be explained by the photosynthetic activity of algae in the surface water and by the mineralization of the bottom water by bacteria. The increase in pH is solely the result of the photosynthetic activity of green algae. High algal activity allows a high CO2 uptake from the waters, which in turn leads to the imbalance of the carbonate buffer system and increases the waters pH level (Ihnken *et al.* 2014, Labrecque *et al.* 2012).

The data collected allow us to appreciate the existence of a stratification state of the pH, depending on the depth and the season (Fig. 3a). Seasonal variations show a stratification from February to October with the highest values at the surface.

Between the surface where photosynthetic activity is very high (intense light, high heat) and the depth where the lack of light and lower temperature (reduced photosynthesis), the pH drops by an average of 0.21 in winter and 0.86 in summer.

The maxima recorded at the surface and at the bottom are 10.20 (Summer 2008) and 7.10 (Autumn 2007), respectively (Fig. 4b), while the minima are around 4.80 in Spring 2013 and 0.10 mg/l in Summer 2012, respectively.

Dissolved oxygen

For bottom waters, the levels are marked by two states (Fig. 4a):

1- State of anoxia: several phases, mainly in summer.

2- State of good oxygenation: the peaks are mainly recorded during the winter phase and exceptionally in summer 2008 when the levels reached 10 mg/l.

The vertical oxygen profile and variation diagram show that the winter mixing, although incomplete, allowed partial reoxygenation of the bottom. Dissolved oxygen concentrations of 6, 8.3 and 5.2 mg O2/L (Fig. 4b) are observed in December, January and February, respectively, with a descent of reoxygenation lower in the column to reach the bottom in January and February and limited to the surface layer in December. This observation suggests that the water-sediment interface of the lake is quasi-anoxic, but the hypolimnion holds a sufficient amount of dissolved oxygen in the summer period. Reservoir mixing is particularly important to provide oxygen to the deep waters and to transport nutrients from the hypolimnion to the epilimnion (Yankova *et al.* 2017, Duvil *et al.* 2018).

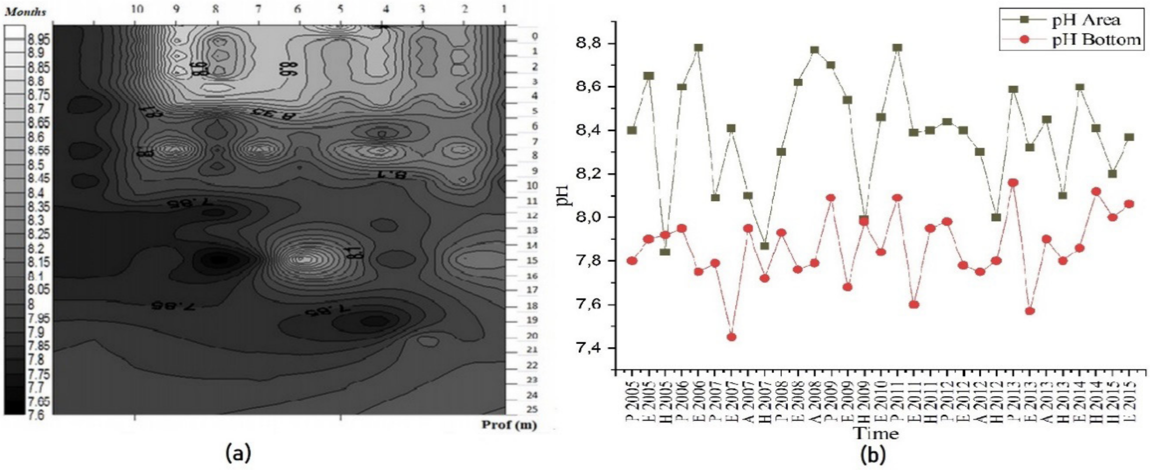

Figure 3. (a) Interannual pH variation of the El Kansra reservoir; (b) Vertical profile and diagram of the monthly pH variation of the El Kansra reservoir.

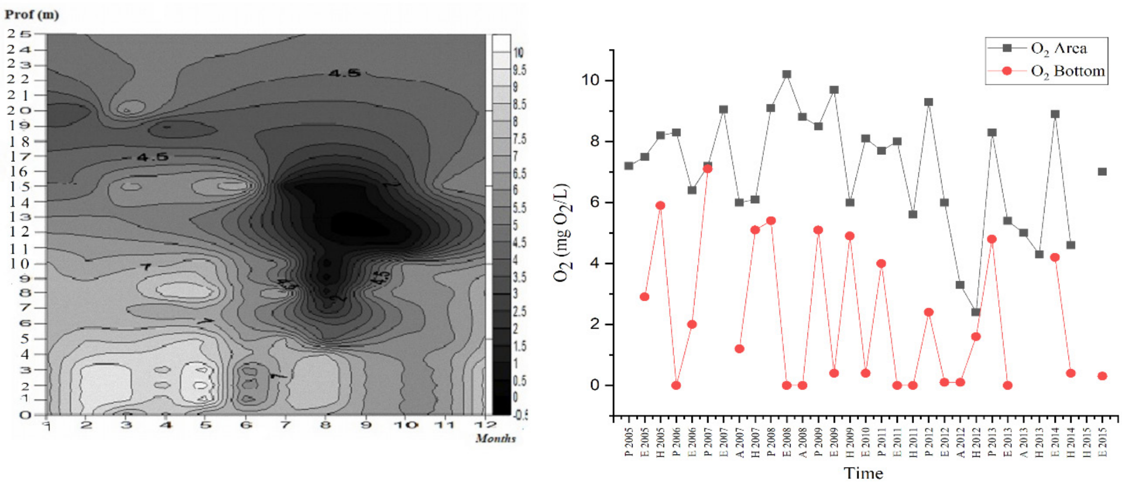

Figure 4. (a) Interannual variation of oxygen in the El Kansra reservoir; (b) Vertical profile and the diagram of the monthly variation of oxygen of the El Kansra reservoir.

In addition, a recent study showed that oxygen levels in 45.148 surface and deep-water samples from 393 temperate lakes declined by an average of 5.5% and 18.6%, respectively. This same study estimates that the loss oxygen main factor in surface waters is the global increase in temperature, which decreases the oxygen solubility in water. While for deep waters, the increase in thermal stratification, in intensity and duration, leads to a decrease in oxygen concentration in the deep layers of lakes (Jane *et al.* 2021).

The vertical profile shows that during the winter period, the entire water column is only completely homogeneous during January, with average dissolved oxygen levels ranging from 8.3 to 8.2 mg/l. The hydrological variability tends to generate a stronger stratification of the reservoirs.

From spring onwards, there is a drop in the deep layers from a depth of 15 m, which accelerates during the spring to reach the superficial layers during the summer (6–7 m) (aphotic zone), reaching the anoxic phase from a depth of 16 m. This state continues until the beginning of autumn with a beginning of reoxygenation of the deep layers from the middle of autumn. This oxygen deficit is indicative of extensive biodegradation at depth. The mean difference in surface-to-bottom oxygenation is significant (Fig. 4a).

It is sometimes noted that the stratification is not stable (case of May), likely due to the mixing caused by winds (Firoozi *et al.* 2020) or flushing operations (Zbierska *et al.* 2015). Light availability in the water column is also a major physical factor, knowing that water transparency plays a dominant role in dissolved oxygen stratification. Indeed, there is a dissolved oxygen compensation depth, defined as the depth where the photosynthetic production rates are equal to the respiration rates of the organism. Considering the high levels of organic matter settling at the bottom of the reservoirs, it is obvious that the oxygen demand at the water-sediment interface is very high. This could explain the development of anoxic conditions at depth in this type of aquatic ecosystems (Boehrer & Schultze 2008, Winton *et al.* 2019, Pawar *et al.* 2020, Liu *et al.* 2021). On the other hand, the evolution of the dissolved oxygen concentration in the Stanca-Costesti reservoir has shown great variations correlated mainly with the water temperature evolution (Dumitran *et al.* 2020).

The thermocline forms a barrier that prevents the transit of well oxygenated water from the epilimnion to the hypolimnion. This is due, on the one hand, to the increased oxygen deficit as the dissolved oxygen in the water of the hypolimnion is consumed and, on the other hand, to the richness in nutrients at the level of the epilimnion which constitutes a very favorable environment for the development of phytoplankton at the beginning of the summer. The production of microscopic algae in the superficial layers is due to the penetration of light, which, in the presence of nutrients, leads to an excessive sedimentation of detritus. This sedimentation causes the deoxygenation of the hypolimnion, where established anaerobic conditions tend to rise very high in the water column, particularly in the summer season.

Trophic status

The assessment of trophic status showed a very marked seasonal variation in total phosphorus, chlorophyll(a), transparency, and total nitrogen.

Total phosphorus

Total phosphorus (TP-P) is considered one of the most important parameters to determine the degree of organic matter pollution in a water system. Indeed, during the monitoring period, total phosphorus (TP-P) levels hardly exceeded 1 mg/L with the exception of the winter 2007 at the bottom and the autumn 2013 at the surface, where maximum values of about 2.6 mg/L and 6.99 mg/L were recorded, respectively (Fig. 5b). Phosphorus concentrations are significantly higher at the surface than at the bottom. This indicates that bacterial activity in the hypolimnion is less intense. Compared to the national standards for lake water, the values recorded in this way classify El Kansra dam water as of poor quality.

The high phosphorus loads, taken at the dam, come simultaneously from scoured water and from release. Indeed, this high content in an entrophic reservoir supports an increased level of primary production until nitrogen limitation (Shekha *et al*. 2017).

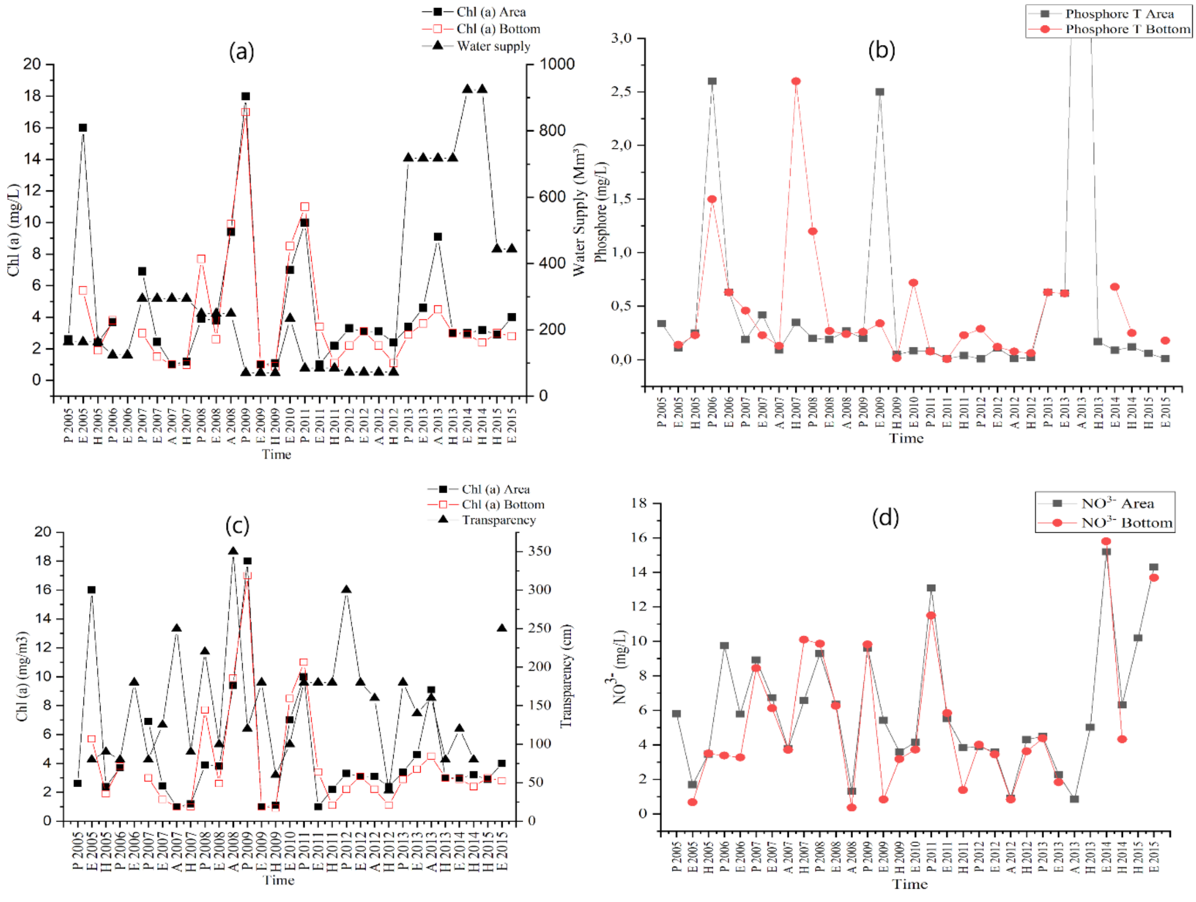

Figure 5. Interannual evolution of the parameters of the El kansra reservoir.

(a) : Variation of Chl (a) and water supply with time.
(b) : Variation of phosphorus as a function of time.
(c) : Variation of Chl (a) and transparency.
(d) : Variation of nitrate with time.

If the total phosphorus concentrations in the lake are maintained at around the current load and provided that there are no long periods of poor water mixing and prolonged anoxia of the lake bottom. This would cause a strong release of phosphorus from the sediment (decrease in the sedimentation constant) which could cause the lake to shift to a hyper-eutrophic state.

Accumulation of soluble phosphorus through the nutrient release in the hyplimnion layer depends on oxygen concentration, microbial decomposition, hypolimnetic temperature, and thermocline depth (Benateau *et al.* 2019, Pitoi *et al*. 2019, Dumitran *et al.* 2020). However, high water input intensifies vertical water mixing, moving phosphorus from the bottom (hypolimnion) to the epilimnion (Dumitran *et al.* 2020).

Chlorophyll (a)

The interannual evolution of chlorophyll(a) is illustrated by a very marked seasonal variability during 2007/2011. The highest concentration (39 mg/m3) was obtained in spring 2008 and the lowest 0.9 in winter 2011 (Fig. 5a). This high level of chlorophyll(a) reflects the presence of significant phytoplankton biomass and nutrient enrichment of the water column. Analysis of the data series revealed a significant and more or less stable downward trend in chlorophyll(a) measurements, suggesting a stable productivity of the water mass. This lack of trend is also consistent with the lack of change observed in phosphorus concentrations. Thus, the transition from one trophic state to another relies on the conversion of the degree of nutrient supply and reservoir productivity (Odagiri *et al.* 2020).

Chlorophyll(a) concentration in the reservoir was lower during the stratification period, likely due to increased nutrient concentrations. The lack of nutrient limitation and the intense water fluxes caused mainly by the low water inflow time, could also be responsible for the observed high chlorophyll(a) levels. similar findings were reperted in two reservoirs from Brazil (Coulliette & Noble 2008). In addition, the level of chlorophyll(a) in the water can vary due to turbidity and other factors unrelated to algal growth. The highest chlorophyll-a values corresponded to lower transparencies. The strong direct correlation between total phosphorus and chlorophyll-a presented supports this conclusion. (Galvez-Cloutier *et al.* 2007).

Transparency

The interannual evolution of transparency is illustrated by a very marked seasonal variability during the period 2008/2012. The highest concentrations 300 cm and 350 cm were obtained in Spring 2012 and Autumn 2008, respectively (Fig. 5c).

Comparison of the chlorophyll(a) variation profiles with that of transparency (Fig. 5c) shows some correlation except for a few points. This suggests that the productivity of the lake is the factor responsible for this condition but not the winter and autumn inflow of water highly loaded with suspended matter. Consistent with our study, Transparency correlates with increasing phytoplankton density (higher chlorophyll(a) content) (Shekha *et al.* 2017). Indeed, seasonal variations show that the waters of the dam are slightly transparent, especially in winter, and relatively transparent in summer and autumn.

Nitrate

Nitrate levels (NO3-), which represent the bulk of total nitrogen, show significant seasonal and cyclical variations. They are relatively high in the winter-spring period in relation to the good oxygenation of the water, combined with the importance of liquid inputs (Fig. 5d). The majority of these levels comply with water quality standards (excellent class) (<10 mg/l). Overall, the concentrations at the bottom are similar to those at the surface. Indeed, the importance of denitrification at the bottom (Bonin *et al.* 1989) and low allochthonous inputs and algal assimilation would lead to the depletion of this element in the water column during the summer. During this period, nitrates would be the limiting factor for algal production in the reservoir.

Nitrate levels show little variability except for a few peaks where we found values of 0.36 mg/l (Autumn 2008) at the bottom and 0.92 mg/l (Autumn 2012) at the surface. On the other hand, the maxima are respectively 15.8 and 15.2 (Summer 2014) at the bottom and at the surface (Fig. 5d). In fact, nitrate has decreased compared to spring, probably due to the decrease in agricultural activities (Asadian *et al.* 2020).

Due to the presence of sufficient nitrate as an additional oxidizing material, bacteria do not need to use sulphate in the decomposition process of organic matter, but iron and manganese are present. The decomposition of these organic residues and the decrease in temperature can contribute to the decrease in nitrate levels in the water. (Abdelhay *et al.* 2018). Mixing processes can alter the vertical concentration of ions and influence the nitrate presence in the hypolimnion nutrients (Liu *et al.* 2021). These elements released from the sediments can diffuse through the thermocline and reach the upper levels of the water body.

Conductivity

The water productivity can be classified according to its conductivity: very low productivity (10 to 50 µS/cm), medium productivity (50 to 150 µS/cm) or high productivity (150 to 750 µS/cm) (Aktas *et al.* 2007). In the same way that high conductivity reflects either abnormal pH or, more often, high salinity (El Morhit & Mouhir 2014).

The conductivity data for the lake reveal a very high level of mineralization (> 800 µS/cm) for the period from spring 2005 to autumn 2007 and a high level for the rest of the readings (between 500 and 1200 µS/cm). A similar variation between the surface and the bottom can be noted (Fig. 5a). According to Aktas *et al.* (2007), the waters of the El Kansra dam lake are very productive. This sudden increase may be an indication of minerals release by the decomposition of organic matter at the bottom. The electrical conductivity showed slight variability in both seasons. Higher conductivity values were observed during the rainy season due to the erosion process in the basin.

Indeed, seasonal differences in dilution/concentration seem to have an impact on parameters such as conductivity and nitrate. Surprisingly, increasing reduced compounds did not affect conductivity. (Chanudet *et al.* 2016).

The difference between the surface and the bottom is very small. According to Rast & Thornton (1996), a difference of less than 80 µs/cm is not very significant and allows a single point to provide a realistic description of water quality. This can be applied for a large monitoring period. It should be noted that all the values recorded are in the minimum required value.

Iron

Average iron levels range from 0.03 mg/1 (Autumn 2008) to 0.54 mg/1 (Spring 2005) at the surface and from 0.06 mg/l (Summer 2001) to 2.6 mg/l (Summer 2014) at the bottom of the lake (Fig. 5b). Maximum concentrations are systematically observed at the bottom of the lake. On the surface, not all values exceed the guide values. They vary between 0 and 1.2 mg /L the significant values of which are recorded during the wet seasons.

Manganese

The phenomenon of manganese seasonal variations is more pronounced, particularly at the bottom where the average concentrations are higher (Fig. 5b). With the exception of a few points, all background values are well above the guide value. They vary between 0.01 mg/1 (spring 2011) and 1.9 mg/1 (spring 2005) at the bottom and between 0.01 mg/1 (spring 2006) and 0.15 mg/l (autumn 2012) at the surface. The increase in concentrations begins in summer and reaches its maximum in late fall for the entire cycle. This situation coincides with the conditions of fall of the oxygen content at the bottom of the lake (anoxia conditions). In fact, during this period, the decrease in dissolved oxygen was recorded simultaneously with the increase in Fe and Mn concentrations in the deep layers of the lake (phenomenon of iron release from the bottom sediments). In the reservoir, the evolution of these two elements shows a very important seasonal variation.

The average value of the trophic status index and that of the three associated parameters (TP, chlorophyll (a) and transparency) are reported in the following Tab.3.

According to these TSI indices, the lake can be classified as mesotrophic to slightly eutrophic. The same finding was noted by the calculation according to the following diagram (Fig. 6).

In summary, the trophic status of the lake corresponds to a meso-eutrophic stage. This conclusion is based on the three indices that show low water transparency, average phytoplankton biomass and high total phosphorus concentrations.

Pearson correlation analysis of water quality parameters determined how eutrophication indicators correlated with IST in the reservoir (Islam *et al.* 2020). Thus, these coefficients show a strong correlation in wet years and a weak correlation in dry years (Vasilache *et al.* 2020). However, the approach to the trophic status of the El-Kansra dam, based on the overall average chlorophyll(*a)* and according to the classification of Vollenweider (1968), this dam is classifies as a Mesotrophic lake (Tab. 4).

Eutrophication dynamics

The typology of eutrophication in the 41 samples showed a seasonal trend between the nine variables (water temperature, pH, DO, Ec., Chl (a), Transp., PT, Iron, and Mn). The eigenvalues of the two components F1 and F2 and their contribution to the total inertia are shown in Fig. 7. The codes of the variables with a high correlation and their coordinates are shown in Tab. 5. The PCA eigenvalues, correlation circle and factor maps are shown in Fig. 7.

Table 3. The mean values and TSI of the three parameters (Transparency, Phosphorus, and Chlorophyll(a)).

	Total phosphorus (µg/L)	Chlorophyll(a) (µg/L)	Transparency (m)	**Average IST**
Average	560	6,700	1.46	568.08
TSI	68.3	32.6	49.9	**50.26**

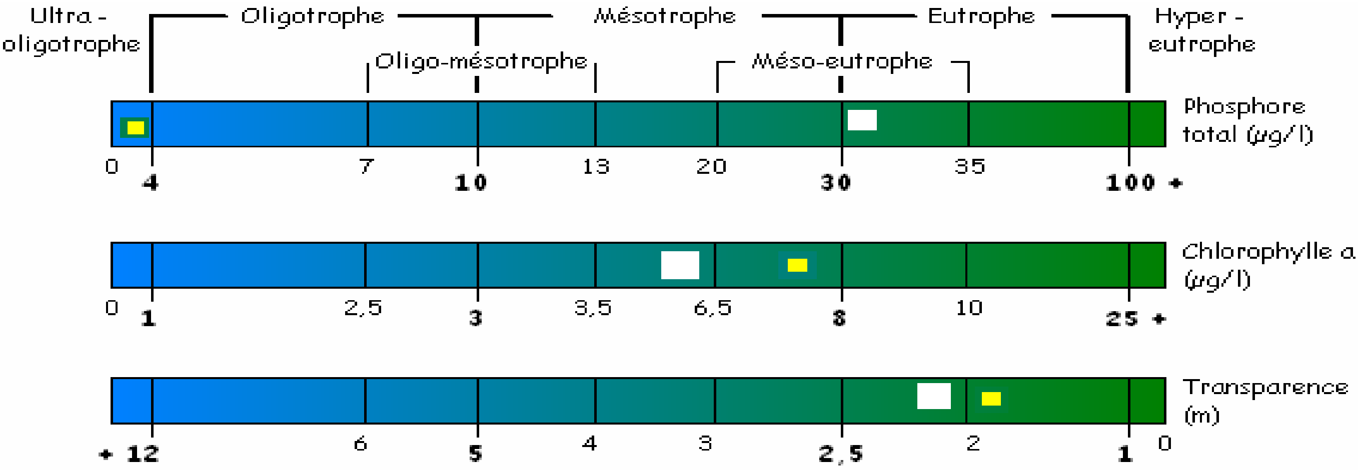

Figure 6. Diagram of the different trophic status of the parameters (Phosphorus, Chlorophyll(a), and transparency) (Concepcion II *et al.* 2020).

Table 4. Classification of lakes according to Vollenweider (1968),

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

Table 5. PCA code and correlations of variables with axes 1 and 2.

Site	Campagnes	Code	Variables	Axe 1	Axe 2
El Kansra	2005	1 à 6	Water temperature	-0.35	0.75
	2006	7 à 8	pH	-0.61*	0.51
	2007	9 à 13	O_2	-0.54*	0.02
	2008	14 à 18	Cond.	0.47	0.59*
	2009	19 à 22	Chl(a)	-0.37	-0.07
	2010	23 à 24	Transp.	-0.62*	0.01
	2011	25 à 27	PT	0,09	0,61*
	2012	28 à 32	Fer	0.56*	0.36
	2013	33 à 36	Mn	0.80*	0.03
	2014	37 à 39	-	-	-
	2015	40 à 14	-	-	-

Starred values (*) are significantly different from 0 at the alpha=0.05 significance level.

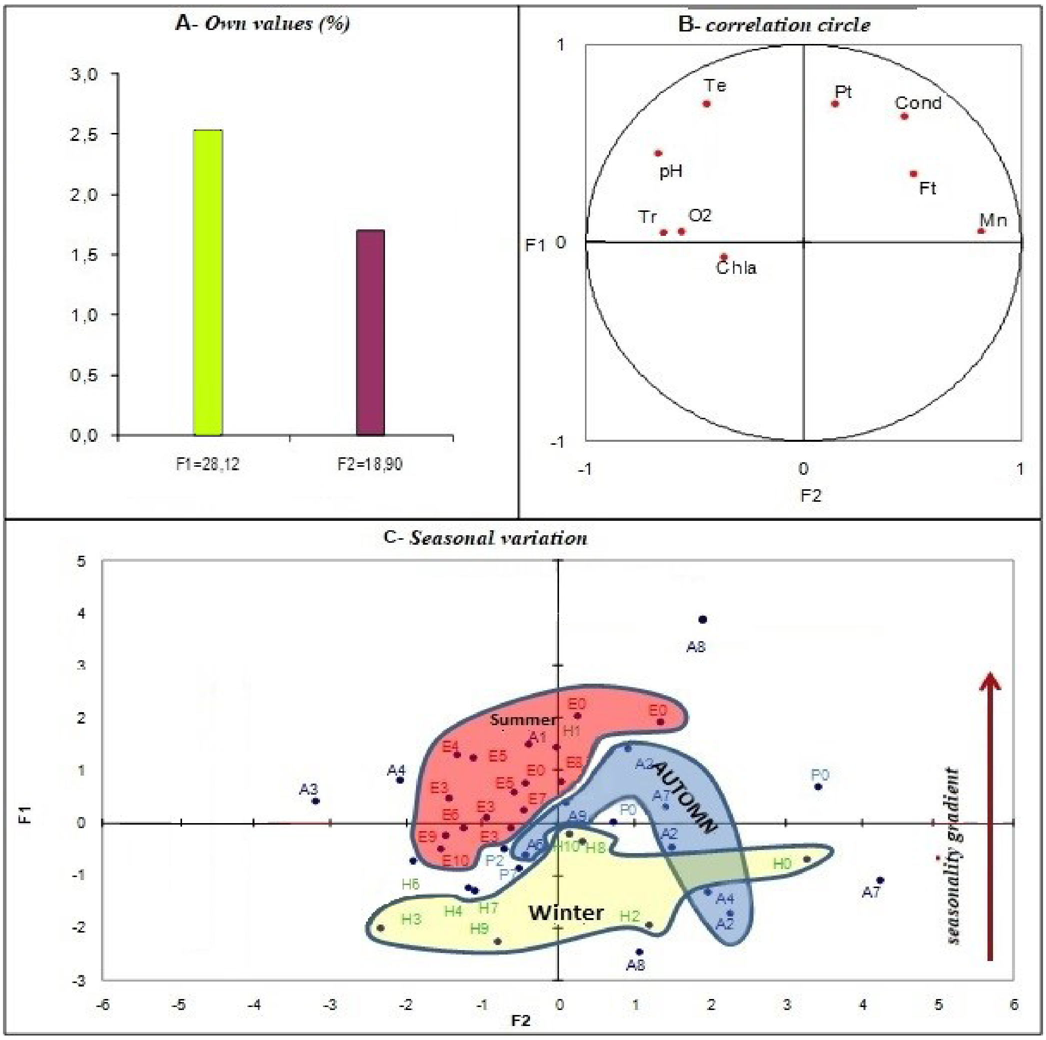

Figure 7. Graphical approach to PCA

A : Distribution of the inertia between the axes.
B : Correlation circles of variables.
C : Factual map of the campaigns.

The results of Tab. 4 and Fig. 7A allow a first typological approach of the different variables, according to their affinities and their groupings on the first two principal components based on their contribution. The first two axes determine 47.02% of the total information (28.12% for axis 1 and 18.90 % for axis 2). Examination of the correlation matrix between variables reveals the presence of set of variables made up of descriptors that are well correlated between waters, namely: pH/Te and Mn/Cond (Tab. 5).

The observation of the circle formed by the F1 and F2 axes shows, according to the F1 axis **(**horizontal**),** an opposition between waters strongly enriched in chlorophyll and well oxygenated (Tr, DO and Chl (a)), occupying the negative part of the axis and waters strongly charged with Mn and total iron occupying its positive part (Fig. 7B). This F1 axis defines two states of water quality:

- a state dominated by water rich in chlorophyll favored by good oxygenation leading to high water turbidity.
- an inverse state, marked by a lack of dissolved oxygen but with a high mineral load (Mn, iron), which generally corresponds to the summer and autumn periods.

Indeed, when the reservoir is stratified, an increase in Mn and Fe in the hypolomnion of the lake coincides with lower oxygen concentrations, as demonstrated in the study of Munger *et al.* (2017). Thus, oxygen replenishment leads to some oxidation of Mn and Fe in the epilimnion to achieve vertical homogenization of oxygen by brazing and flushing operations, which was confirmed by Munger *et al.* (2016). Otherwise, Mn and Fe concentrations are considerably lower during the stratification period (Munger *et al.* 2017). Other studies have observed high Fe concentrations during the winter and spring in other reservoirs due to increased water inflow (Blakar & Hongve 1997, Zaw *et al.* 2002, Giles *et al.* 2016).

The overall analysis allows us to define a typology dominated by the individualization of two clear seasons, namely winter (H) and summer (E), which have a dominant and determining tendency given the importance of the changes taking place during these latter seasons. In comparison to the other two seasons (autumn (A) and spring (P)), the evolution does not follow a particular tendency (Fig. 7C).

CONCLUSION

The stratification and water mass regime shows a monomictic water body with a thermal stratification that generally extends between April and November. The parameters of total phosphorus, chlorophyll (a) and Secchi disk transparency classify the El Kansra Dam reservoir in a meso-eutrophic state with a medium mesotrophic situation.

The seasonal and vertical analysis of the evolution of the different parameters in this dam allowed to identify the main qualitative and quantitative characteristics such as:

- ♦ a strong mineralization of the lake water,
- ♦ reduction of dissolved oxygen with installation of a summer stratification and total anoxia at depth during a certain period of the year.

The PCA showed a state dominated by waters rich in chlorophyll favored by the good oxygenation, leading to a high turbidity of the waters and an opposite state, marked by a deficit in dissolved oxygen but with a high mineral load (Mn, iron).

The trophic status of the dam, which evolves between mesotrophy and hypereutrophy depending on the period and year considered, is very descriptive and must be taken with great caution. It is a very estimated classification, especially in an arid climate, where the seasonal contrast is very important. The importance of exogenous (flood) and/or endogenous (sediment) inputs may overestimate the trophic status of this dam.

ACKNOWLEDGEMENTS

The authors would like to thank the editors of “Bulletin de l’Institut Scientifique, Section Sciences de la Terre” for all their hard work. They also thank the anonymous reviewers for their valuable comments and suggestions.

REFERENCES

Abdelhay A., Al Bsoul A., Al-Othman, A. *et al*. 2018. Kinetic and thermodynamic study of phosphate removal from water by adsorption onto (Arundo donax) reeds. *Adsorption Science and Technology*, 36(1–2), 46–61.

Aktas, A., Andreev V., Anthonis T. *et al*. 2007. Tests of QCD Factorisation in the Diffractive Production of Dijets in Deep-Inelastic Scattering and Photoproduction at HERA. *European Physical Journal*, C 51 (3), 549–68.

Ansari AA., Singh GS., Lanza GR. *et al*. (2010). Eutrophication: causes, consequences and control (vol. 1). Springer Verlag, Dordrecht, New York.

Asadian N., Chamani A., Hadi Abolhassani M., *et al*. 2020. The Trophic Status of the Zayandeh River Dam Lake in the Spring and Summer. *International Journal of Aquatic Biology*, 8 (3), 209–15.

Benateau S., Gaudard A., Stamm C. *et al*. 2019. Climate Change and Freshwater Ecosystems: Impacts on Water Quality and Ecological Status. Federal Office for the Environment (FOEN) and Eawag, Bern, 10.5167/uzh-169641.

Berrada D.F., Berrada R., Benzekri A. *et al*. 1999. Phytoplankton dynamics in relation to certain physico-chemical parameters in the El Kansra reservoir (Morocco). *Annales de Limnologie-International Journal of Limnology*, *EDP Sciences*, 35 (3), 155–166.

Binzer A., Guill C., Rall, B.C. *et al*. 2016. Interactive effects of warming, eutrophication and size structure: impacts on biodiversity and food-web structure. *Global Change Biology*, 22(1), 220–227.

Blakar I.A., & Hongve D. 1997. On the chemical water quality in Høylandet, a reference area for acidification research. *Hydrobiologia*, 348(1), 39–47.

Boehrer B. & Schultze M. 2008. Stratification of lakes. *Reviews of Geophysics*, 46(2), 18–26.

Bonin P., Gilewicz M., Bertrand JC. *et al*. 1989. Effects of Oxygen on Each Step of Denitrification on Pseudomonas Nautica. *Canadian Journal of Microbiology*, 35 (11), 1061–64.

Carlson G.P. & Harrold D.R. 1977. Relationship of protein concentration and water content of equine serum and plasma samples. *Veterinary Clinical Pathology*, 6(3), 18–20.

Chanudet V., Guédant P., Rode W. *et al*. 2016. Evolution of the Physico-Chemical Water Quality in the Nam Theun 2 Reservoir and Downstream Rivers for the First 5 Years after Impoundment. *Hydroécologie Appliquée*, 19, 27–61.

Chen K., Chen H., Zhou H. *et al*. 2020. Comparative analysis of surface water quality prediction performance and identification of key water parameters using different machine learning models based on big data. *Water research*, 171, 115454.

Cheng N., Wang B., Wu P. *et al*. 2021. Adsorption of emerging contaminants from water and wastewater by modified biochar: A review. *Environmental Pollution*, 273, 116448.

Concepcion II, RS., Loresco, PJ., Bedruz, RAR *et al*. 2020. Trophic state assessment using hybrid classification tree-artificial neural network. *International Journal of Advances in Intelligent Informatics*, 6(1), 46–59.

Cooke G., Eugene B., Peterson A. *et al*. 2005 1994?. Restoration and Management of Lakes and Reservoirs. *CRC press.*

Coulliette, AD. & Noble RT. 2008. Impacts of rainfall on the water quality of the Newport River Estuary (Eastern North Carolina, USA). *Journal of Water and Health*, 6(4), 473–482.

Derraz M., Dauta A., Capblancq J. *et al.* 1995. Influence de la lumière et de la température sur les taux de croissance et de photosynthèse de Scenedesmus crassus Chodat, isolée de la retenue El Kansera (Maroc). *Annales de Limnologie-International Journal of Limnology*, 31(1), 65–74.

Duan W., He B., Takara, K. *et al*. 2013. Spatiotemporal evaluation of water quality incidents in Japan between 1996 and 2007. *Chemosphere*, 93(6), 946–953.

Dumitran GE., Vuta LI., Popa B. *et al*. 2020. Hydrological Variability Impact on Eutrophication in a Large Romanian Border Reservoir, Stanca–Costesti. *Water (Switzerland)*, 12 (11), 1–23.

Duvil R., Beutel MW., Fuhrmann B. *et al*. 2018. Effect of oxygen, nitrate and aluminum addition on methylmercury efflux from mine-impacted reservoir sediment. *Water research*, 144, 740–751.

El Morhit M., & Mouhir L. 2014. Study of physico-chemical parameters of water in the Loukkos river estuary (Larache, Morocco). *Environmental Systems Research*, 3(1), 1–9.

Firoozi F., Roozbahani A., Massah Bavani AR. *et al*. 2020. Developing a Framework for Assessment of Climate Change Impact on Thermal Stratification of Dam Reservoirs. *International Journal of Environmental Science and Technology*, 17 (4), 2295–2310.

Galvez-Cloutier R., Sanchez M., 2007. Trophic Status Evaluation for 154 Lakes in Quebec, Canada: Monitoring and Recommendations. *Water Quality Research Journal of Canada*, 42 (4), 252–68.

Giles CD., Peter DF., Tom M. *et al*. 2016. The Mobility of Phosphorus, Iron, and Manganese through the Sediment–Water Continuum of a Shallow Eutrophic Freshwater Lake under Stratified and Mixed Water-Column Conditions. *Biogeochemistry,* 127 (1), 15–34.

Halim H., Simon J., Lieberwirth I. *et al.* 2020. Water-dispersed semiconductor nanoplatelets with high fluorescence brightness, chemical and colloidal stability. *Journal of Materials Chemistry B*, 8(1), 146–154.

Herawati M., Endang Y., Ruly I. *et al*. 2020. The Effect of Hydro-Oceanographic Factors on the Community Structure of Plankton in Natural and Artificial Coral Reefs in Paiton Waters. *AACL Bioflux*, 13 (1), 71–85.

Islam ARMT., Al Mamun A., Rahman MM. *et al*. 2020. Simultaneous comparison of modified-integrated water quality and entropy weighted indices: implication for safe drinking water in the coastal region of Bangladesh. *Ecological Indicators*, 113, 106229.

Ihnken S., Beardall J., Kromkamp JC. *et al*. 2014. Light acclimation and pH perturbations affect photosynthetic performance in Chlorella mass culture. *Aquatic Biology*, 22, 95–110.

Jane SF., Gretchen JA., Benjamin M. *et al*. 2021. Widespread Deoxygenation of Temperate Lakes. *Nature*, 594 (7861).

Janjua MY., Ahmad T., Akhtar N. *et al*. 2009. Limnology and Trophic Status of Shahpur Dam Reservoir, Pakistan. *Journal of Animal and Plant Sciences*, 19 (4), 217–23.

Jin Z., Lv J., Jia H. *et al*. 2019. Nanoporous Al-Ni-Co-Ir-Mo high-entropy alloy for record-high water splitting activity in acidic environments. *Small*, 15(47), 1904180.

Kaup E. 2005. "Developmnet of Anthropogenic Eutrophication in Lakes of the Schirmacher Oasis. Antarctica." Verh. Internat. Verein. Limnol 29: 678–82.

Kuperman WA., D'spain GL., Song HC. *et al*. 2002. The generalized waveguide invariant concept with application to vertical arrays in shallow water. *In AIP Conference Proceedin*g, 621(1), 33–66). American Institute of Physics.

Labrecque LI., & Milne GR. 2012. Exciting red and competent blue: the importance of color in marketing. *Journal of the Academy of Marketing Science*, 40(5), 711–727.

Lee S., Cho HJ., Choi W. *et al.* 2018. Organophosphate flame retardants (OPFRs) in water and sediment: Occurrence, distribution, and hotspots of contamination of Lake Shihwa, Korea. *Marine pollution bulletin*, 130, 105–112.

Le Moal M., Gascuel-Odoux C., Ménesguen A. *et al.* 2019. Eutrophication: a new wine in an old bottle?. *Science of the Total Environment*, 651, 1–11.

Liu C., Shiyan W., Liang W. *et al*. 2021. Characteristics and Driving Factors of Thermal Stratification Evolution in Daheiting Reservoir. E3S Web of Conferences, 261.

Maavara T., Chen Q., Van Meter K. *et al*. 2020. River dam impacts on biogeochemical cycling. *Nature Reviews Earth & Environment*, 1(2), 103–116.

Moss B., Kosten, S. Meerhoff M. *et al*. 2011. Allied attack: climate change and eutrophication. *Inland waters,* 1(2), 101–105.

Munger ZW., W., Thomas D., Madeline E. *et al*. 2017. Effects of Reservoir Stratification and Watershed Hydrology on Manganese and Iron in a Dam-Regulated River. *Hydrological Processes*, 31 (8), 1622–35.

Munger ZW., Carey CC., Gerling AB., *et al*. 2016. Effectiveness of hypolimnetic oxygenation for preventing accumulation of Fe and Mn in a drinking water reservoir. *Water Research*, 106, 1–14.

Nõges P., Argillier C., Borja Á. *et al*. 2016. Quantified biotic and abiotic responses to multiple stress in freshwater, marine and ground waters. *Science of the Total Environment*, 540, 43–52.

Odagiri M., Cronin AA., Thomas A., *et al*. 2020. Achieving the Sustainable Development Goals for water and sanitation in Indonesia–Results from a five-year (2013–2017) large-scale effectiveness evaluation. *International Journal of Hygiene and Environmental health*, 230, 113584.

ONEP 1989. [Intervention of the" ONEP" [Office National de l'Eau Potable, National Office of Drinking Water] in the rural centers]. *Revue Marocaine des Sciences Agronomiques et Veterinaires*.

O'Reilly CM., Sharma S., Gray DK. *et al*. 2015. Rapid and highly variable warming of lake surface waters around the globe. *Geophysical Research Letters*, 42(24), 10–773.

Pawar RS., Zambare NS., VM W. *et al*. 2020. a review of eutrophication. *UGC CARE Journa,*40(88), 1–3.

Pitoi MM., Ariyani M., Agustini Koesmawati T. *et al.* 2019. Pyrethroids Residues Analysis in Indonesian Commercial Tea by GC-ECD, *AIMS Agriculture and Food*, 4 (2), 447–57.

Quevedo C., Alberto ER., Bandala JG. *et al*. 2019. Temporal and Spatial Study of Water Quality and Trophic Evaluation of a Large Tropical Reservoir. *Environments*, 6 (6), 61.

Rast W. & Thornton JA. 1996. Trends in eutrophication research and control. *Hydrological processes*, 10(2), 295–313

Shekha YA., Yahya A., Luay Abdul Qader A. *et al*. 2017. Assessment of Water Quality and Trophic Status of Duhok Lake Dam. *Baghdad Science Journal*, 14 (2), 335–42.

Valerio C., De Stefano L., Martínez-Muñoz G. *et al*. 2021. A machine learning model to assess the ecosystem response to water policy measures in the Tagus River Basin (Spain). *Science of the Total Environment*, 750, 141252.

Vasilache N., Diacu E., Gabriela V. *et al*. 2020. Groundwater quality assessment for drinking and irrigation purpose using GIS, Piper diagram, and water quality index. *Romanian Journal of Ecology & Environmental Chemistry*, 2(2), 109–117.

Van Belle J., Barendregt A., Schot P. *et al*. 2006. The effects of groundwater discharge, mowing and eutrophication on fen vegetation evaluated over half a century. *Applied Vegetation Science*, 9(2), 195–204.

Vollenweider RA 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication. Organisation for Economic Cooperation and Development, Technical Report DAS/CSI/68.27, Paris

Winton RS., Calamita E., & Wehrli B. 2019. Reviews and syntheses: Dams, water quality and tropical reservoir stratification. *Biogeosciences,* 16(8), 1657–1671.

Woolway RI. & Merchant CJ. 2019. Worldwide alteration of lake mixing regimes in response to climate change. *Nature Geoscience*, 12(4), 271–276.

Yan Q., Bi Y., Deng Y. *et al*. 2015. Impacts of the Three Gorges Dam on Microbial Structure and Potential Function. *Scientific Reports*, 5, 1–9.

Yankova Y., Neuenschwander S., Köster O. *et al*. 2017. Abrupt stop of deep water turnover with lake warming: Drastic consequences for algal primary producers. *Scientific Reports*, 7(1), 1–9.

Yin Q., Wang R., Zhao Z. *et al*. 2018. Application of Mg–Al-modified biochar for simultaneous removal of ammonium, nitrate, and phosphate from eutrophic water. *Journal of Cleaner Production*, 176, 230–240.

Zaw M. & Emett M. T. 2002. Arsenic removal from water using advanced oxidation processes. *Toxicology Letters*, 133(1), 113–118.

Zbierska Z., Agnieszka J., Ławniczak E. *et al*. 2015. Changes in the Trophic Status of Lake Niepruszewskie (Poland). *Journal of Ecological Engineering*, 16 (4), 65–73.

Manuscrit reçu 06/01/2022
Version révisée acceptée le 09/06/2022
Version finale reçue le 13/06/2022
Mise en ligne le 14/06/2022