EFFECT OF CLIMATIC FACTORS ON THE EVOLUTION OF WATER OXYGENATION OF THE KEDDARA DAM (BOUMERDES, ALGERIA)

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Abstract. The Mediterranean region is renowned for its notable climate variability, which can impact the physico-chemical properties of dam waters. Throughout the research conducted from January 2002 to March 2021 at the Keddara dam in Algeria, it was observed that the average air temperatures (Ta), minimum (T min), and T maximum (Tmax) experienced an increase of 0.783°C, 0.942°C, and 0.35°C, respectively. Conversely, precipitation (RF) exhibited a decrease of 2.77 mm, while humidity (H), mean wind speed (WM), and visibility (VV) demonstrated an increase. The variance analyses revealed significant temporal fluctuations in the oxygen-related parameters within the water. Statistical models indicated that both temperature and water volume of the dam negatively impacted water oxygenation, nutrients (NO2, NH4, PO4), and algal activity. Conversely, precipitation, humidity, wind, and visibility exerted a positive influence on the oxygenation process. A notable positive correlation was identified between dissolved oxygen and nitrates.
Keywords: *Mediterranean, hydrology, ecosystem, freshwater, statistics, modelling*

Introduction

A dammed lake is a dynamic aquatic environment that chemical, physical and biological properties all influence and interact with each other. They are dynamic systems that change from year to year. Many phenomena linked to the chemical constitution of the lake are involved, in particular the distribution of oxygen, which is a fundamental element for life and can have a considerable influence on the lake health (Jorgensen, 2009; Ramade, 2012). The concentration of dissolved oxygen in water results from physical, chemical and biological parameters. The supply of oxygen

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constitutes a significant part of the operating costs of a biological treatment plant (Rodier et al., 2009). Most mitigation measures for increased dissolved oxygen in dam waters are quite expensive. The current state of low oxygen levels in continental aquatic ecosystems has become a major problem associated with major changes in climatic factors that are substantially modifying the physical and chemical environment of lakes (Hanson et al., 2003; Jane et al., 2021; Rose et al., 2016; Williamson et al., 2008).

According to the Global Lake Ecological Observatory Network, since 1980, lakes have been losing oxygen at an average rate of 5.5% in surface waters. Since the 1980s, due to climate change driven by our greenhouse gas emissions, the average surface water temperature of lakes has increased by 0.38°C per decade, while oxygen concentration has decreased by 0.11 mg/L per decade (Jane et al., 2021; INRAE, 2021; GLEON, 2022).

Algeria is an important Mediterranean country in Africa and the world, with a great wealth of natural resources but faced with numerous socio-economic, environmental and ecological challenges. These challenges are exacerbated by global and regional issues, such as climate change (Ersoy and Terrapon-Pfaff, 2021; Negm et al., 2020; Touitou and Abul Quasem, 2018). In water resources management, water quality plays as important role as water quantity. The Algerian authority has encountered serious problems in the management of its water resources; However, academics and specialized engineers have paved the way with integrated solutions for decision-makers to address these issues and make the right decisions to achieve sustainable management of these vital resources (Ersoy and Terrapon-Pfaff, 2021; Ferrah and Oubelli, 2013; Negm et al., 2020). In the scientific literature, we have noted that in Africa and particularly Algeria, there is a lack of study on the effect of climate change on the oxygenation of lakes and dams (Bernus, 2022; Lambs and Labiod, 2009; Messerer et al., 2019; Woolwayet al., 2022). This study is based on the continental aquatic ecosystem evoking an important source of drinking water for the inhabitants of the Algerian capital and its surroundings, the Keddara dam. The latter has an estimated capacity of 145 (hm3). The fill rate was 45.68% in 2000 and suffered a sharp reduction of 19.96% in 2022 (Attou, 2014; Touati, 2010). This is due to drought aggravated by climate change observed in recent years (ANBT, 2022; ONM, 2022). The main objective of our study was to detail and demonstrate the impact of climatic factors on the oxygenation of water from the Keddara dam (Algeria) for a period from 2002 to 2021.

Material and methods

The Keddara dam is located in the province of Boumerdes (Algeria) in the coastal chain of the Atlas Tellien (*Fig. 1*). Located at an average altitude of 466 m at 36°65’ N and 3°43’ E, it has a volume of 145.6 hm3 of water for an area of 5.2 km² at its maximum high limit. Its average depth is 28.5 m; the maximum depth at the dam is 150 m and it is located in the “sub-humid bioclimatic stage with temperate winter” (Attou, 2014; Attou and Arab, 2019).

Water oxygen parameter data DO (dissolved oxygen in mg/l), SO (dissolved oxygen saturation rate in %), BOD5 (Five-Day Biochemical Oxygen Demand in mg/l), COD (Chemical Oxygen Demand in mg/l) and Water T (water temperature in °C), nutritive parameters (NO2 in mg/l, NO3 in mg/l, NH4 in mg/l and PO4 in mg/l) and algae abundancy (U/ml) were collected at the SEAAL and ANRH laboratories over a period from December 2002 to March 2021. Therefore, hydrological parameter (total volume of water VLM m^3) was provided by the dam administration.

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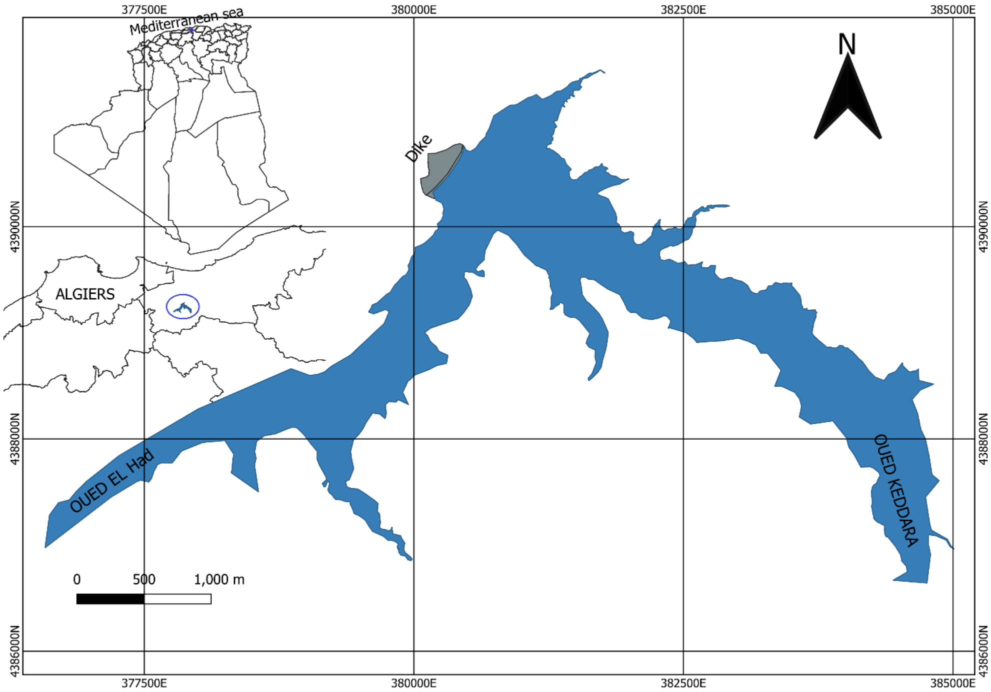

Figure 1. *Geographical location and delimitation of the Keddara dammed lake*

Climatic data represented by Ta (average air temperature in °C), Tmin (minimum air temperature in °C), Tmax (maximum air temperature in °C), PP (rainfalls in mm), H (Average relative humidity in %), V (Average wind speed in Km/h), VM (Maximum sustained wind speed in Km/h), VV (average visibility in Km) and AP (Atmospheric Pressure in hPa) were recovered from the tutiempo site (2022) over the same study period. The quality levels given by ANRH are represented in *Table 1*.

Table 1. *Water's physical and chemical parameters' quality levels (ANRH)*

Parameters	Unit	Excellent	Good	Fair or average	Mediocre or bad	Excessive or very bad pollution
Dissolved oxygen	mg/l	7	5 to 7	3 to 5	<3	—
Oxygen saturation rate	%	90	70 to 90	50 to 70	<50	—
BOD5	mg/l	—	5	5 to 10	10 to 15	sup 15
COD	mg/l	—	20	20 to 40	40 to 50	sup 50

The statistical tests used in this work are: the parametric analysis of variance to discuss the significance of temporal variability and the effect of the year, month and season on the variation of the different parameters. We applied the Principals Corposants Analysis (PCA) and numeric correlation matrix to highlight the relationships between climatic, hydrological, biological and physico-chemical factors of dam water. We used a generalized linear model (GLM) to identify the climatic parameters influencing the oxygenation levels of the dam waters. A redundancy analysis (RDA) was carried out taking into account years, months and seasons and using climate data as an explanatory model. Significance was tested by the Monte Carlo permutation test. The various analyzes were carried out using the R language (Cran, 2024).

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Results

Variability of the climatic parameters

According to the time factor (years, months and seasons) illustrated in *Table 2*, *Figures 2* and *3*: Ta, Tmin and Tmax as well as rainfalls, maximum wind speed and atmospheric pressure, we note that there is not a great difference between the annual averages recorded with a non-significant statistical test (*Table 2*, *p*-value > 5%). However, there is some significant variability for relative humidity, average wind speed and visibility (*Table 2*, *p*-value < 5%).

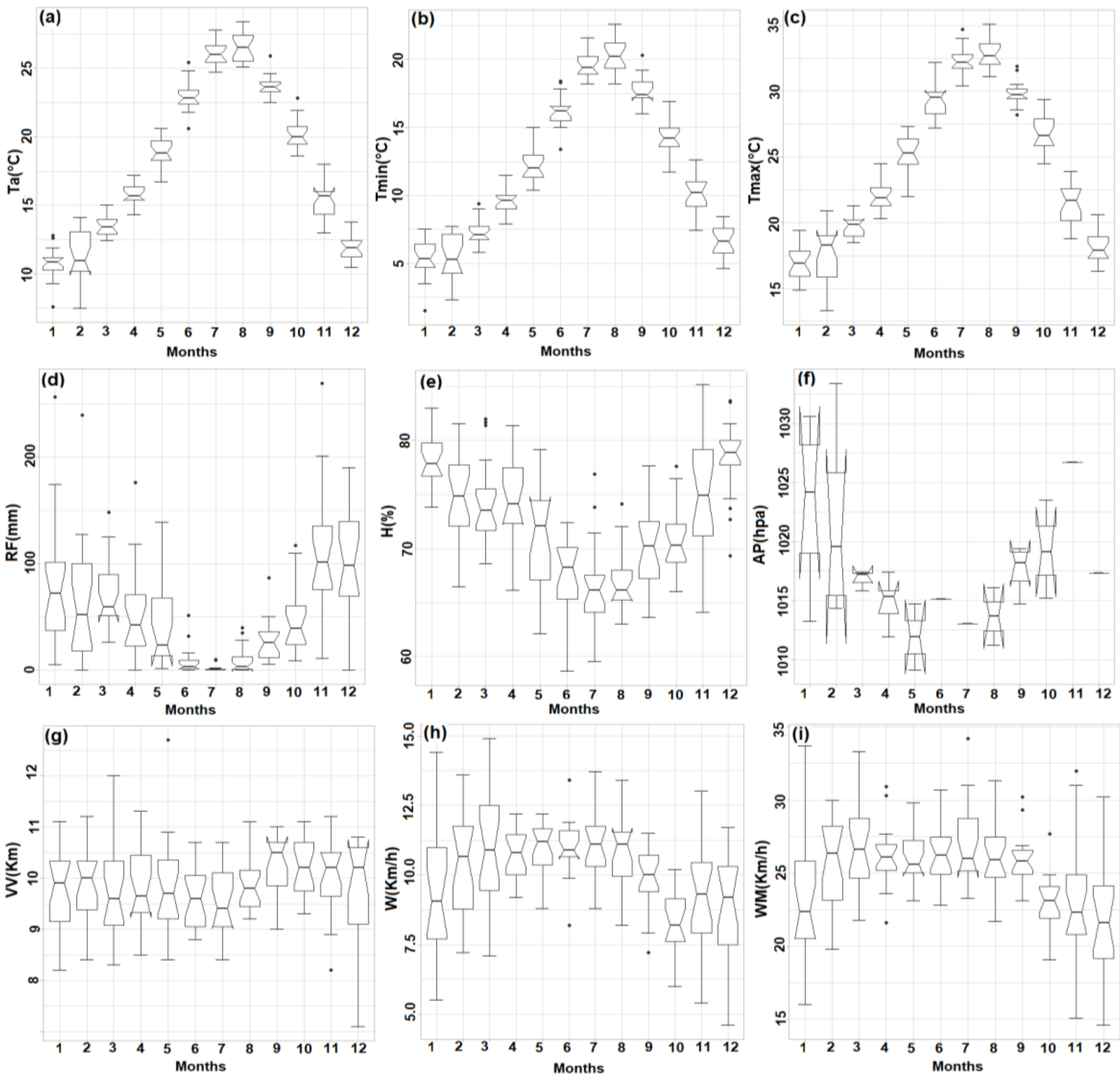

Figure 2. *Monthly evolution of climatic parameters during the period 2002-2021 in the Keddara region (Boumerdes, Algeria). Ta: Temperature average (°C); Tmin: Temperature minimal (°C); Tmax: Temperature maximal (°C); RF: Runfful (mm); H: Humidity (%); AP: Atmospheric pression (hpa); VV: Visibility (Km); W: average wind (Km/h); WM: maximum wind (Km/h)*

On the other hand, for all climatic variables, the monthly and seasonal fluctuations are remarkable and significant (*Table 2*, *p*-value < 5%). Except for the monthly

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variations in visibility and atmospheric pressure which are not significant (*Table 2*, *p*-value > 5%).

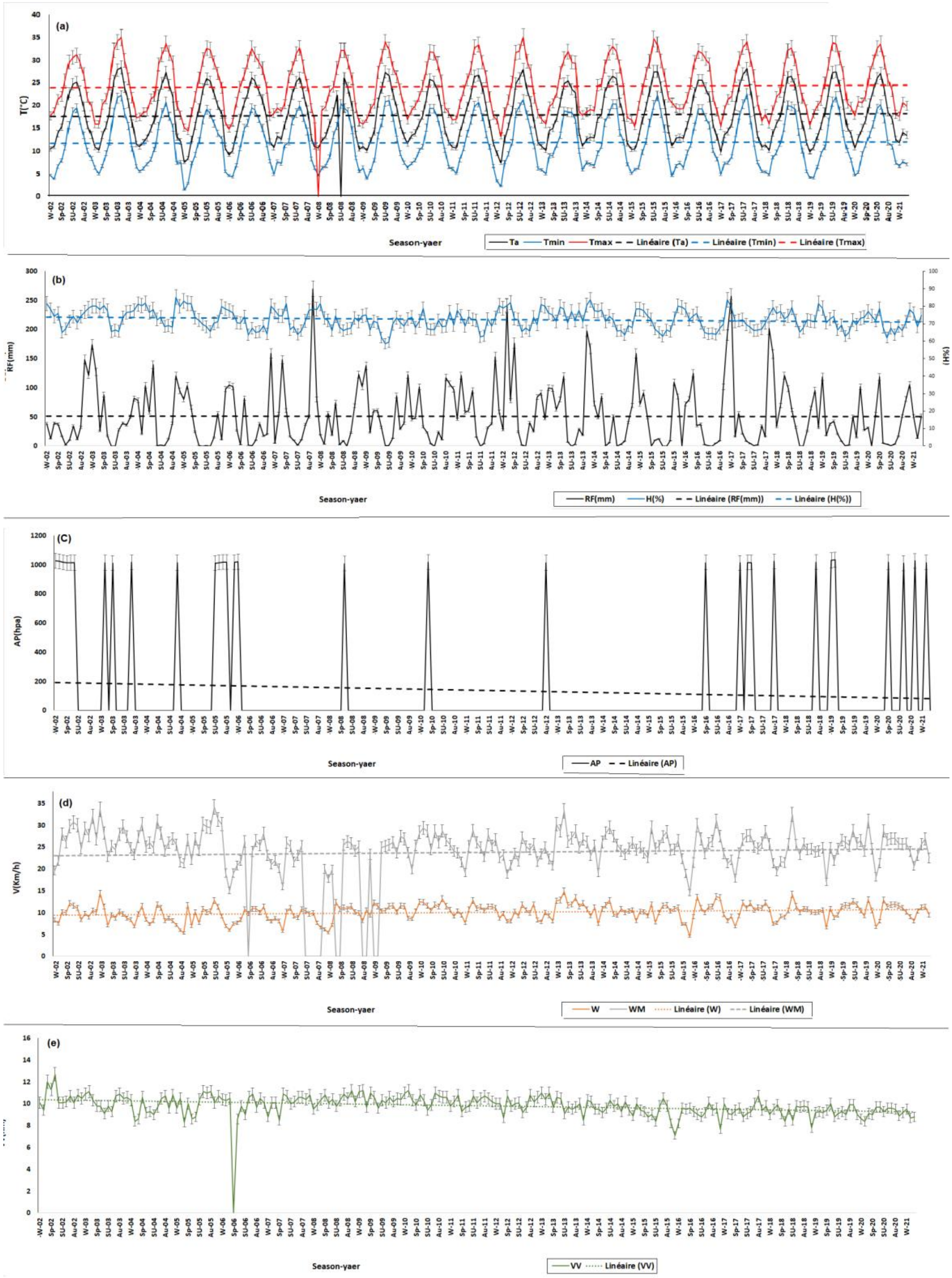

Figure 3. *Seasonal evolution of climatic parameters during the period 2002-2021 in the Keddara region (Boumerdes, Algeria). Ta: Temperature average (°C); Tmin: Temperature minimal (°C); Tmax: Temperature maximal (°C); RF: Runfful (mm); H: Humidity (%); AP: Atmospheric pression (hpa); VV: Visibility (Km); W: average wind (Km/h); WM: maximum wind (Km/h)*

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Table 2. *Statistical summary of the physical-chemical parameters of the water from the Keddara dam (SEAAL 2002-2021)*

Years	DO	SO	BOD5	COD	TW	Ta	Tmin	TMax	RF	H	W	WM	VV	AP
2002	6.328±0.457	93.617±12.516	1.983±0.345	27.25±2.970	19.871±1.499	17.842±1.516	11.333±1.536	24.567±1.425	42.162±13.181	73.967±1.382	9.900±0.399	27.242±1.055	10.667±0.268	1018.6±2.244
2003	7.411±0.62	93.697±6.911	2.000±0.213	15.000±1.059	15.403±0.636	18.533±1.904	12.733±1.799	24.500±2.00	55.756±15.314	74.825±1.657	9.708±0.594	27.100±0.912	10.233±0.19	1014.5±1.562
2004	5.788±0.666	86.589±4.706	1.683±0.298	16.458±1.947	15.529±0.592	17.800±1.716	11.65±1.569	24.225±1.796	55.92±14.517	76.2±1.674	8.542±0.597	25.617±0.755	9.725±0.243	1014.700
2005	6.23±0.659	85.878±4.246	1.458±0.212	20.133±1.906	13.354±0.301	17.483±1.861	11.300±1.713	23.992±1.919	38.016±11.656	74.567±1.725	9.167±0.605	25.983±1.72	10.017±0.286	1016.9±1.124
2006	7.074±0.548	84.548±4.591	1.882±0.383	17.336±3.423	17.282±1.08	18.242±1.701	12.292±1.569	24.642±1.753	47.072±15.044	70.275±1.604	9.442±0.386	23.667±0.744	10.036±0.213	1020.9
2007	8.958±0.239	86.847.342	1.736±0.278	16.992±2.234	13.933±0.225	17.567±1.608	12.017±1.49	23.725±1.606	62.184±22.349	73.258±1.671	8.892±0.539	23.308±0.927	10.142±0.219	NA
2008	7.835	NA	1.49±0.253	11.655±1.699	13.286	17.775±1.672	11.900±1.664	24.000±1.623	41.701±12.118	71.258±1.315	9.808±0.567	24.208±0.904	10.333±0.139	1009.1
2009	6.452±0.696	NA	2.391±0.624	19.842±4.668	15.118±0.543	18.108±1.754	11.892±1.713	24.583±1.768	50.546±12.984	68.242±1.575	10.742±0.332	25.333±0.629	10.442±0.146	NA
2010	6.201±0.833	NA	2.818±0.501	8.308±0.435	15.525±0.564	17.900±1.478	12.017±1.387	23.858±1.553	51.011±12.443	70.608±1.149	11.217±0.352	26.350±0.719	10.475±0.154	1017.400
2011	6.169±0.841	NA	5.467±1.51	8.617±2.013	15.611±0.676	18.275±1.672	12.475±1.555	24.425±1.693	56.96±13.413	71.608±1.528	10.375±0.443	24.300±0.894	10.192±0.136	NA
2012	5.114±0.854	NA	NA	NA	14.982±0.621	17.917±1.948	11.975±1.849	24.242±2.014	69.68±20.912	74.142±1.772	9.625±0.400	23.492±0.588	9.983±0.174	1015.2
2013	5.242±0.842	NA	NA	NA	15.956±0.802	17.550±1.633	11.867±1.504	23.417±1.698	73.743±18.989	76.083±1.212	11.658±0.553	26.65±1.023	9.975±0.219	NA
2014	5.164±0.691	NA	3.045±0.59	21.667±3.675	16.408±0.557	18.667±1.584	12.525±1.498	25.017±1.651	45.508±13.682	71.742±1.519	10.425±0.332	25.692±0.547	9.775±0.118	NA
2015	5.936±0.751	76.3±6.4	2.415±0.384	14.542±2.42	14.445±0.429	18.225±1.838	12.042±1.78	24.958±1.809	36.553±12.131	71.842±1.809	9.517±0.655	24.117±1.195	9.100±0.266	NA
2016	7.951±1.27	NA	3.091±0.53	15.364±2.725	17.138±0.639	18.467±1.5	12.250±1.398	24.792±1.546	55.013±17.486	70.817±1.812	10.625±0.633	24.800±1.108	9.167±0.192	1015.300
2017	9.800	99.367±10.653	2.222±0.465	23.667±3.801	14.457	18.300±1.802	11.95±1.743	24.617±1.823	64.706±25.643	71.392±1.331	10.425±0.480	24.850±0.812	9.517±0.155	1017.075±2.228
2018	6.548±0.837	104.77±8.085	2.273±0.407	16.000±2.040	17.351±0.975	17.958±1.669	12.017±1.619	23.917±1.651	52.92±11.25	73.392±1.331	10.383±0.499	24.442±1.007	9.225±0.195	1019.400
2019	7.586±0.589	104.308±6.408	2.917±0.839	18.833±2.510	17.888±1.233	18.258±1.784	12.083±1.79	24.517±1.796	36.975±10.903	70.675±1.283	10.975±0.372	25.850±0.671	9.342±0.113	1032±1.400
2020	5.722±0.68	102.897±8.273	2.182±0.296	7.958±0.780	18.038±0.905	18.625±1.565	12.275±1.474	25.050±1.573	39.39±12.364	70.55±1.605	10.275±0.543	24.500±0.898	9.217±0.125	1018.433±4.504
2021	10.344±1.22	91.433±7.495	3.333±1.453	9.667±2.906	13.632±0.474	13.167±0.657	7.167±0.291	19.4±0.929	38.78±12.786	72.967±2.305	10.667±0.584	25.033±1.313	9.000±0.252	1015.8
P-value	The parametric analysis of variance results (α = 5%)													
Years	0.042	0.366	0.001	$0.036\ 10^{-5}$	$0.042\ 10^{-4}$	1	1	1	0.966	0.018	0.001	0.07154	0.09252e-11	0.098
Months	<2.2e-16	9.702e-10	0.707	0.181	<2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16	4.762e-10	3.543e-10	0.124	0.209
Seasons	2.639e-16	$0.070\ 10^{-5}$	$0.079\ 10^{-3}$	0.151 10-3	<2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16	0.0018	8.316e-15	$0.043\ 10^{-6}$	$0.056\ 10^{-4}$	2.047e-10	$0.765\ 10^{-3}$

DO: dissolved oxygen (mg/l); SO: dissolved oxygen saturation rate (%): BOD5: Five-Day Biochemical Oxygen Demand (mg/l); COD: Chemical Oxygen Demand (mg/l); TW: water temperature (°C); Ta: Temperature average (°C); Tmin: Temperature minimal (°C); Tmax: Temperature maximal (°C); RF: Runfful (mm); H: Humidity (%); AP: Atmospheric pression (hpa); VV: Visibility (Km); W: average wind (Km/h); WM: maximum wind (Km/h)

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Variability of water temperature and oxygen parameters of dam water

For the annual averages (*Table 2*) of water temperature, DO, BOD5 and COD show strong significant fluctuations (*Table 2, p*-value < 5%). However, there is some non-significant variability for SO (*Table 2, p*-value < 5%). Monthly (*Fig. 4*) and seasonal (*Fig. 5*) fluctuation averages are remarkable and significant for water temperature and oxygenation parameters (*Table 2*, *p*-value < 5%). Except for the monthly variations in BOD5 and COD which are not significant *(Table 2*, *p*-value > 5%).

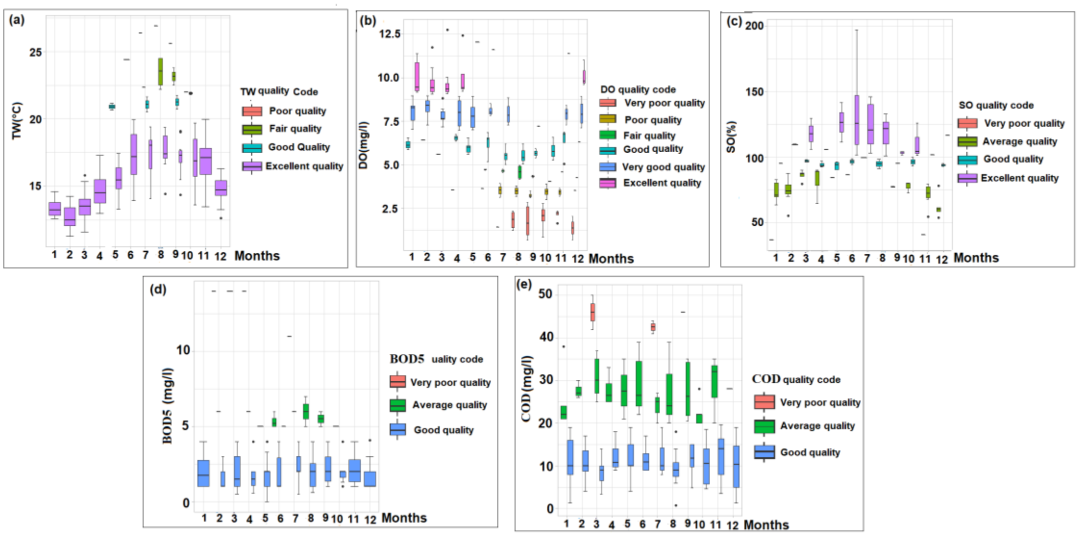

Figure 4. *Monthly evolution of water temperature and water oxygen parameters during the period 2002-2021 in the Keddara dam (Boumerdes, Algeria). TW: water temperature (°C); DO: dissolved oxygen (mg/l); SO: dissolved oxygen saturation rate (%): BOD5: Five-Day Biochemical Oxygen Demand (mg/l); COD: Chemical Oxygen Demand (mg/l)*

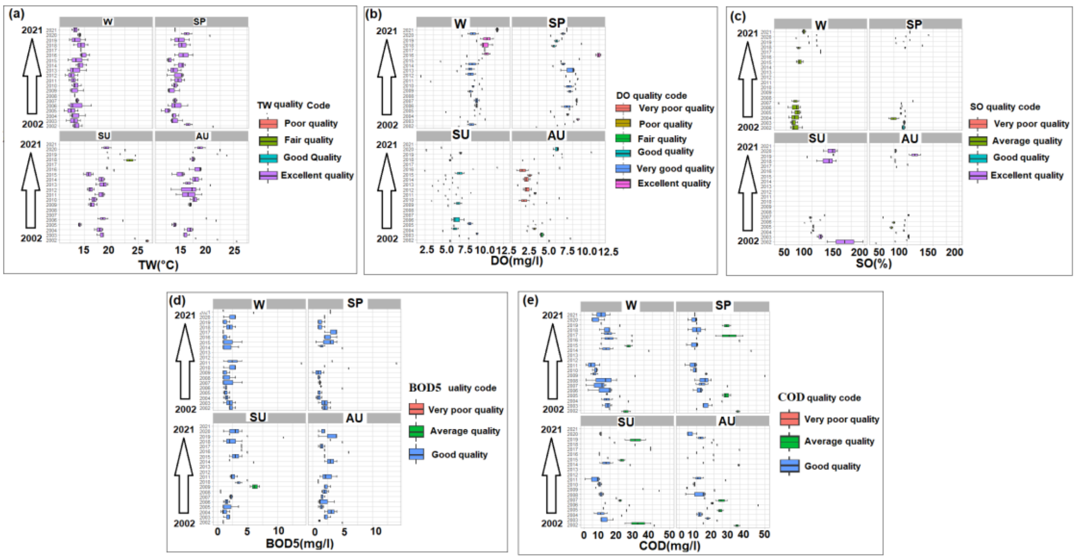

Figure 5. *Seasonal evolution of water temperature and water oxygen parameters during the period 2002-2021 in the Keddara dam (Boumerdes, Algeria). TW: water temperature (°C); DO: dissolved oxygen (mg/l); SO: dissolved oxygen saturation rate (%): BOD5: Five-Day Biochemical Oxygen Demand (mg/l); COD: Chemical Oxygen Demand (mg/l)*

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Relationships between climatic, hydrological, biological and physico-chemical factors of dam water

The Principal Component Analysis and the numerical correlation matrix establish the connections among the factors of climate, hydrology, biology, and physicochemistry of the waters of the Keddara dam spanning from January 2002 to March 2021. The PCA yielded a comprehensive explanation of 63.09% of the data. Axis 1 (44.62%) reveals a positive correlation among Tw, T, Tmin, and Tmax, while they are inversely related to Od, PP, H, and SLP. Axis 2 (18.47%) elucidates the VM parameters, with V showing a positive correlation to Od. Additionally, a distinct cluster characterized by nitrogen nutrients NO2, NO3, NH4, and PO4 is linked to the water volume of the dam VLW and VV (*Fig. 6A*). The clustering of individuals predominantly exhibits a seasonal activity (*Fig. 6B*).

According to the correlation matrix, a notable positive correlation exists among (NH4, NO2, PO4 with Algae), (NH4, PO4 with H), and (DO with NO3). Conversely, there is a significant negative correlation between (NH4, NO2, NO3, PO4, Algae) with (Twater, T, Tmin, Tmax, VLW) (*Fig. 6C*).

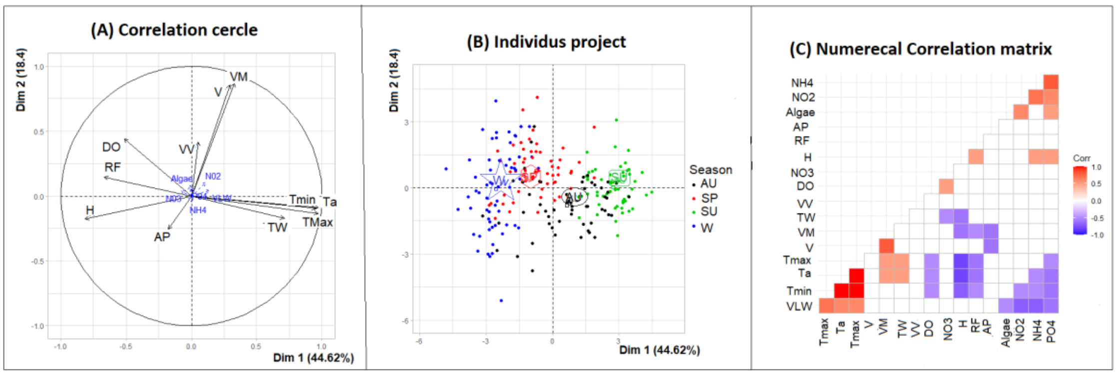

Figure 6. *Relationships between climatic, hydrological, biological and physico-chemical factors in dam water (Keddara dam, January 2002-March 2021). DO: dissolved oxygen (mg/l); SO: dissolved oxygen saturation rate (%): BOD5: Five-Day Biochemical Oxygen Demand (mg/l); COD: Chemical Oxygen Demand (mg/l); TW: water temperature (°C); NO2: Nitrite (mg/l); NO3: Nitrate (mg/l); NH4: Ammoniac (mg/l); PO4: phosphor (mg/l): Algae abundancy (U/ml; VLM: Total volume of water (m^3); Ta: Temperature average (°C); Tmin: Temperature minimal (°C); Tmax: Temperature maximal (°C); RF: Runfful (mm); H: Humidity (%); AP: Atmospheric pressure (hpa); VV: Visibility (Km); W: average wind (Km/h); WM: maximum wind (Km/h)*

Analysis with GLM model: effect of climatic parameters on the oxygenation levels of the dam water

The effect of TW is negative for DO, BOD and COD but statistically not significant (p-value > 5%). It is significantly positive for SO (*Table 3*, p-value < 5%). The temperatures Ta, Tmin and Tmax present the same effects as the water temperature, except that the test of the effects shows that it is significant for Ta on DO, SO and BOD, for Tmin on DO and SO and for Tmax on SO (*Table 3*, p-value < 5%). Rainfalls and relative humidity positively influence DO, BOD and COD. This influence is significant between RF and DO and between H, DO and BOD. The two climatic parameters act

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significantly and negatively on SO (*Table* 3, *p*-value < 5%). On the other hand, V and VM present a positive and significant influence for DO and SO. This effect is negative for BOD, statistically significant between V and BOD and not significant between VM and BOD. While for DCO the effect is not significant. It is positive for V and negative for VM (*Table 3, p*-value > *5%*). Finally, VV and AP present a non-significant effect on the oxygenation levels of the dam water (*Table 3, p*-value > *5%*).

Table 3. *Statistical results of the generalized linear model (GLM)*

GLM		Levels DO		Levels SO		Levels DBO		Levels DCO	
Model parameters		**I**	**P**	**I**	**P**	**I**	**P**	**I**	**P**
TW	E	0.015708	0.014873	0.535	-0.012	0.335	0.0008	0.326	0.003
	Pr (>|t|)	0.689	0.181 10^{-7}	<2e-16	0.081 10^{-3}	<2e-16	0.484	<2e-16	0.102
Ta	E	0.090	0.009	0.552	-0.010	0.326	0.001	0.347	0.001
	Pr (>|t|)	1.42e-05	5.31e-13	<2e-16	2.23e-10	<2e-16	<2e-16	<2e-16	0.098
Tmin	E	0.136	0.010	0.487	-0.011	0.333	0.0011	0.357	0.001
	Pr (>|t|)	<2e-16	.97e-14	<2e-16	0.01 10^{-7}	<2e-16	0.0637	<2e-16	0.128
Tmax	E	0.034456	0.009	0.614	-0.011	0.319	0.001	0.337	0.002
	Pr (>|t|)	0.203	4.01e-13	<2e-16	3.96e-10	<2e-16	0.053	<2e-16	0.085
RF	E	0.273	-0.044 $10{-}2$	0.308	0.09 10^{-2}	0.352	-0.09 $10{-}3$	0.381	-0.0001
	Pr (>|t|)	<2e-16	0.0005	<2e-16	0.0001	<2e-16	0.156	<2e-16	0.226
H	E	0.561	-0.004	-0.302	0.009	0.451	-0.001	0.392	-0.0002
	Pr (>|t|)	0.045 $10{-}7$	0.0007	0.016	0.077 10^{-5}	<2e-16	0.021	0.052 10^{-6}	0.804
V	E	1.78e-15	0.006	0.477	-0.013	0.298	0.005	0.385	-0.0009
	Pr (>|t|)	1.78e-15	0.0063	1.37e-13	0.0213	<2e-16	0.009	<2e-16	0.732
VM	E	0.402	-0.006	0.519	-0.007	0.317	0.001	0.345	0.001
	Pr (>|t|)	6.52e-12	0.00485	1.36e-10	0.0193	<2e-16	0.222	9.2e-16	0.438
VV	E	0.092	0.016	0.239	0.011	0.384	-0.004	0.425	-0.005
	Pr (>|t|)	0.269	0.063	0.050	0.369	<2e-16	0.353	1.88e-10	0.431
AP	E	4.108	-0.004	-3.792	0.004	0.399	-0.056 $10{-}3$	-2.278	0.003
	Pr (>|t|)	0.248	0.277	0.363	0.321	0.709	0.957	0.401	0.327

DO: dissolved oxygen Levels; SO: dissolved oxygen saturation Levels BOD5: Five-Day Biochemical Oxygen Demand Levels; COD: Chemical Oxygen Demand Levels; TW: water temperature (°C); Ta: Temperature average (°C); Tmin: Temperature minimal (°C); Tmax: Temperature maximal (°C); RF: Runfful (mm); H: Humidity (%); AP: Atmospheric pressure (hpa); VV: Visibility (Km); W: average wind (Km/h); WM: maximum wind (Km/h); I: intercept; P: parameter; E: Estimate; Pr: *p*-value of t-test

Effect of climatic parameters on the temporal variability of the oxygen in the dam water - RDA and Monte Carlo test

The temporal variability of oxygen in the dam water also presents temporal variability (year, month and seasons) during the period 2002-2021, as indicated by the Redundancy Analysis (*Fig. 7; Table 4*). According to *Figure 7A*, the annual variability explains on the whole 72.45%, of the total variability of oxygenation of the Keddara dam waters.

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According to the first axis (RDA1 = 40.65%), the annual component between 2010-2011 and 2015 to 2021 seems to be positively linked to SO and BOD5. These periods and these parameters are mainly influenced by W. Negatively to this axis, the years from 2004 to 2006 in addition to the year 2015 are positively associated with the COD and are affected by VV and H. These last components are negatively linked to the first one. The second axis (RDA1 = 31.80%), explains more the annual variability 2002 and from 2009 to 2019 linked positively to the COD and influenced by the temperatures TW, Ta, Tmin and Tmax as well as AP and WM. Negatively to this axis, are the years 2007-2008, 2010, 2015 and 2021. The results of *Table 4* of Monte Carlo test show W that significantly explains the annual variability of the oxygenation parameters of the Kaddara dam waters. According to *Figure 7B*, the monthly variability explains on the whole 83.31% of the total variability of oxygenation of the Keddara dam waters. According to the first axis (RDA1 = 59.29%), the monthly component explains the negative variability of BOD5, COD and SO. These mark positively the months of June and July and negatively the months of November, December and January. The second axis (24.02%) evokes the DO which is positively correlated to this axis which marks the months of February, March, April and May while it is weak during the months of August, September and October. These results are well illustrated according to *Figure 7C* which represents the seasonal variability with a rate of 95.79% (axis 1: 74.22% and axis 2: 21.57%) where the BOD5, COD and SO mark positively the SU period and negatively W while the DO marks positively the SP season and negatively the Au season. The significance of the effect of climatic factors on the oxygenation of the Keddara Dam waters is illustrated in *Table 4*.

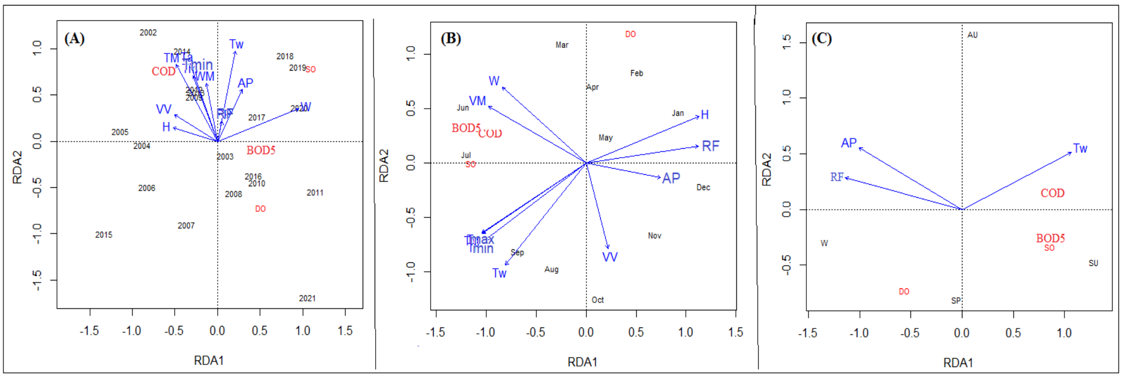

Figure 7. *Redundancy analysis (RDA) illustrating the effect of climatic parameters on the oxygenation of dam waters (years, months, seasons and season-years). DO: dissolved oxygen (mg/l); SO: dissolved oxygen saturation rate (%): BOD5: Five-Day Biochemical Oxygen Demand (mg/l); COD: Chemical Oxygen Demand (mg/l); TW: water temperature (°C); Ta: Temperature average (°C); Tmin: Temperature minimal (°C); Tmax: Temperature maximal (°C); RF: Runfful (mm); H: Humidity (%); AP: Atmospheric pressure (hpa); VV: Visibility (Km); W: average wind (Km/h); WM: maximum wind (Km/h)*

Discussion

Climate change is one of the major challenges of our time, impacting the environment, the economy and society as a whole. This may be due to the effect of human activities and natural climate variations (Zhang and Wang, 2019). Over the last decades, the Mediterranean has experienced a notable reduction in rainfalls and average

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annual raw water flows, in addition to temperature increases, droughts, evaporation phenomena that influence the quality and quantity of this raw water (Milin et al., 2016). According to several authors, climatic trends in this region indicate that the annual temperature would show a very marked increase (IPCC, 2013, Etcheber et al., 2013; Lajaunie-Salla, 2016; Saber et al., 2018; Espinosa and al, 2022). During the period 2002 – 2021, we noticed a climate warming of the Keddara study region with an increase in temperatures of 0.783°C for average annual temperatures, and of 0.942°C for minimum temperatures and 0.35°C for maximum temperatures. The overall increase in atmospheric temperature will have repercussions on aquatic environments and modify their biological activity and their physicochemical conditions (Lajaunie-Salla, 2016). Water temperature has a direct impact on oxygen solubility. An increase in temperature can lead to a reduction in the water’s capacity to dissolve oxygen. In the context of climate change, higher temperatures can therefore exacerbate periods of hypoxia, particularly during the summer, when levels of biological activity are at their highest. This phenomenon is often observed in eutrophied lakes, where decomposing algae consume the available oxygen (Mahaffey et al., 2020).

Table 4. *Statistical influences of significant climatic factors using Monte Carlo test according the RDA analysis (years, months and seasons)*

Variability	**Years**			**Months**			**Season**		
Parameters	**AIC**	**F**	**Pr (>F)**	**AIC**	**F**	**Pr (>F)**	**AIC**	**F**	**Pr (>F)**
AP	29.660	0.9611	0.485	16.477	2.9634	0.070	5.0406	2.6256	0.16667
H	29.898	0.7369	0.570	11.429	9.7428	0.005	3.1984	5.3313	0.08333
RF	30.578	0.1101	0.980	11.991	8.8392	0.010	3.8402	4.2446	0.16667
Ta	28.875	1.7194	0.200	12.310	8.3447	0.005	3.3728	5.0186	0.08333
Tmin	29.186	1.4153	0.215	12.647	7.8371	0.010	3.6082	4.6175	0.08333
TMax	28.651	1.9419	0.115	12.302	8.3574	0.005	3.3819	5.0027	0.08333
TW	28.709	1.8845	0.130	14.178	5.7008	0.005	4.4925	3.3050	0.04167
VV	29.915	0.7202	0.610	17.849	1.5626	0.190	7.4445	0.5361	0.75000
W	27.690	2.9238	0.025	14.698	5.0343	0.010	6.3778	1.3112	0.50000
WM	29.896	0.7380	0.525	13.709	6.3259	0.005	5.7680	1.8565	0.25000
Sig. α			5%						10%

DO: dissolved oxygen (mg/l); SO: dissolved oxygen saturation rate (%): BOD5: Five-Day Biochemical Oxygen Demand (mg/l); COD: Chemical Oxygen Demand (mg/l); TW: water temperature (°C); Ta: Temperature average (°C); Tmin: Temperature minimal (°C); Tmax: Temperature maximal (°C); RF: Runfful (mm); H: Humidity (%); AP: Atmospheric pressure (hpa); VV: Visibility (Km); W: average wind (Km/h); WM: maximum wind (Km/h)

On the other hand, in Keddara dam, rainfalls decreased by a value of 2.77 mm. These results have been confirmed throughout the world, particularly in the Mediterranean regions, and especially North Africa, the number of rainy days is to decrease and the risk of drought to increase (IPCC, 2013; El Harraki et al., 2020; Zittis et al., 2021). Wind parameters and visibility are indeed relevant parameters of climate change that have a strong relationship with rainfalls. For wind speeds, the average has slightly increased while the maximum has decreased. This shift is linked to climate change (Soukissian et al., 2021). According to our visibility results, the Keddara region presents a clear atmosphere with gas molecules (Babari, 2012). The atmospheric pressure is

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stable. However, there is a significant variation in relative humidity, average wind speed and visibility. Depending on months and seasons, the fluctuations are remarkable and significant, except for the monthly variations in visibility and atmospheric pressure, which are stable. Increase in temperature combined with the reduction in low flow rates under the effect of climate change and agricultural practices in the watershed, suggest that under-oxygenation could worsen in future years. Increase in temperatures and decrease in rainfall rates and percentage of relative humidity may be explained by the evaporation phenomenon. Expected climate-induced changes in the water cycle influencing human and social well-being, include increased evaporation, altered spatial distribution and quantity of rainfalls. (IPCC, 2013). Factors that have an influence on evaporation are relative humidity and saturation vapor tension at the temperature of the evaporating surface (Assouline et al., 2007, Quinn et al., 2018, Guo et al., 2021). The increase in wind speed alternates with the decrease in temperatures compared to the result (annual, monthly and seasonal) of the Keddara dam. Wind is the movement of air across the earth's surface. It is caused by the difference in air pressure at the surface. This pressure is according to temperature. Wind is characterized by its direction and speed. There is an indirect effect by changing temperature and humidity (Dajoz, 1985).

Precipitation also influences lake oxygenation. Run-off can introduce nutrients into lakes, encouraging algal blooms. Although this increase in biomass may initially increase oxygenation through photosynthesis, the decomposition of these algae at the end of their life cycle can result in very low oxygen levels, leading to episodes of hypoxia (Akinnawo, 2023).

As mentioned previously, dissolved oxygen in surface waters comes from the atmosphere and the photosynthetic activity of algae and aquatic plants. Oxygen concentration varies monthly and seasonally because it depends on many factors such as atmospheric pressure, temperature and nutrient availability. (De Villiers, 2005). Oxygen enters water either through diffusion by high water turbulence and when there is a strong wind blowing, or through photosynthesis by primary producers (Mccaffrey, 1997). Wind and currents reduce visibility by creating turbulences that divide the surface, thus reducing the light that penetrates water and blocking the phenomenon of photosynthesis, which negatively affects dissolved oxygen level.

The increase in temperature has an effect on other parameters, also during summer. Water is more oxygenated than in other seasons. This is probably due to the photosynthetic activity carried out by phytoplankton thanks to sunshine and the low contents of dry residues and organic matter that facilitates penetration of the sun. Which explains the high content of dissolved oxygen, the chemical and biochemical demand for oxygen with organic matter.

Climatic factors, such as temperature and precipitation patterns, modify the dynamics of nutrients in lakes. For example, higher temperatures increase the solubility of nutrients, favoring their use by aquatic organisms. Intense precipitation can lead to increased runoff, introducing more NO_3 and PO_4 into lakes (Chen-Yang et al., 2022; Chowfin et al., 2024).

Water volume plays a key role in nutrient dilution, water turnover rate and biological interactions, directly affecting dissolved oxygen levels (Mark et al., 2002). A large volume of water can moderate the effects of high temperatures by preventing a rapid rise in water temperature, which helps to maintain adequate oxygen levels. Changes in climate and precipitation patterns alter the volume and flow of rivers feeding lakes, which can have consequences for oxygenation (Didi et al., 2024). The volume of water

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in a lake is also a key factor in nutrient management. Larger lakes have a greater dilution capacity, which can mitigate the effects of excessive nutrient inputs. In large lakes, nutrient concentrations can remain relatively low, helping to maintain adequate oxygen levels. However, water volume dynamics are also affected by climate; for example, prolonged droughts can reduce water volume, concentrating nutrients and exacerbating hypoxia problems (Scofield et al., 2020).

In many Mediterranean lakes, eutrophication is a growing problem, often fueled by nutrient inputs from agriculture and wastewater. Enrichment in nitrates (NO_3) and phosphates (PO_4) leads to algal blooms that can damage water quality and lower oxygen, especially when algae decompose. Furthermore, studies show that Mediterranean lakes are particularly sensitive to these inputs due to their small volume and reduced residence time, which exacerbates the effects of eutrophication (Turley, 1999; Bucak et al., 2012; Akinnawo, 2023). Prolonged droughts can reduce the volume of water, increasing the concentration of nutrients and increasing the risk of hypoxia. Luigi and Barone (2005) observed that seasonal variation in water volume in Mediterranean lakes leads to fluctuations in oxygen levels, particularly during the summer months when thermal stratification is most pronounced.

With global warming predicted, lakes are likely to experience greater temperature variations, changes in precipitation patterns, and an intensification of sunlight, thus affecting oxygenation in complex ways, making it necessary to integrate these factors into water resource management models, in order to anticipate and mitigate the impacts on aquatic ecosystems.

Understanding the interactions between these nutrients and climatic factors is crucial for managing water resources and preserving aquatic biodiversity. With climate change, the Mediterranean region is likely to experience increases in temperature and changes in rainfall patterns. These changes could exacerbate the problems of eutrophication and hypoxia in lakes, making water quality management more complex. Management strategies must therefore include approaches to minimize nutrient inputs while taking long-term climate variations into account.

Conclusion

Our investigation indicates that there is a direct link between the oxygenation of the Keddara dam and the climate, with significant heterogeneity and a favorable pattern over time.

This has an impact on the entire ecosystem, particularly the ichthyology fauna. It will subsequently affect the water quality of this dam of great socio-economic importance in the capital of Algeria. This demonstrates the importance of planning upstream management of raw water of the dam in order to reduce the costs of downstream treatment.

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