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Spatial evolution of the physico-chemical, organoleptic and bacteriological properties of a municipal artificial lake

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ABSTRACT

is study is a contribution to the study of the spatial evolution of the properties of the municipal lake of Yaounde-Cameroon. The objective was the characterization of the physico-chemical, bacteriological and organoleptic parameters of water of this lake in order to provide the scientifically exploitable data. To understand the sources and the evolution of the pollution of this lake, we carried out on the surface of water, fifteen samples horizontally representative and arranged on the longitudinal axis and the transverse axis of this one. Analyzes of the parameters of these samples allowed us to establish that three classes of water coexist within the expanse of this lake, in this case water of class 5 (colour = 380.3 mgPt-Co/L, conductivity at 20 °C = 3620 µS/cm, pH = 6.2, dissolved oxygen = 0.4 mg/L) at its its eastern bank; water of class 4 (101.4 ≤ colour ≤ 172.8 mgPt-Co/L, 25.7 ≤ temperature ≤ 26.1 °C, 6.6 ≤ pH ≤ 7.0, 8.9 ≤ BOD_5 ≤ 20.7 mg/L, 43.0.10^3 ≤ total coliforms ≤ 49.7.10^3 CFU/100 mL) around 300 meters from its tributary and water of class 3 (54.9 ≤ colour ≤ 93.4 mgPt-Co/L, 24.2 ≤ temperature ≤ 25.5 °C ; 7.4 ≤ pH ≤ 7.7, 6.6 ≤ BOD5 ≤ 8.7 mg/L) in the rest of the lake. These water classes, as indicated above, cause this lake to be polluted differently. The study also allowed us to identify two directions of self-purification within the lake expanse.

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INTRODUCTION

Aquatic environments in sub-Saharan Africa located in or around cities are characterized by the receipt of untreated domestic effluents and runoff due to lack of sanitation facilities. The relationship between urbanization and degradation of the natural environment by bacteria and viruses present in human waste and nutrients, has been the subject of many studies (He *et al.*, 2017; Azam and Khan, 2016; Fang and Wang, 2013; Li *at al.*, 2012; Nyenje *et al.*, 2010, UN- Water / Africa, 2006). Work carried out in aquatic environments in the Yaounde region by the Hydrobiology and Environment Unit highlights results on organisms that could be potential candidates as quality indicator species or sentinel species (Togouet *et al.*, 2005; Togouet, 2011). Lakes occupy a good place among these aquatic environments. We will distinguish the natural lakes of artificial lakes. The water quality of a lake is determined using several physicochemical, organoleptic and bacteriological parameters. Thus, an oligotrophic lake is a young

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lake characterized by nutrient-poor, transparent and well-oxygenated waters as well as a low production of aquatic plants. Conversely, a eutrophic lake is rich in nutrients and aquatic plants. It is an advanced stage of eutrophication that leads, among other things, to a change in animal communities, an increase in organic matter and a deficit of oxygen in deep water. Finally, a mesotrophic lake has an intermediate level of aging. When the values obtained for the various parameters are at the limit of the main trophic levels, we speak of oligo-mesotrophic and meso-eutrophic (Bhateria and Jain, 2016; Kalinowska, 2004; Lang, 1989). According to Noori *et al.* (2018) the degree of pollution of a lake is often a function of depth. It appears that the extent of the disturbances depends on the sampling location of the sample to be analyzed. It is therefore necessary to take into account a constraint that is the representatively of the samples to be analyzed. In general, we distinguish the horizontal representatively of vertical representatively. The quality of the water reveals the location and the level of pollution, according to a set of parameters. Based on reference values, it is assessed using several parameters, the most significant of which are recorded in Table 1 (APHA, 1998).

Table 1 does not mention some important parameters. This is for example a physical parameter (turbidity) and bacteriological (total coliforms). Thus, Table 2, which gives the usual turbidity classes in NTU, is complementary to Table 1 (RéFEA, 2001).

For total coliforms, the threshold set by the WHO Guide (2012) is 1000 CFU / 100 ml. Beyond this limit, water must undergo bacteriological treatment before any human use. In Cameroon, analyzes of the bacteriological and physicochemical quality of five rivers (Abiergué Est, Ekozoa, Olézoa, Biyémé and Mfoundi) of the Mfoundi network in Yaounde have shown that in the various watercourses of the city pollutions were strong but were essentially organic. Overall, pollution was gradually changing from upstream to downstream (PDM, 2003). A watercourse in general and a particular lake whose water quality is good becomes an attractive place, a real territorial marketing element of this locality. It is not uncommon to see large cities in the world that identify with their lake. It is therefore a new role that urban planners attribute to lakes and streams in a city. The Yaounde municipal lake in Cameroon has all the potential to fulfill this function because of its position in the heart of the city. It is also a shallow lake representing about 4 % of the surface of the upstream part of the catchment area around Yaounde. Its shape is almost triangular with an area of 79,500 m^2, a maximum length of 576.3 m, a maximum width of 567.5 m, a maximum depth of 4.3 m and a volume of 190,000 m^3 (Togouet, 2011; Kemka *et al.*, 2006; Kemka *et al.*, 2004). This lake created in the early 1950s after the construction of a dam on the Mingoa river is an artificial lake that today is an issue in the urban development strategy of this city. Despite its significant degradation for more than a decade, the municipal lake of Yaounde is a major concern of

Table 1: Extract from the surface water quality grid

	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5
Parameter	Excellent	Good	Average	Bad	Very bad
Organoleptic					
Colour (mg Pt/L)	< 20	20 - 50	50 - 100	100 - 200	> 200
Physical					
Temperature (°C)	< 20	20 - 25	25 - 30	30 - 35	> 35
Conductivity at 20 °C (µS/cm)	< 750	750 - 1300	1300-2700	2700-3000	>3000
Chemical					
pH	6,5 - 8,5	6,5 - 8,5	6,5 - 9,2	<6,5 ou >9,2	< 6,5 ou > 9,2
DBO_5 (mg/L)	< 3	3 - 5	5 - 10	10 - 25	> 25
Disolved oxygen (mg/L)	> 7	7 - 5	5 - 3	3 - 1	< 1
Ammonium (mg/L)	≤ 0,1	0,1 - 0,5	0,5 - 2	2 - 8	> 8
Nitrates (mg/L)	≤ 10	10 - 25	25 - 50	≥ 50	-

Table 2: Usual turbidity classes

Turbidity	NTU < 5	5 < NTU < 30	30 < NTU < 50	NTU > 50
Assessment of water	Slightly cloudy water	Slightly cloudy water	Cloudy water	Most surface waters in Africa

several researchers because of its tourist nature for the political capital of Cameroon (Ekangele *et al.*, 2015; Ji *et al.*, 2012; Kamka *et al.*, 2009; Ekangele *et al.*, 2008). Recent administrative acts have led us to believe that institutional investors measure this issue well. Its tourism and economic valuation that was mentioned in these administrative acts is possible only if its pollution problem is mastered. This essential prerequisite is the control and management of the problem of pollution within the perimeter of the Yaounde municipal lake is our concern in this work. Around the municipal lake of Yaounde, several point sources of pollution have been identified. The main problems of water pollution seem to be mainly due to the absence of a real waste management strategy, with the result that there are no sewage networks (Ngnikam, 2007). This institutional failure is coupled with the incivism of the populations, who consider the aquatic environment as the receptacle of all waste resulting from their activities. More specifically, this lake receives waste water of all kinds and untreated sludge from septic tanks and a water treatment center that has been out of order for more than a decade (Assako, 2001). It should be noted that this treatment center and today out of use. The prolonged reception of untreated wastewater from the watershed around Yaounde, the hotel called «Hôtel des députés» situated at a few meters from the left bank of the lake, as well as the wastewater treatment plant of the « Société Immobilière du Cameroun » social housing in Messa-Yaounde of Cameroon's real estate company has progressively degraded its quality (Ekengele *et al.*, 2008). Moreover, Vadde *et al.* (2018) has determined the parameters of the pollution of the water points that are in connection with a lake, including the sewage outlet of a nearby hotel. His works showed how this lake was not immune to heavy pollution of all kinds. The option to develop the Yaounde municipal lake site into a tourist and economic hub decided by the Cameroonian government is actively being considered and the prerequisite for remediation is in the process of being resolved. Following its prolonged exposure to untreated effluents from « Société Immobilière du Cameroun » social housing in Messa-Yaounde (Kemka *et al.*, 2004) and to the wastewater of the « Hôtel des Députés » and other constructions on the watershed around the lake, the plan of water now had eutrophic and hypereutrophic status (Kemka *et al.*, 2003). Its urban situation predisposes its operation to fairly frequent disturbances, at the same time that its shallow depth makes it vulnerable to wind action and human actions. Some studies have shown significant vertical variations in temperature, pH, dissolved oxygen and ammonium in the epilimnion of the Yaounde municipal lake (Togouet, 2011; Togouet *et al.*, 2007; Kemka *et al.*, 2006, Njine *et al.*, 2002). These various studies showed that the Yaounde municipal lake is a polluted lake. Some of these studies even have identified its sources of pollution, but did not say anything about the magnitude of this one even less on its evolution within the extent of this lake. This is why in the context of our work we were, on horizontally representative samples, measured the physical parameters (turbidity, conductivity, temperature), chemical (pH, BOD5, dissolved oxygen, ammonium, nitrates) but also organoleptic (colour) and bacteriological (total coliforms) characteristics of the water of the municipal lake of Yaounde. The scientific data on the sources and evolution of its pollution, resulting from this research, will constitute a reference base for the development project in perspective. The physicochemical and bacteriological characterization of the Yaounde municipal lake has been the focus of our research. The objective of this work is to determine the evolution of the characteristic parameters of the municipal lake of Yaounde-Cameroon, in order to provide the scientifically exploitable data. This study has been carried out in Yaounde-Cameroon from January to August 2019.

MATERIALS AND METHODS

Materials

The equipment of the effluent analysis laboratory of the National Advanced School of Public Works was involved in this work. These include:

- a WTW Multi 350i brand multi-parameter for measuring pH, temperature, conductivity and dissolved oxygen,
- a HACH brand spectrocolourimeter for the measurement of turbidity and colour,
- a Merck KGaA brand box for 100 ammonium ion tests,
- a MQuant brand box for 100 nitrate ion tests,
- a WTW Oxitop branded device in a Lovibond thermoregulator cabinet for measuring BOD_5,
- an OLYMPUS BH2 microscope for reading total coliforms.

Fig. 1: kit instruments of the analysis equipment used

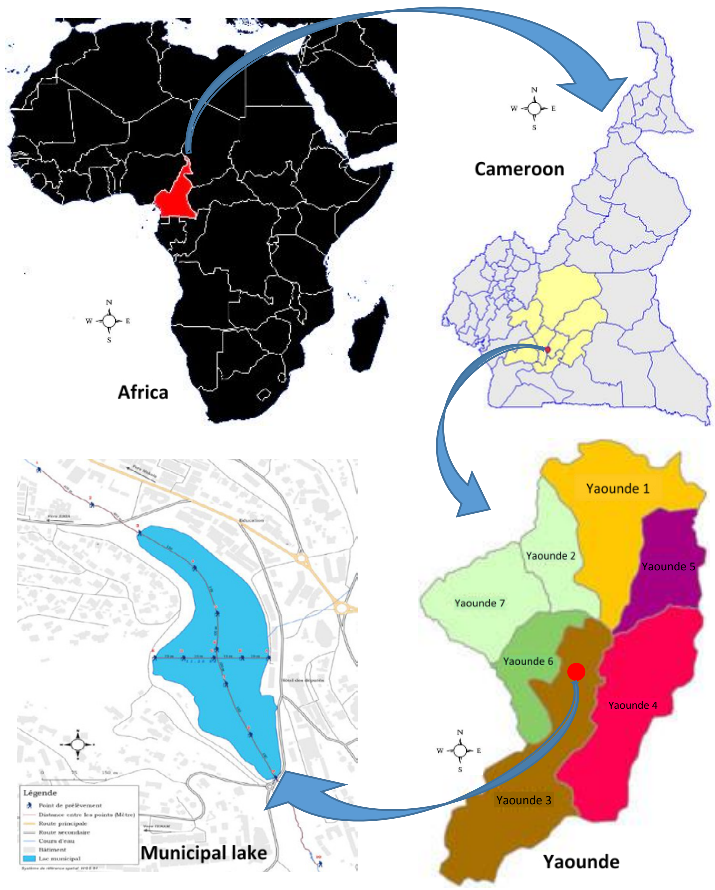


Fig. 2: Geographic location of the study area along with the sampling plan for water samples from the Yaounde Municipal Lake

The particularity of all these devices is their high sensitivity and precision of measurement. Fig. 1 shows the kit containing some of the analytical material we used in the laboratory.

In addition, Fig. 2 shows the Geographic location of the study area along with the sampling plan for water samples from the Yaounde Municipal Lake. The reliability of the results was largely dependent on the methodological approach which, in our case, was divided into three main phases: sample collection, transport and analysis. As soon as the day was cleared and according to a plan of experiments previously elaborated as shown in Fig. 3, we took from the surface of the lake water fifteen horizontally representative samples, five on the East-West axis (Fig. 3a), and ten on the North-South axis (Fig. 3b). Since the analyses are ex situ, the samples have been suitably packaged in labelled and sterilized plastic bottles and then stored in coolers at temperatures of the order of 0 ° C. The samples were then transported and placed in a refrigerator at the laboratory for parameter measurements. Fig. 3 shows the samples in the laboratory some time before the start of the analyses.

Measurement of temperature, dissolved oxygen, electrical conductivity and hydrogen potential

The measurements of the four physico-chemical parameters of the sampled samples were carried out using a multi-parameter with a single output configured for several probes with different uses. A probe, calibrated in the ambient air, makes it possible to measure the temperature, the dissolved oxygen and the electrical conductivity. Another probe was used to measure the pH, after plunging into a potassium chloride solution of known pH before each measurement for calibration. We have first taken the water sample from the lake to be analysed in a beaker. Then we plugged and calibrated the appropriate probe. At the end of the calibration, we dived the probe into the water sample. After calibration, it is necessary to wait until the screen display is stabilized after a few seconds, an action on the reading key allows the display of the measurement of the previously selected parameter.

Turbidity and colour

The turbidity and colour measurements were performed using a HACH spectrophotometer. After switching on the instrument and selecting the parameter to be measured in the program list, we calibrated to zero before inserting the tube containing the solution to be analysed. The measurement of the parameter was then made after closing the chamber containing the tube.

Ammonium and nitrates

Ammonium and nitrate measurements were made by taking the test solution in a beaker and adding an indicator. We then had a box on which the detailed measurement protocol was written and which contains measuring strips. We dipped a strip into the solution contained in the beaker and after one minute, as indicated, we read the value of ammonium. The nitrate measurement procedure was similar to that of ammonium except that there was no indicator.

Biochemical oxygen demand for five days (BOD_5)

As part of our work, measurements were made using the WTW Oxitop device in a Lovibond thermoregulator cabinet. The BOD measuring station consisting of the sampling flask and the BOD probe was a closed system. In the sample flask, there was a gaseous space above the sample volume containing a defined amount of air. When the BOD was measured, the bacteria in the wastewater sample consume the oxygen it contains in dissolved form (the sample can be diluted or not). This oxygen was replaced by that present in the gaseous space of the sampling flask. The carbon dioxide produced simultaneously was trapped by a potassium hydroxide solution contained in the reservoir of the sampling flask. At the system

(a) Samples on the transversal axis

(b) Samples on the longitudinal axis

Fig. 3: Water samples taken at the Yaounde municipal lake

level, a pressure loss representing the value of the BOD, measured by the BOD sensor, occurs and was displayed directly on the screen. It was after five days that we measured the value of BOD_5 according to HACH (2015).

Total coliforms

To measure total coliforms, we used pre- coloured media with OLYMPUS BH-2 microscope reading. The measurement technique used was membrane filtration. Total coliform enumeration was done according to the standard protocol described by Rodier (2009). According to this protocol, after filtration of the water to be studied, the membrane was deposited on a suitable agar medium. This allowed colonies of total coliforms to develop preferentially during an incubation period of 18 to 24 hours, and in a sufficiently characteristic manner to allow a presumptive diagnosis. This can be confirmed by judicious transplanting. Direct enumeration on the membrane led to a presumptive inventory of total coliforms. In sum, we measured ten parameters.

In order to increase the reliability of our results, each analysis was repeated and when there was a strong agreement between the two measures, we retained the average.

RESULTS AND DISCUSSION

Results

The presentation of the results is along the longitudinal axis and the transverse axis of the lake. Fig. 4 to 6 show the variations of the organoleptic, physical and chemical parameters, according to the longitudinal axis and the transverse axis. Fig. 4 shows that, on the longitudinal axis, the colour varies little from north to south up to approximately 600 m of the affluent of this lake, then increases to reach a peak around 1100 m before decreasing to stabilize itself with a lower value towards the discharge system. On the transverse axis, the value of the colour strongly decreases from the east bank to the western bank of the lake.

Turbidity and conductivity evolve on the two axes with the same pace observed for the colour (Fig. 5a). On the longitudinal axis of this lake, the Fig. 5b shows that the temperature varies little, with a difference between the minimal value and the maximum value lower than 1.5 °C. Fig. 6 illustrates the variation of the chemical parameters within lake. Nitrate, BOD_5 and ammonium, vary on the longitudinal axis of the lake with the same pace as the colour. The variation of dissolved oxygen and the pH along the longitudinal axis, take on the other hand an opposite form. On the transverse axis, dissolved oxygen and the pH believe from the eastern to the western bankside of the lake.

Fig. 7 illustrates the variation of the bacteriologic parameter within lake. This figure shows that total coliforms, vary on the longitudinal axis of the lake with the same pace as the colour.

In the longitudinal axis of the Yaounde municipal lake, the tributary and outlet of the lake correspond respectively to 800 and 1600 m of the distance measurement reference located upstream. To facilitate the interpretation of the results, a careful observation of the evolution of the parameters led us to the

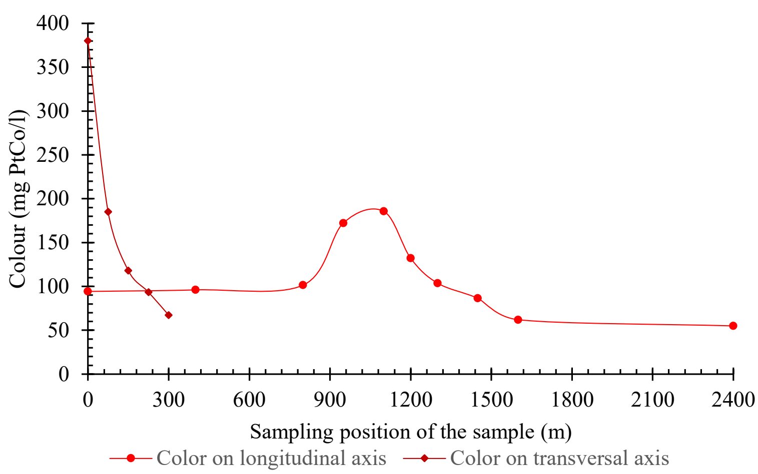
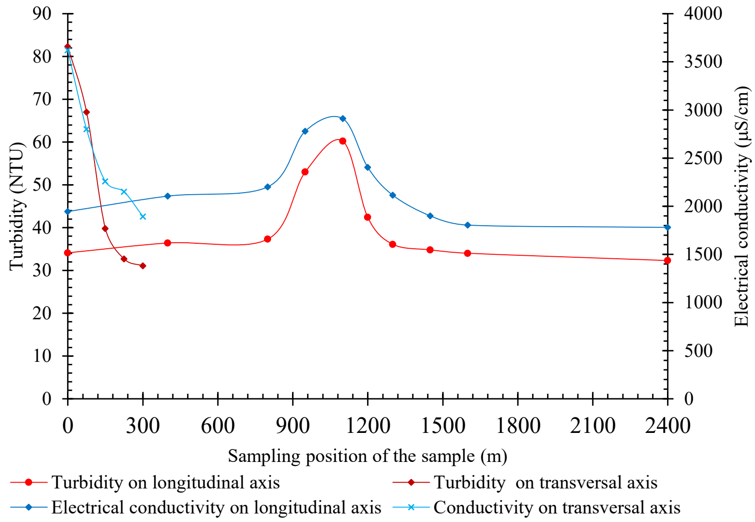
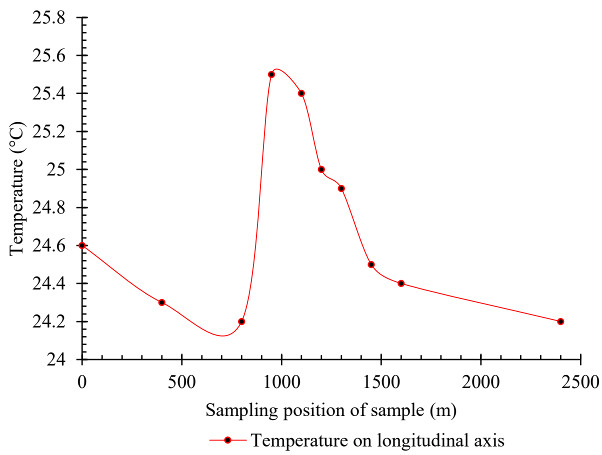


Fig. 4: variation of the organoleptic parameter of the municipal lake of Yaounde



(a) Turbidity and electrical conductivity



(b)Temperature

Fig. 5: Variation of physical parameters of the Yaoundé municipal lake

division of the distance covered in the longitudinal axis into three distinct zones which are the zone 1 (from 0 to 800 m), the zone 2 (800 to 1200 m) and zone 3 (1200 to 2400 m). Fig. 4 to Fig. 6 show a strong consistency in the evolution of the ten measured parameters. First of all, in zone 1, all the measured parameters showed that the water entering the lake was of class 3 or of average quality. Then, in zone 2, the pollution detected in the previous zone increased with a peak at about 300 m along the lake from its tributary. The water in this area was class 4 or of poor quality. Finally, in zone 3, there was a decrease in pollution corresponding to a medium quality water as in zone 1. In particular, figure 5 shows a slight variation in temperature (less than 1.5 °C) while along the lake. Its average is 25 °C, which corresponds to a low solubility of oxygen. Low solubility means a decrease in the amount of dissolved oxygen (Fig. 6) and thus a reduction in self-purification. This results in the accumulation of nauseating deposits and accelerated growth of plants. This was an explanation of the vegetation development observed over a distance of about 300 m along the lake from its tributary. The study of the longitudinal axis variation of the Yaounde municipal lake of ten characteristic parameters of its water shows us with a good coherence that the pollution was born upstream of the

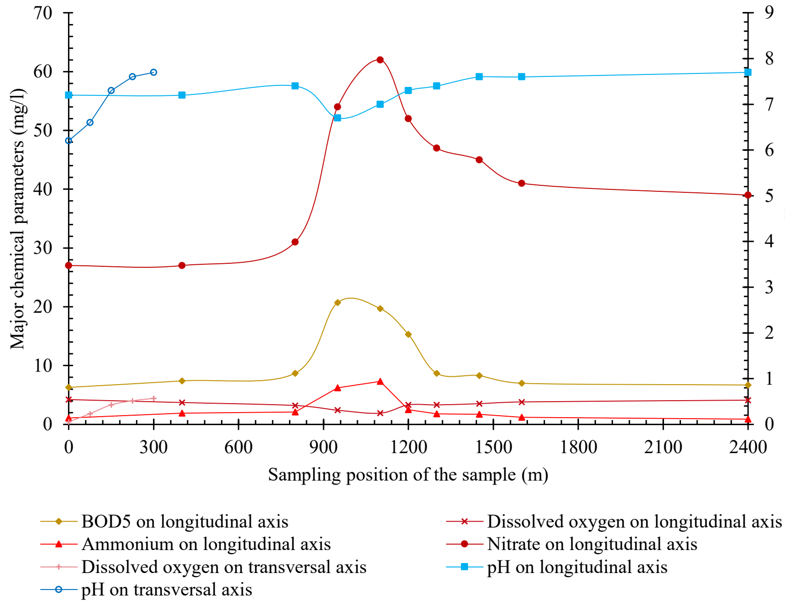


Fig. 6: Variation of chemical parameters of the municipal lake of Yaounde

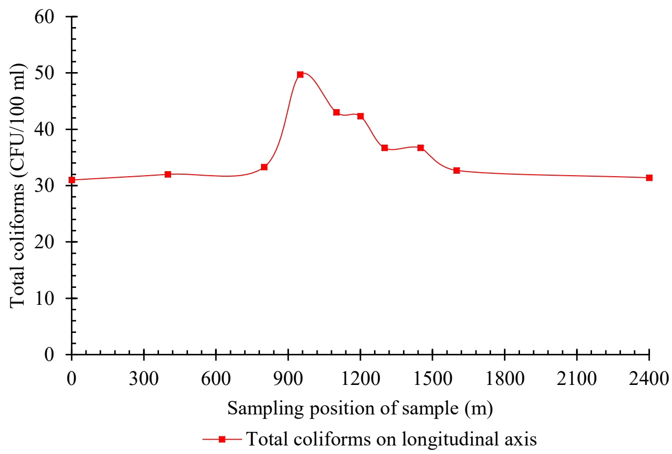


Fig. 7: Variation of bacteriologic parameter of the municipal lake of Yaounde

tributary, was accentuated on about 300 m starting from its tributary. Then, by self-purification, this multi-source pollution gradually dissipated in the rest of the lake, losing its content. Also, it revealed to us that two classes of water coexist. In the transversal axis, the division of the 300 m width covered by this lake was not necessary because the five measured parameters show unequivocally that a class 5 water systematically evolved towards a class 3 water. At the limit of the lake, eastern bankside, the measurements show that we were dealing with water of class 5 or of very poor quality. Approximately 75 m from this bank, the water is class 4. Beyond 75 m to the western bankside, the water was class 3. As in the case of the longitudinal analysis of characteristic parameters water from the Yaounde municipal lake, the study of the transversal axis variation of five of these parameters shows with great coherence (Fig. 4, Fig. 5a and Fig. 6) that most of the pollution was from the eastern bankside of the lake and spread progressively to the rest of the lake. In addition, it introduced an additional water class (class 5) at this bankside, bringing to three the number of water classes that coexist in the Yaounde municipal lake. This study also established self-purification from eastern bankside to western bankside, bringing to two, the directions of self-purification. This was a further explanation of the eutrophication phenomenon observed in zone 2 of the longitudinal axis division.

CONCLUSION

This work consisted in characterizing the water quality of the Yaounde municipal lake. It had a dual purpose. At first, it made it possible to establish the quality of this water using physicochemical, organoleptic and bacteriological parameters. The parameters measured within the framework of this work are of three orders namely: physical (turbidity and temperature), chemical (pH and BOD5) and bacteriological (total coliforms). In a second stage, he provided the literature with scientific data that could be used to understand the sources and evolution of the pollution of the Yaounde municipal lake in particular, and artificial lakes similar to it in general. The samples taken on its euphotic layer have allowed us to identify three major lessons; 1) the water of the Yaounde municipal lake was a polluted water, with a variable level of pollution depending on whether one goes from its tributary to its outlet on the one hand, and from its eastern bankside to its western bankside on the other hand; 2) concerning the identified sources of pollution of this lake, the measures carried out in the framework of this work, allowed us to confirm the conclusions of the multiple previous works related to the question, namely the area of Messa-Yaounde and the eastern bankside of the Yaounde municipal lake as its main sources of pollution; 3) In the case of the Yaounde municipal lake pollution areas, the evolution of the measured parameters made it possible to locate them at the eastern bankside and the corresponding zone at a distance of about 300 m from its tributary.

The eutrophication observed in these two areas is by definition, one of the proofs of a strong pollution with nitrates and phosphates. Any attempt to resolve the pollution problem of this lake, requires mastering the phenomena taking place in these two areas. But we do not have all the informations to have a definitive statement. To fully understand this problem, this work must be completed in future studies.

AUTHOR CONTRIBUTIONS

A. Talla performed the literature review, experimental design, compiled the data, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. F.D. Motto performed the experiments. G.E. Nkeng helped in the literature review and manuscript preparation.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

°C	Degree Celsius
APHA	American Public Health Association
BOD_5	Biological oxygen demand for five days
Fig.	Figure
m	Metre
mg/L	Milligram per litre
mgPt-Co/L	Milligram Platinum-Cobalt per litre (Degree Hazen)
mL	Millilitre
NTU	Nephelometric Turbidity Unit
pH	hydrogen potential
REFAA	Francophone Network on Water and Sanitation
UFC/100 mL	Colony Forming Units per 100 millilitres of water samples
UN	United Nations
WHO	World Health Organisation
µS/cm	Micro Siemens per centimetre

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