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Influence of the Thermal Stratification on the Water Quality of the Cheffia Reservoir (North-East Algeria)

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ABSTRACT

The aim of this work aim is to evaluate the thermal stratification, the physicochemical and the bacteriological characteristics of the Cheffia reservoir located in the North-East of Algeria. Samplings were monthly carried out from December 2012 to November 2013 at a unique station at the deepest point of the reservoir. Samples of water were collected from the surface to a depth of -13 m at intervals of 1 meter in order to evaluate the depth profile of the water temperature, dissolved oxygen, pH, electrical conductivity and organic matter. The heterotrophic bacteria abundance was also estimated by culture on PCA medium. The results showed a permanent presence of a thermal stratification but mixing water conditions were also recorded during the spring season. The thermal layering showed a weak or even no effect on the measured parameters. Still, a strong correlation was calculated between the physicochemical and the biotic mechanisms characterizing the water of the Cheffia reservoir.
KEYWORDS: Thermal Stratification, Water Quality, Heterotrophic bacteria, Cheffia reservoir, Algeria.

1. INTRODUCTION

The thermal stratification, the vertical layering related to water temperature, is an important natural phenomenon in the aquatic systems such as the drinking water reservoirs. It interferes significantly with the abiotic and biotic components creating complex gradients or simply leading to an increased heterogeneity of the water column [1,2]. The features of the thermal stratification of a particular system, such as the timing of turnover and the onset of stratification, the vertical dimensions of the layers and the layers temperatures, are manifestations of a number of specific characteristics systems which are the result of the influence of some environmental factors prevailing in the geographical region where the water system is located [3,4].

The water temperature layering also influences on the nutrient metabolism and transformation in the drinking water reservoir ecosystem, and consequently on the growth of aquatic organisms particularly in deep reservoirs [5,6]. Phytoplankton, zooplankton, insects, fishes and other aquatic species have preferred ranges of temperature. As the later reaches values too far above or below this preferred range, the number of individuals of species decreases until finally reaching very low values, or simply characterizing their disappearance. One of these particular freshwater organisms is the microbial community, particularly the Heterotrophic Bacteria (HB) which play vital roles in sustaining the function and the health of the ecosystem of the drinking water reservoirs as they drive several metabolism and energy conversion pathways that regulate the water quality [7], and also the nutrient cycling processes [8,9,10].

In water bodies, the abiotic parameters (temperature, oxygen, pH, conductivity, water transparency, organic matter concentration) as well as the biotic factors (chlorophyll *a* content, interactions between phytoplankton and zooplankton, grazing, competition) regulate the temporal and spatial distribution of the HB community in the aquatic environments [11,12,13]. However, it is important to note that the freshwater reservoirs may have some specificities in comparison to natural lakes, such as shorter water retention times, water level fluctuations and important shifts of nutrient, making the HB community reacting differently to biotic and abiotic factors in water reservoir than in natural lake [14,15,16].

The water temperature is an important factor because of its influence on the water chemistry and on the trophic state of the water bodies [17]. The rate of the chemical reactions generally increases at higher temperature, which in turn affects the biological activity. An important example of the effects of temperature on water chemistry is its impact on the oxygen dissolution. Currently, a lot of superficial freshwaters are increasingly suffering from eutrophication owing to natural and anthropogenic factors generating great concerns particularly for the quality of drinking waters supplies [18,19,20]. Since no

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work has been done in this field in the North-East Algerian reservoirs, the main aim of this work was first, to detect an eventual presence of a thermal stratification in the Cheffia reservoir water, and secondly study its influence on the vertical profile of both heterotrophic bacteria and some physicochemical parameters on the basis of monthly samplings covering a period of four successive seasons.

2. MATERIALS AND METHODS

2.1. Samplings

This investigation took place in the Cheffia reservoir, one of the largest water resources in the North-East of Algeria. Its main annual water input comes from wadi Bounamoussa with a supply of about 40 Hm^3. This reservoir provides irrigation waters to the nearby agricultural lands as well as drinking waters to the surrounding urban areas. The main hydro-morphologic features of the Cheffia reservoir [21] are summarized in **Table 1**.

Table 1: Main characteristics of the Cheffia reservoir.

Characteristics	Measurements
Elevation	337 m
Surface area	9.78 Km2
Shore Line	20.48 Km
Maximum Length	4.58 Km
Total Capacity	168 Hm3
Storage volume	101 Hm3

Samplings were monthly carried out from the 16th December 2012 to the 14th November 2013 covering four successive seasons. The unique sampling station (**Fig.1**) is located approximately at the deepest point of the reservoir with the following GPS coordinates 36°37'44"N, 8°03'82"E, at 2.3 Km North-East of the dam structure where occurs the water extraction, and at 2.8 Km North-West from the contact point of the water reservoir with wadi Bounamoussa. This location of the station permitted to avoid the mixing effects induced by both of the extraction and input of waters.

Figure 1: Geographic location of the Cheffia reservoir [22].

2.2. Analysis of the physicochemical parameters

Temperature (Temp), Dissolved Oxygen concentration (DO), pH and electrical conductivity of the water were measured in situ, at intervals of 1 m, from the surface to a depth of 13 m, recorded at 4-minute intervals, using a Handheld Multimeter probes type WTW-197-S. The apparatus was standardized using the acid modification of the Winkler method for dissolved oxygen measurements [23]. The quantification of dissolved organic matter was realised by calculating the Permanganate Index (PI) performed in an acid medium at high temperature [24]. When water conductivity ranged from 166 to 333 and from 333 to 833 µS/cm the total mineralization of water (Min) was calculated from the electrical conductivity of water according to the following equations 1 and 2 respectively:

Eq.1: Total mineralization (mg/L) = 0.769574 x electrical conductivity (µS/cm) at 25°C.
Eq.2: Total mineralization (mg/L) = 0.715920 x electrical conductivity (µS/cm) at 25°C.

For the determination of Chlorophyll *a* (Chl *a*), the samples were filtered in a 4.7 cm GF/F filter and extraction was performed overnight in 10 ml of 95% ethanol. The concentrations were determined by spectrophotometry with phaeopigment and Chlorophyll *b* correction [25].

2.3. Bacteriological water analysis

In order to estimate the vertical profiling counts of the Heterotrophic Bacteria (HB), water samplings were made at 1m interval from the surface to -13 m of depth. After dilution of the water samples in a Ranger solution diluted to ¼ (composition w/v: NaCl 0.65%, KCl 0.025%, NaHCO 30.020% and $CaCl_2$ 0.03%), isolation was achieved on the surface of a Plate Count Agar culture medium (PCA) habitually used to monitor the Total or viable heterotrophic bacterial growth of a sample. The PCA composition was (w/v): Peptone 0.5%, Yeast extract 0.25%, Glucose 0.1% and Agar 1.5%. The pH of the medium was adjusted to neutral at 25°C. For each Dilution-Triplicate-Isolation, a repetition was made and then incubated at 20°C for 72 hours [24].

3. RESULTS AND DISCUSSIONS

3.1. *Thermal profile and oxygen distribution*

The temperature profiles of the whole period of the investigation indicate stratification from mid-June to late February, covering 3 seasons of the year (i.e. summer, autumn, winter) but with different stratification characteristics (**Fig.2**). During the summer season, the average values of temperature for each depth indicate that the epilimnion extended from the surface to about 3m deep (**Fig.2a**). In this layer, the temperature decreased very slightly from 25°C to 24.6°C. The dissolved oxygen concentrations ranged from 6.61 to 5.45 mg/L. The metalimnion ranged from -3m to -6m below the surface with a rapid drop in temperature from 24.6°C to 15.2°C. At the same time, within the whole profile, the dissolved oxygen followed the same evolution kinetics as the temperature's one until it reaches a minimum recorded concentration (i.e. 1.79 mg/L) localized at the end of the metalimnetic layer. The occurrence of a metalimnetic dissolved-oxygen minimum is indicated in the literature [26,27]. Kusnetzov and Karsinkin [28] reported a zone of oxygen minimum in Lake Glubokoje in Russia. Because of the sharp increase in density that occurred in the thermocline, they concluded that organic materials, specifically dead plankton concentrated in this layer, provided favourable conditions for bacterial growth. These later authors also indicated that the increased bacterial activity in the thermocline is responsible for the dissolved-oxygen minimum. In addition, the thermocline can behave as a barrier for the dissolved oxygen that can drop well below the standard limit of 5 mg l-1 leading to the development of anoxia [29].

At the Chefia reservoir, deeply below, the temperature of the hypolimnion was almost uniform with an average of 15.22°C and the concentration of dissolved oxygen was almost constant. This phenomenon of dissolved oxygen stratification, particularly during the warm season, is also reported by Kamarianos and al. [30] who related this stratification to an excessive phytoplankton growth in the upper water layer and to the enhanced biodegradation of organic matter at the bottom. During the fall season, the thickness of the hypolimnion in the Chefia reservoir extended to a depth of -3 m (**Fig.2b**) and the dissolved oxygen was almost uniform with an average value of 6.81 mg/L. The metalimnetic and epilimnion layers became rather thinner than in summer with a thickness of 2 m and 1 m respectively. In 2013 during the fall season, the concentration of dissolved oxygen underwent a very slight variation throughout the entire depth profile despite the significant changes in the values of the water temperature which is known to influence actively on the dissolution and the vertical distribution of dissolved oxygen in the waters.

A progressive deepening of the epilimnion from -1m to -2 m as well as of the metalimnion from -2m to -6m was observed during the following winter season (**Fig.2c**). The cooling and deepening processes of the thermal layers are generally observed during the cold season [31]. From late march to early June, the temperature decreases linearly with no distinguishable thermal layering (**Fig.2d**). These conditions are considered indicative of a spring ‘'turnover" (a mixing event throughout the water column) related to a minimal resistance to the mixing event associated with the absence of a vertical density difference. On the other hand, the concentration of dissolved oxygen decreases very slightly from the surface to the bottom from about 7.12 to 5.21 mg/L. These features of the thermal stratification regime in the Cheffia reservoir (including dimension, temperatures of layers and timing) are characterizing a warm monomictic water body.

The principal sources of dissolved oxygen are the photosynthesis and the inputs from the atmosphere. In the Cheffia reservoir, the hypolimnion is generally isolated from these two sources, and this induces a progressive depletion of the DO which was recorded within the deep layer. In the literature [32,33,34], it is indicated that water currents from rivers supplying reservoirs can considerably modify the vertical profile of the oxygen dissolved with the appearance of an atypical curve profile of dissolved oxygen. This event is due to the fact that the waters of the rivers are characterized by a high oxygen demand. Such inflowing water current is also related to other factors, such as turbidity, CO2, pH, and nitrite [35]. On other hand, the rate of the hypolimnetic DO depletion is recognized as an integrator of the metabolism of waters systems (lake or reservoir) and specifically defining a trophic state [36,37,38].

The hypolimnetic oxygen deficit, recognized as a quantitative representation of the oxygen depletion [39], was calculated in the Cheffia reservoir during the four seasons in 2013. The records are represented by a yellow area bounded by the upper limit of the hypolimnion and the concentration profile of DO concentration and their saturation values (**Fig.2**). These results confirm that the largest oxygen deficit was recorded during the summer season with a value of 7.3 mg/L, followed by 4.43 mg/L in spring and 4.35 mg/L in winter, with the lowest values recorded during the cold season from mid-September until mid-December.

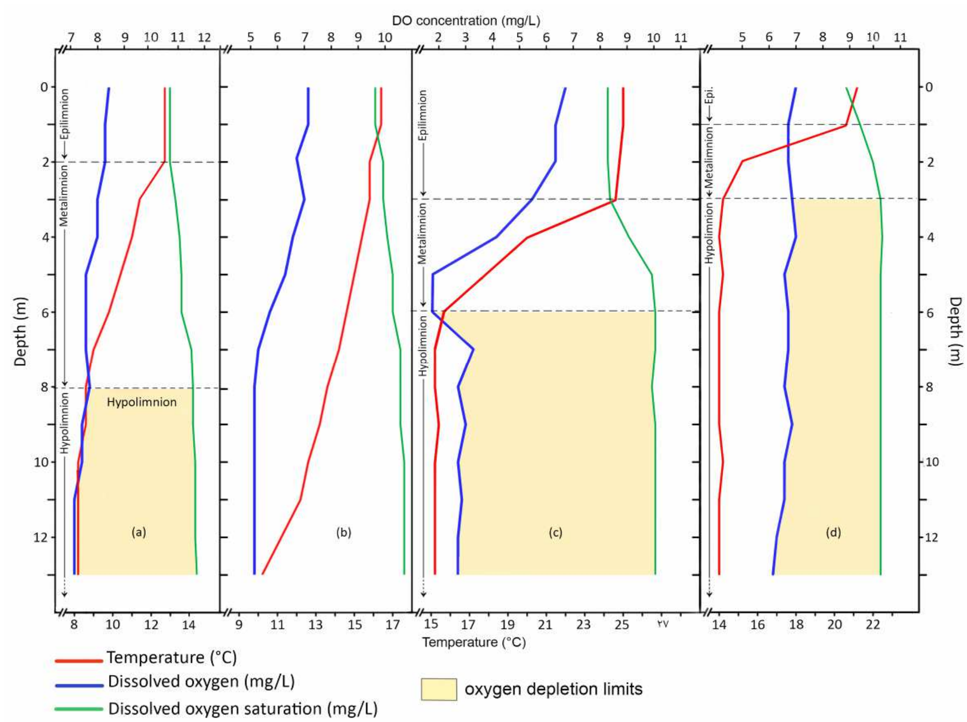


Figure 2: Vertical profiles of water temperature and dissolved oxygen (Dec. 2012 - Nov. 2013).

3.2. *Distribution of the heterotrophic bacteria in water reservoir*

In a water body, the microbial populations can rapidly undergo a quantitative change in both time [40,41,42], and space [43,44,45,46]. In this work, two types of mean comparison were calculated from the values obtained during the monthly counts of HB within the different water depths of the Cheffia reservoir (**Tab.2**):

- In order to enhance an eventual seasonal cell density differences in the waters of the reservoir, a comparison was made between the average of the overall numbers of the heterotrophic bacteria/ml from all the water depths estimated for each season of the year 2013,
- In order to evaluate the thermal layering influence on the abundance of the heterotrophic bacteria in the waters, a comparison was made between the average number of HB/ml obtained from the different

thermal layers during a same season (i.e. comparison between the average obtained from the epilimnion, the metalimnetic and the hypolimnion during the winter season).

Table 2: Vertical seasonal distribution of the heterotrophic bacteria in the Cheffia reservoir (Dec. 2012 to Nov. 2013).

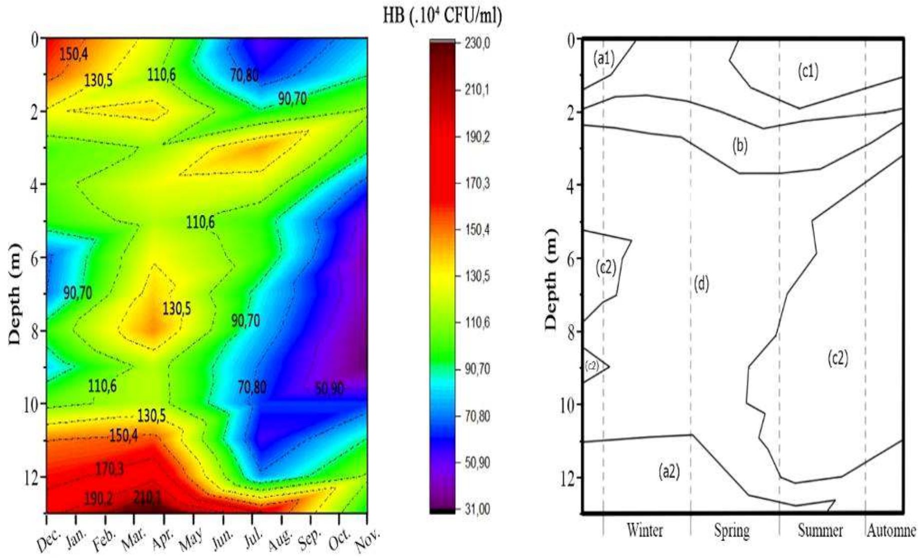
<table>
<tr><th colspan="13">Number of HB (x10^4 CFU/ml)</th></tr>
<tr><th></th><th colspan="3">Winter</th><th colspan="3">Spring</th><th colspan="3">Summer</th><th colspan="3">Automne</th></tr>
<tr><th>Depth (m)</th><th>Range</th><th>Mean D.</th><th>Mean St.</th><th>Range</th><th>Mean D.</th><th>Mean St.</th><th>Range</th><th>Mean D.</th><th>Mean St.</th><th>Range</th><th>Mean D.</th><th>Mean St.</th></tr>
<tr><td>0</td><td>145
176</td><td>165</td><td rowspan="3">**150.00**</td><td>99
142</td><td>125</td><td rowspan="14">139.35</td><td>42
66</td><td>51</td><td rowspan="4">**87.25**</td><td>72
84</td><td>79</td><td rowspan="2">84.50</td></tr>
<tr><td>1</td><td>142
166</td><td>156</td><td>94
125</td><td>114</td><td>52
94</td><td>61</td><td>74
112</td><td>90</td></tr>
<tr><td>2</td><td>110
142</td><td>129</td><td>115
154</td><td>137</td><td>74
117</td><td>92</td><td>94
123</td><td>113</td><td rowspan="2">**1.40**</td></tr>
<tr><td>3</td><td>97
111</td><td>102</td><td rowspan="6">**90.67**</td><td>89
125</td><td>112</td><td>129
172</td><td>145</td><td>87
100</td><td>95</td></tr>
<tr><td>4</td><td>87
121</td><td>105</td><td>111
136</td><td>126</td><td>118
140</td><td>123</td><td rowspan="3">**107.67**</td><td>52
79</td><td>65</td><td rowspan="10">**61.20**</td></tr>
<tr><td>5</td><td>88
107</td><td>99</td><td>94
136</td><td>117</td><td>88
105</td><td>98</td><td>37
51</td><td>45</td></tr>
<tr><td>6</td><td>48
81</td><td>68</td><td>115
138</td><td>129</td><td>57
134</td><td>102</td><td>29
45</td><td>38</td></tr>
<tr><td>7</td><td>52
84</td><td>71</td><td>124
145</td><td>138</td><td>77
94</td><td>85</td><td rowspan="7">**85.28**</td><td>52
34</td><td>40</td></tr>
<tr><td>8</td><td>87
105</td><td>99</td><td>122
162</td><td>147</td><td>67
87</td><td>79</td><td>24
42</td><td>34</td></tr>
<tr><td>9</td><td>68
97</td><td>81</td><td rowspan="5">**136.60**</td><td>97
150</td><td>117</td><td>66
72</td><td>69</td><td>28
37</td><td>31</td></tr>
<tr><td>10</td><td>86
121</td><td>105</td><td>92
136</td><td>118</td><td>57
68</td><td>64</td><td>55
71</td><td>64</td></tr>
<tr><td>11</td><td>137
174</td><td>150</td><td>145
166</td><td>156</td><td>42
64</td><td>55</td><td>84
104</td><td>92</td></tr>
<tr><td>12</td><td>157
172</td><td>162</td><td>168
194</td><td>185</td><td>62
79</td><td>73</td><td>105
122</td><td>113</td></tr>
<tr><td>13</td><td>177
201</td><td>185</td><td>205
243</td><td>230</td><td>132
197</td><td>172</td><td>83
102</td><td>90</td></tr>
</table>

After comparison of the «P» value to 5% value (0.05) with a degree of confidence equal to 95%, in the first comparison, the obtained results showed that there are no significant differences between the average number of HB/ml through the entire depth of the water between the winter and the spring seasons as well as between the summer and the autumn seasons ($P = 0.155 > 0.05$). In the second type of comparison, the results indicated that there is no significant statistical difference between the different thermal layers during the summer season. For the other seasons, a significant statistical difference was recorded between the epilimnion and the metalimnetic layers in winter ($P = 0.009 < 0.05$) as well as between the hypolimnion and the metalimnion in autumn ($P = 0.028 > 0.05$).

The evaluation of the occurrence, the seasonality and the depth distribution of the freshwater bacteria in the waters supplying the domestic needs is recommended by various authors [47,48] who indicated that the maximum bacterial numbers occurred during winter and the minimum numbers in summer corresponding to the circulation and the stratification periods of the waters.

In the spatiotemporal distribution of HB, the different cell density areas are highlighted in **Figure 3**. The monthly vertical distribution of HB (**Fig.3A**) showed a heterogeneous spatial and temporal distribution of the number of HB in the waters. However, if compared with the warm season (late spring to mid-autumn), the highest cell density was recorded during the cold season (winter and early spring). Indeed, the deep water samples were taken from a depth ≥ -12m gave a higher number of CFU/ml of HB than in the case of the shallow waters.

The areas (**a1**) and (**a2**) (**Fig.3B**) are corresponding to the highest cell density (≥15.4x104CFU/ml). The area **(a2)** is almost ubiquitous throughout the year but intensifying during the spring season. The later area can be related to a condition where the depth is close to the sediments whose characteristics are richness in organic and mineral matters promoting the microbial growth [49].



(A) **(B)**

Figure 3: Monthly (**A**) and seasonal (**B**) profile of abundance of the heterotrophic bacteria in the waters of the Cheffia reservoir.

The area **a1** (**Fig.3B**) is occupying vertically the layer of waters with depths <-2m and horizontally the period between the late autumn and the beginning of winter. These findings corroborate with those indicated in Lake Lunz by Ruttner [50] who confirmed that in January, the bacteria were fairly distributed at all depths excepting near the surface where much higher counts were recorded. The periodic fluctuations in the numbers of bacteria take place at all depths, particularly in shallow waters, it is directly correlated with the amounts of rain which had fallen in the drainage area during the week before the samples were taken [51,52]. On the other hand, the washing waters are loaded with the soil heterotrophic microorganisms [51], and also with high quantities of dissolved and particulate organic carbon and dissolved inorganic carbon from the terrestrial sources [53,54]. If these nutritive elements are not a limiting factor, it is important to indicate that particularly after heavy rains these conditions are more suitable for the growth of some groups of micro organisms, or maybe are in favour of a symbiosis among the different types of micro organisms that stimulates their multiplication.

The area (**b)** (**Fig.3B**) is extending throughout the year 2013, with a depth limit between -2m to -3 m and with a thickness not exceeding 1.5m. It is characterized by a density cell whose interval is [130.5; 150.4] x 104CFU/ml. In the vertical distribution of the phytoplankton and the photosynthetic activity, area (**b**) shows the largest phytoplankton biomass, promoting the proliferation of the heterotrophic bacteria by the production of photosynthetic organic matter [55,56,57]. On the other hand, the area (**c1)** is horizontally concentrated in summer and autumn but vertically ranging to a depth not exceeding -2m. The (**c2)** area starts from a depth of -3.5m to -12m and is characterized by a lower cell density (90.7 x 104CFU/ml). Finally, an intermediate area (**d)** is extending between the various other areas and is characterized by a cell density interval of [90.7; 130.5] x 104CFU/ml., and having no particular interpretation because it is influenced by the entire intrinsic and extrinsic factors of the reservoir in a small proportion. During this investigation the horizontal distribution of the bacteria has not been explored. However, it is interesting to mention that, unless mixed by wind, water turbulence, stream inflows, or seasonal or artificial destratification, bacteria and more particularly micro-organisms of intestinal origin can concentrate in areas near the adjacent shore to recreational sites [58,59,60,61] and also at the inflow zones of feeder streams [62,63].

When the profile of the microbial density (**Fig.3B**) is overlapped with the spatiotemporal distribution of the water temperature (**Fig.4**) it appears that the specific density areas display a spatiotemporal distribution completely independent to a vertical distribution profile of the temperature and that for the year 2013. In the literature, it is indicated that the changes in temperature have no relation with the fluctuations of the bacterial population, and that there are no noticeable bacteriostatic effects of the sunlight in the lake waters [48,64]. However, an important influence is exerted by the community of bacterivorous organisms (mainly protozoa) can be observed in aquatic ecosystems, creating a trophic link between the bacterial biomass, the micro and macro-inverbrates [65,66,67,68,69]. In quantitative terms, if the heterogeneous distribution of the temperature is incriminated as a factor controlling the microbial community, the temperature however covariates with the composition of the bacterial community in the lake systems [70,71]. On the other hand, in shallow waters such as rivers, a positive correlation is reported between the temperature and the quantitative abundance of the bacterial community [72].

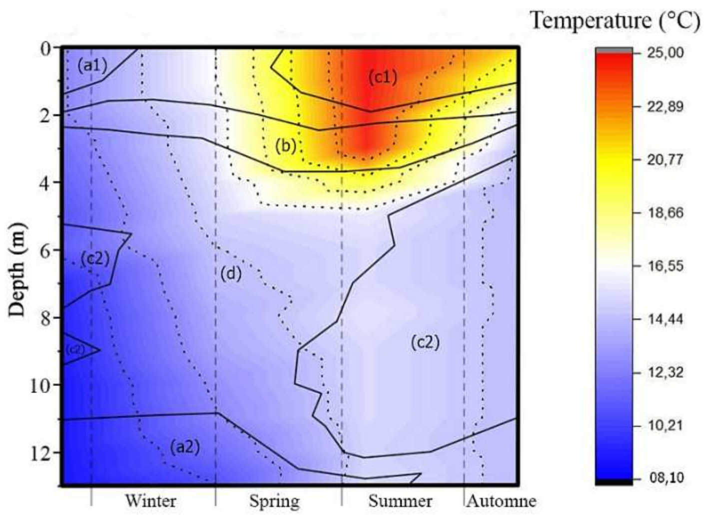


Figure 4: Cell density areas and seasonal vertical distribution of the water temperature in the Cheffia reservoir.

3.3. ***Relationship between the different physicochemical and bacteriological parameters***

The data in **Tab.3** provide the seasonal correlation matrix of the various parameters (physicochemical, Chlorophyll *a* and heterotrophic bacteria) obtained from the Pearson correlations. The water temperature, a determinant factor of the thermal stratification, showed a positive correlation towards the content of dissolved oxygen in the water and that for the four seasons.

Table 3: Pearson correlation coefficients between the physicochemical variables, Chlorophyll *a* and heterotrophic bacteria during the four seasons.

		Temp	DO	Chl *a*	Min	pH	PI	HB
Winter	Temp	1,000						
	DO	0,704*	1,000					
	Chl *a*	0,307	0,693*	1,000				
	Min	0,491	-0,109	-0,766*	1,000			
	pH	0,220	0,072	-0,209	-0,281	1,000		
	PI	0,302	0,358	0,109	-0,336	0,181	1,000	
	HB	0,023	-0,045	-0,241	-0,079	-0,067	0,796**	1,000
Spring	Temp	1,000						
	DO	0,602*	1,000					
	Chl *a*	0,214	0,709*	1,000				
	Min	-0,596	-0,423	-0,489	1,000			
	pH	0,450	0,276	0,362	-0,192	1,000		
	PI	0,106	0,354	0,303	-0,113	0,088	1,000	

	HB	-0,784**	-0,504	0,537	0,478	-0,414	0,697*	1,000
Summer	**Temp**	1,000						
	DO	0,720*	1,000					
	Chl *a*	0,690*	0,717**	1,000				
	Min	0,024	0,341	-0,277	1,000			
	pH	0,251	0,147	0,032	0,314	1,000		
	PI	0,402	0,191	0,737**	-0,335	0,437	1,000	
	HB	0,002	-0,129	0,704*	0,114	0,089	0,740**	1,000
Automne	**Temp**	1,000						
	DO	0,534*	1,000					
	Chl *a*	0,458	0,818**	1,000				
	Min	-0,561	-0,136	0,419	1,000			
	pH	0,211	0,157	0,018	0,156	1,000		
	PI	0,509	0,682*	0,849**	0,128	0,847**	1,000	
	HB	0,249	0,199	0,792**	-0,153	0,204	0,656*	1,000

In cases where the water temperature is lower, the dissolution of the atmospheric oxygen in the waters is better and thus reflecting a negative correlation. In this survey, the results indicate a contrary correlation because, during the entire period of samplings, these two parameters decreased with the depth influenced by factors independently from each other generating an apparent positive correlation whereas chemically it should be a negative correlation.

On the other side, the dissolved oxygen showed a positive correlation with the concentrations of the Chl *a*, justified by the photosynthetic activity of the phytoplankton who produces oxygen. This correlation is more significant during the hot season with warmer waters reducing the dissolution of the atmospheric oxygen. At this stage, the photosynthetic activity remains the main source of dissolved oxygen.

Another positive correlation was recorded in this survey between the Permanganate index (a parameter representing the content of organic matter in the water) and the number of HB. These two parameters correlated positively with the Chl *a* concentrations but only during summer and autumn. This finding indicates that it is the photosynthetic activity that almost controls the organic matter content in the water during the hot season resulting from the facts that both solar light and air temperature reach their maximum values during this season favouring the algal proliferation and the production of photosynthetic organic matter [73]. In the same time, it indicates that the abundance of HB feeds on the organic materials [74,75]. However, during winter and spring, the organic matter has another origin than the photosynthetic one and is originating from the rainfall washing watershed areas.

This survey demonstrated that the waters of the Cheffia reservoir show a thermal stratification from midsummer to late autumn, with different stratification features, excepting during the spring season during which no distinguishable thermal layering was observed. This suggests the existents of mixing conditions throughout the water column. These thermal stratification regimes define a warm monomictic water body and this statement needs to be enhanced with a further longer investigation. On the other hand, in order to evaluate the metabolic state in the water reservoir, the calculation of the hypolimnetic oxygen deficit shown that the maximum deficit occurs during the summer season.

Concerning the effect of the water temperature on the abundance of the heterotrophic bacteria, we found that each one evolves in an independent way from the other, with a maximum of bacterial abundance in the deep waters close to the sediment, and also during the rainy season near to the surface influenced by the washing catchments. Correlation between the physicochemical parameters showed a strong positive correlation between the abundance of HB and the content of organic matter in the waters, the latter having for origin the photosynthetic activity of phytoplankton in the hot season, while in winter the main source of organic matter is the water coming from reservoir watersheds.

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