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Spatial and temporal dynamics of coliform contamination within Yamoussoukro lakes water in Côte d'Ivoire: impact on the safety of surrounding vegetable cropping

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Abstract

There is a lack of information on the seasonal and spatial variations of bacterial pollution and the drivers of these variations within and around the Yamoussoukro lakes. In order to explain the dynamic of bacterial pollution of these lakes and assess the health risks associated with the contamination of surrounding vegetable crops, *Escherichia coli* and thermotolerant coliforms were used as indicators of pollution. Sampling was conducted from the lakes and surrounding vegetables such as carrots, lettuce and cabbage. In total 31 water points during 4 dry seasons and 4 rainy seasons, for the years 2015-2016 and 2016-2017 were sampled according to the Canadian sampling method. Water bacterial loads were high (710 CFU/mL and 791.8 CFU/mL) during the rainy seasons while the ones on the vegetables were high during the dry seasons (84.6 CFU/mL and 105.8 CFU/mL). The spatial location of the lakes from upstream to downstream and the rainy seasons strongly contributed to the evolution of bacterial loads from one lake to another. Moreover, it was shown that the dissolved organic carbon and the turbidity positively impacted the evolution of the bacterial loads throughout the two years. Overall no matter what season, the lake waters were not suitable for vegetable irrigation.

Keywords: *Escherichia coli*, Thermotolerant coliforms, spacio-temporal dynamic, Yamoussoukro lakes

Résumé

À ce jour au niveau des lacs de Yamoussoukro, il y a un déficit d'informations sur les variations saisonnières et spatiales de la pollution des eaux et des cultures maraichères environnantes et les facteurs qui les déterminent. Afin d'expliquer la dynamique de la pollution bactérienne de ces lacs et d'évaluer les risques sanitaires liés à la contamination des cultures légumières, *Escherichia coli* et les coliformes thermotolérants ont été utilisés comme indicateurs de la pollution. L'échantillonnage a été effectué au niveau des lacs et des légumes environnants tels que les carottes, la laitue et le chou. Au total 31 points d'eau, au cours de 4 saisons sèches et 4 saisons des pluies, ont été échantillonnés pendant les années 2015-2016 et 2016-2017 selon la méthode d'échantillonnage canadienne. Les charges bactériennes dans l'eau étaient élevées (710 UFC/mL et 791,8 UFC/mL) pendant la saison des pluies, tandis que celles des légumes étaient élevées pendant la saison sèche (84,6 UFC/mL et 105,8 UFC/mL). La localisation spatiale des lacs d'amont en aval et les saisons des pluies ont largement contribué à l'évolution des charges bactériennes d'un lac à l'autre. De plus, il a été démontré que le carbone organique dissous et la turbidité avaient un impact positif sur l'évolution des charges bactériennes au cours des deux années. Quelle que soit la saison, les eaux des lacs de Yamoussoukro ne conviennent pas à l'irrigation des légumes.

Mots clés:*Escherichia coli*, coliformes thermolerants, variations saisonnières et spatiales, Lacs de Yamoussoukro

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Introduction

The multiple uses of surface water resources require a good microbiological quality (Rochelle et al., 2015; Mathai et al., 2018). Yamoussoukro, the capital of Côte d'Ivoire is characterized by ten (10) lakes developed since 1970 for its beautification. These lakes constitute the receiving environments of seven (7) purification stations built on the watershed of the so called lakes. However, the malfunctioning of wastewater treatment plants causes a large discharge of liquid and solid waste that pollute the lake waters. The microbiological pollution of Yamoussoukro lakes has been established by various studies that showed that human activities near the lakes have allowed discharges of organic and inorganic matters that contain farmyard and human feces (Aw et al, 2011, Koffi et al., 2011; Tano et al., 2011, Kouakou et al., 2014). In Yamoussoukro, the benefits of the lakes are reflected by the diversity of activities that are practiced within and around (agriculture, fishing, commercial activities, breeding, laundry, washing, ablutions, and dishes) (N'guessan et al, 2014). In terms of agricultural practices, vegetable cropping is the most important economical activity developed around these lakes. Indeed the produced vegetable are used to supply local and surrounding markets and even those in Abidjan the economical capital city 214 km south Yamoussoukro (Abakou and Brou, 2003). These lake waters are the main source of vegetable crops watering. Unfortunately, it is well known that the use of wastewater for irrigation is common in Africa and represents a potential risk for the population (Ferrer et al., 2012). Kouamé et al. (2017) have shown that in Yamoussoukro the use of wastewater constitute a key driver for foodborne disease infections. Sprinkler irrigation, most often practiced in market gardening in Yamoussoukro, presents the highest level of risk of bacterial contamination. Indeed, the type of irrigation can influence the risk of contamination of market garden products (WHO, 2012). The timing of watering, the quality of the water used and the fact that the water has been in direct contact with the edible part of the plant are all factors to consider. It means that the vegetable produced around the lakes in Yamoussoukro may constitute food threats since they are eaten raw and usually without proper decontamination practices (De Oliveira et al., 2011; Stephan et al., 2015). Such products are recognized as possible vehicles of foodborne diseases, which are highlighted by large and serious outbreaks epidemic (Castro-Rosas et al., 2012; Lokerse et al., 2016). Since the risk of contamination is global, several countries and international organizations like the World Health Organization (WHO) and the Food and Agricultural Organization (FAO) have developed codes of practices, guidelines and regulations (Gil et al., 2015; USDA, 2014; WHO, 2012; FAO, 2012; FAO, 2008a; FAO, 2008b) with measures that can be used to prevent and control microbial hazards along the fresh vegetable supply chain. While these preventive measures have been documented, the levels of implementation varies from region to region and country to country. Yet, in Côte d'Ivoire, such measures have to be implemented. It remains that the understanding of lake water pollution and related microbial hazards could help improve the microbiological quality of fresh fruits and vegetables from market gardening. Recent work to assess the quality of Yamoussoukro lake waters in agricultural systems has shown the microbiological risk of these waters (Kouamé *et al.,* 2017). However, the evolution of microbial loads over a long period and the impact of watering vegetable crops with lake waters have not been studied. Thermotolerant coliforms correspond to a bacterial group used as indicators of feces contamination according to the French Standard NF IN ISO 7027 (AFNOR, 1999a). Their presence in aquatic environment is an evidence of recent contamination of the environment by feces. Also, the number of coliforms is an indicator of the presence rate of pathogenic bacteria (Mclellan et al., 2013; Zhang et al, 2018). Thus the aims of this study was to follow the dynamic of bacterial pollution within the Yamoussoukro lakes and its impact on the contamination on the vegetable crops watered by the lake waters. Measures to preserve the health of populations could be considered. For this purpose, thermotolerant coliforms and *Escherichia coli* have been taken as indicators of pollution in the lakes.

Materials and Methods

Study site

The study was conducted using the Yamoussoukro lake system. It consists of ten lakes that cover an area of 124.9 hectares (N Guessan et al., 2014) out of which five (5) were chosen for this study (Figure 1). These lakes were chosen because agricultural, animal husbandry, commercial activities and waste water flow were noticeable. These were Lakes A and Lake B upstream at the entrances to the two branches of the system. Lakes C and D in the center of the system and finally the downstream Lake E.

Water and vegetable crop samplings

Samplings were carried throughout 2015 from December to September 2016 and from November 2016 to September 2017. Samplings were conducted all the four climatic seasons of each year. For each selected lake, 500 ml of water were collected at each sampling point according to the Canadian water sampling method, in U at 50 cm depth (MDDEFP, 2013). A total of 31 points were sampled with respectively for Lake A, five (5) points, Lake B seven (7) points, Lake C seven (7) points, Lake D seven (7) points and Lake E five (5) points. The vegetables selected around the lakes were cabbage, carrot and lettuce. Around each lake, two fields of each vegetable were investigated for the presence of *Escherichia Coli* and thermotolerant coliforms. In each field, six (6) plants of each vegetable spaced 4 m apart (MDDEFP, 2013) were removed from the soil and carefully placed in a sterile bag hermetically closed. The collected water and vegetable samples were kept out of light and at a temperature of 4°C in a cooler. All samples were transferred to the laboratory within 6 hours for subsequent analyzes. In total, for the years 2015-2016 and 2016-2017, eight (8) climatic seasons were explored with three (3) sampling rounds each season, as described in Table 1.

Physicochemical analyses

Physicochemical analyses were carried out in the chemistry laboratory of the Department of Chemical and Agri-Food Engineering at the Institut National Polytechnique Félix Houphouet Boigny (INP-HB) in Yamoussoukro. Dissolved oxygen (DO) (AFNOR 5814, October 2012) was measured, using an HQ40d Portable Multi- Parameter Meter (Hach, USA). Turbidity (AFNOR 7027, March 2000) was measured using a 430 IR/T portable turbidity meter. Dissolved Organic Carbon (DOC) (ISO 8245:1999) was measured by dosing with Thermoreactor ECO 8 (Velp Scientifica, ITALY) and DR/2010 Spectrophotometer (HACH, Colorado USA). Water temperature and pH (AFNOR 10523, May 2012) were measured in situ during the sampling process by Standard Method. They were determined with a HI 991001 portable device (Hanna Instruments Canada).

***Escherichia coli* and thermotolerant coliforms enumeration**

Escherichia coli and other thermotolerant coliforms were isolated from waters and plant leaves using COMPASS ECC agar, a selective agar medium that allows simultaneous enumeration of *E. coli* and thermotolerant coliforms. The medium was autoclaved and poured into 90 mm Petri dishes. Water samples (1 mL) were serially diluted 1/10th and 1/100th according to the French standard NF 9308-3 (AFNOR, 1999b) and (100 µL) were cultured in triplicate. Concerning the vegetable crops, thirty (30) g of leaves were kneaded in 5 mL of sterile distilled water. 1mL of this solution was serially diluted (1/10th and 1/100th) and 100 µL were surface spread in triplicate on petri dishes. Petri dishes were incubated at 44°C overnight. *E. coli* were characterized by their blue to violet colonies and other thermotolerant coliforms by pink color. Petri dishes, with more than 15 and fewer than 150 colonies were considered.

Statistical analyses

The values of the evaluated parameters were subjected to analysis of variance (ANOVA) using a General Linear Model. Significant Difference were carried out using Fisher's Least Significant Difference test at 0.05 level of probability when the F-ratio was significant. Principal Component Analysis (PCA) and Pearson correlations of bacterial samples and physicochemical parameters of the lakes were also conducted to determine the different possible relationships between bacterial loads and lake physico-chemical parameters. Statistical analyses were performed using the XLSTAT 2018 software.

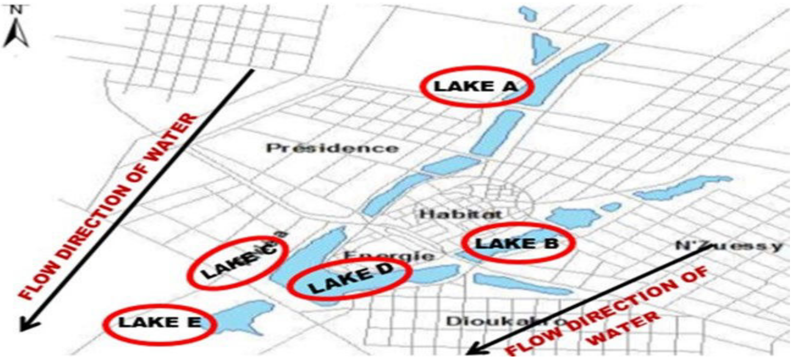

Figure 1: Location of lakes defined for sampling and water flow direction of Yamoussoukro lacustrine system

Table 1. Lake Sampling during 2015-2016 and 2016-2017

CLIMATE SEASONS	2015-2016 Sampling periods (P)	2015-2016 Sampling periods (P)
Long Dry Season (LDS)	P1 December.28th P2 January 12th P3 February 01 rst	P1 November 26th P2 December 14th P3 January 14th
Long Rainy Season (LRS)	P1 March 02nd P2 May 19th P3 June 06th	P1 April 11th P2 May 06th P3 May 17th
Small Dry Season (SDS)	P1 July 01rst P2 July 19th P3 August 01rst	P1 June 22nd P2 July 12th P3 July 29th
Small Rainy Season (SRS)	P1 August 28th P2 September 12th P3 September 30th	P1 August 09th P2 August 28th P3 September 12th

Results

Dynamics of the physicochemical characteristics within the lakes

The water temperature (Figure 2) within the five lakes did not vary significantly during the different climatic seasons over the years 2015/2016 and 2016/2017. The values were on average around 27°C. However in general, during the rainy seasons, the temperatures decreased. For the 2015-2016 season during the Long Rainy Season (LRS), Lake A recorded the lowest temperature values (25.6°C). For 2016-2017 during the Long Rainy Season (LRS), Lake D recorded the lowest temperature values (25.6°C). The turbidity dynamic was related to lake locations and seemed to follow the direction of the water flow of the lake system (Figure 3). Lake A and Lake B upstream of the lake system exhibited the lowest turbidities during all seasons, while downstream Lake E had the highest turbidities. Lake D and Lake C in the center of the lacustrine system exhibited intermediate turbidities. Unlike the turbidity, the pH of all lakes fluctuated during the seasons in the same range between 6.3 and 7.09 (Figure 4) no matter the lake location. During the year 2016-17, the pH at Lake A in the Long Dry Season was the lowest (6.33), while the highest pH (7.09) was observed at Lake D in Heavy Rainy Season. Moreover, the dissolved Oxygen (O2) varied among lakes during seasons over the two years (Figure 5). Lake A had the highest dissolved oxygen content throughout the seasons. From 2015 to 2016 and from 2016 to 2017, at each lake, dissolved carbon levels were constant (Figure 6) over the course of the climate seasons. However, the lowest values of dissolved organic carbon were observed with Lake A. The highest carbon content in Lake E decreases during the short rainy season (SRS) in 2015/2016. Lake D on average had high carbon (C) content.

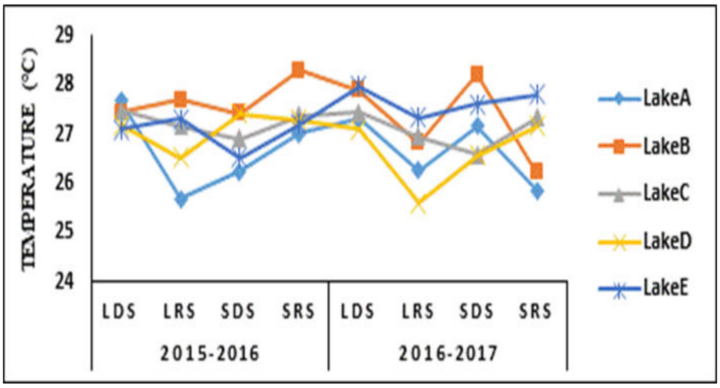

Figure 2. Temperature of the five lakes in different climate seasons of 2015-2016 and 2016-2017

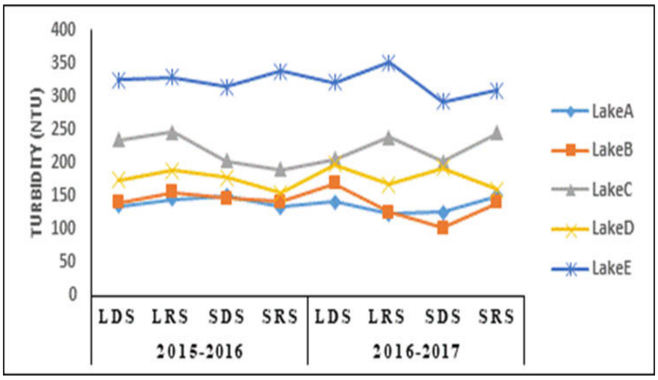

Figure 3. Turbidity of the five lakes in different climate seasons of 2015-2016 and 2016-2017

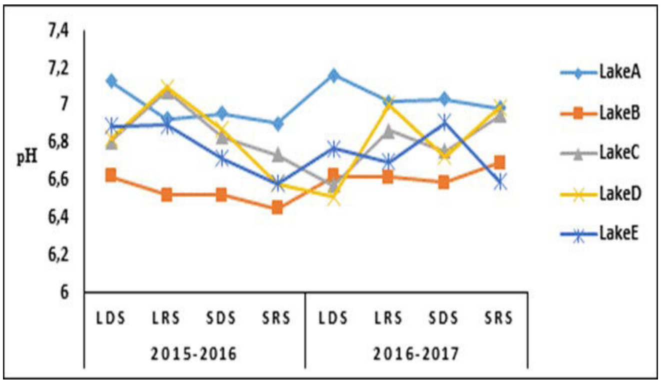

Figure 4. pH of the five lakes in different climate seasons of 2015-2016 and 2016-2017

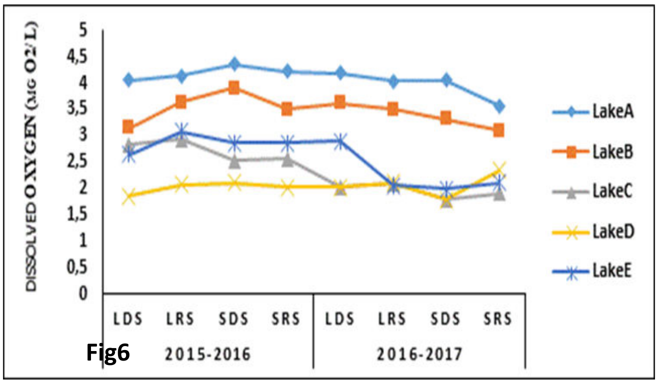

Figure 5. Dissolved Oxygen (O2) of the five lakes in different climate seasons of 2015-2016 and 2016-2017

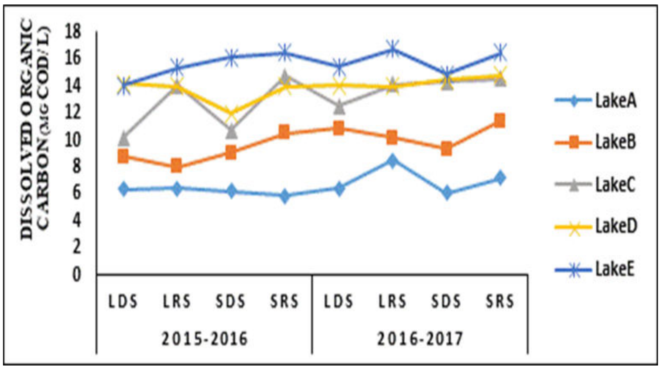

Figure 6. Dissolved organic carbon (DOC) of the five lakes in different climate seasons of 2015-2016 and 2016-2017

Seasonal and spatial dynamics of bacterial loads in lake waters

For each lake, *E. coli* and thermotolerant coliforms showed the same load values and their evolution curves during the climatic seasons were similar **(Figure 7)**. The bacterial loads evolved according to the direction of the water flow of the lacustrine system. Lake A and then Lake B, upstream of the lacustrine system, had the lowest loads of *E. coli* and thermotolerant coliforms, Lakes C and D, in the intermediate position, showed intermediate loads, and Lake E, downstream of the lake lacustrine system presented the highest loads. During the two years, peaks of *E. coli* and thermotolerant coliforms loads were obtained during the Long Rainy Season (LRS). The lowest loads were obtained during the period between the Short Rainy Season (SRS) and the Long Dry Season (LDS). *E. coli* loads varied from 69 CFU/mL to 984 CFU/mL, while the loads of all the thermotolerant coliforms ranged from 149 CFU/mL to 1364 CFU/mL.

Dynamics of bacterial loads in vegetable crops grown near the lakes

Bacterial loads for *Escherichia coli* (268 CFU/mL) and thermotolerant coliforms (447 CFU/mL) were highest in carrots surrounding Lake D (**Figure 8**). Carrots grown in the perimeters of Lake A showed the lowest bacterial loads. The most important loads were also noticed during the Short Dry Seasons (SDS) of the two years while in general, a drop in loads was noted during the Long Rain Saison (LRS) and the Short Rain Season (SRS). Concerning the cabbages, bacterial loads for *Escherichia coli* (237 CFU/mL) and thermotolerant coliforms (386 CFU/mL) were higher in cabbages near Lake E than elsewhere (**Figure 9**) Lake C had peaks in the Short Dry Seasons (SDS) for *Escherichia coli* (176 CFU/ mL) and thermotolerant coliforms (375 CFU/ mL). Lake A had the lowest bacterial loads. Concerning the seasonal factor, the highest loads were observed in the Long Dry Season (LDS) of the year 2016-2017. The bacterial loads on lettuce for *Escherichia coli* (196 CFU/mL) and for thermotolerant coliforms (297 CFU/mL) in Lake C were the highest, followed by Lac E (Figure 10). Lake A had the lowest bacterial loads. Regarding the seasonal factor, the highest loads were observed in the Long Dry Seasons (LDS) and Short Dry Seasons (SDS) of the 2 years for Lake C.

Links between bacterial pollution of lake waters and bacterial pollution of surrounding vegetable crops according to climatic seasons

Bacterial loads of vegetable crops changed proportionately to bacterial loads of lake water with a significant positive correlation ($R2 = 0.8990$) (Figure 11A). Vegetable crops with high bacterial loads were found near lakes with higher bacterial loads. The bacterial loads of the water were greater during the rainy seasons and lower during the dry seasons while the opposite results were observed in the vegetables where the bacterial loads were greater during the dry seasons and lower during the rainy seasons (Figure 11B).

Impact of physicochemical parameters on the dynamics of *E. coli* and thermotolerant coliform communities

A Principal Component Analysis and Pearson correlation were conducted to establish the links between lakes physicochemical parameters and the bacterial loads obtained during the year 2015-2016. On the F1 axis whose contribution is 65.12 %, turbidity, dissolved organic carbon (DOC), dissolved oxygen (O2), *E. coli* and thermotolerant coliforms were well represented (Figure 12A). On this axis, turbidity, dissolved organic carbon (DOC), *E. coli* and thermotolerant coliforms moved in the same direction with significant positive correlations (Table 2). There was a significant negative correlation between the Dissolved Oxygen (O2) with both *E. coli* and thermotolerant coliform loads (Table 2). Moreover there were 4 classes of bacterial loads (*E. coli* and thermotolerant coliforms) ranging from the smallest to the highest in time and space (Figure 12B). The first class consisted of all seasonal bacterial loads of Lake A. The second class included all seasonal bacterial loads of Lake B and the bacterial loads of Lake C at season-LDS. The third class consisted of the bacterial loads of Lake C (season-SDS, season-SRS, season-LRS) and all seasonal bacterial loads of Lake D. The fourth class consisted of all seasonal bacterial loads of Lake E. Turbidity, dissolved organic carbon (DOC), *E. coli* loads and thermotolerant coliforms loads were higher at Lake E, followed by Lake D, Lake C, Lake B, and Lake A, respectively (Figure 12C). These parameters evolved according to the direction of the water flow of the lacustrine system. In contrast, dissolved oxygen (O2) was more abundant at Lake A and Lake E had the lowest levels of dissolved oxygen (O2).

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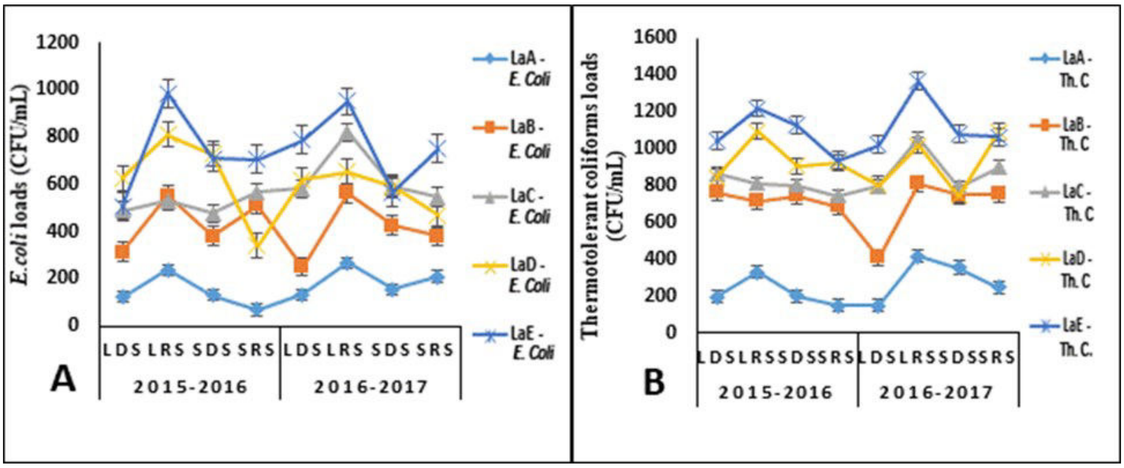

Figure 7: Lake bacterial load dynamics during 2015-2016 and 2016-2017 sampling seasons. A: *Escherichia coli*. B: Thermotolerant coliforms

LDS: Long dry season; LRS: Long rainy season; SDS: Short dry season; SRS: Short rainy season; Th. C. :*Thermotolerant coliforms*

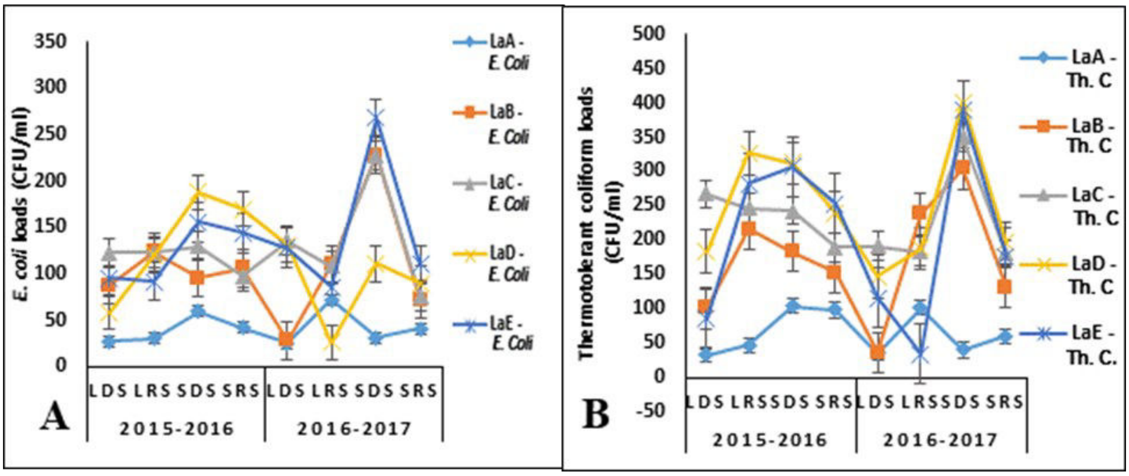

Figure 8: Dynamics of bacterial loads on the leaves of carrots surrounding different lakes at sampling seasons in 2015-2016 and 2016-2017. A: *Escherichia coli* B: Thermotolerant coliforms

LDS: Long dry season; LRS: Long rainy season; SDS: Short dry season; SRS: Short rainy season; Th. C.: Thermotolerant coliforms

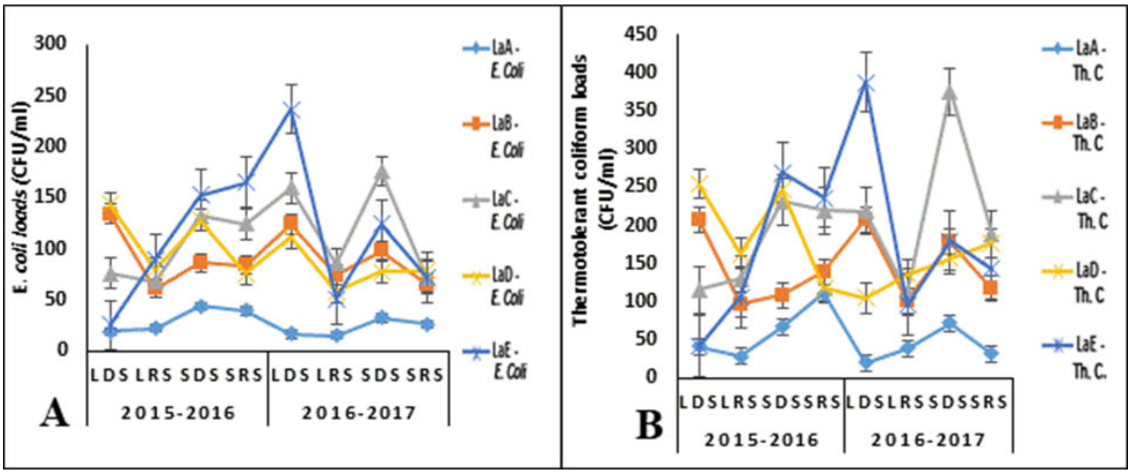

Figure 9: Dynamics of bacterial loads on cabbages at different sampling seasons in 2015-2016 and 2016-2017. A: *Escherichia coli* B: Thermotolerant coliforms

LDS: Long dry season; LRS: Long rainy season; SDS: Short dry season; SRS: Short rainy season; Th. C.: Thermotolerant coliforms

A Principal component analysis and Pearson correlation were also conducted to determine the impact of lake physicochemical parameters on the bacterial loads obtained in 2016-2017. On the F1 axis whose contribution was 70.42 %, turbidity, dissolved organic carbon (DOC), dissolved oxygen (O2), pH, *E. coli* and thermotolerant coliforms were well represented (Figure 13A). On this axis, turbidity, dissolved organic carbon (DOC), pH, *E. coli* and thermotolerant coliforms moved in the same direction with a significant positive correlation between these variables (Table 3). There was a significant negative correlation between Dissolved Oxygen (O2) with both *E. coli* and thermotolerant coliform loads (Table 3).

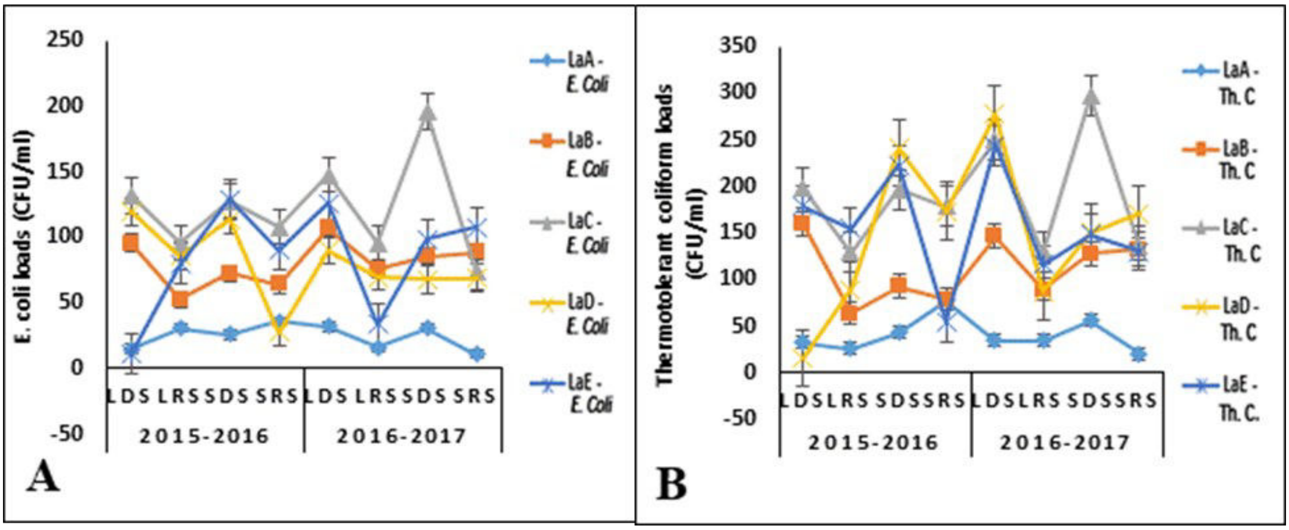

Figure 10: Dynamics of bacterial loads on lettuce different sampling 2015-2016 and 2016-2017 seasons A:*Escherichia coli* B: Thermotolerant coliforms

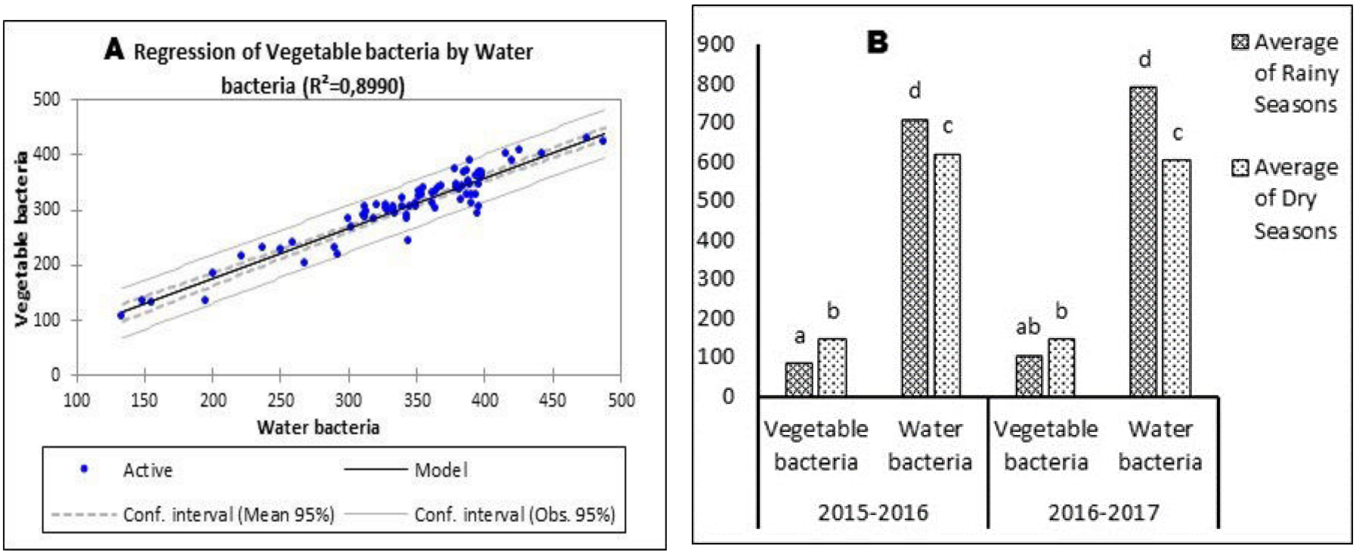

Figure 11. Evolution vegetable bacterial loads according to that of lake waters during years 2015-2016 and 2016-2017climatic seasons

Histogram with different letters are significantly different (Fischer LSD, p < 0.05)

Three (3) classes of bacterial loads (*E. coli* and thermotolerant coliforms) ranging from the smallest to the highest were found (Figure 13B). The first class consisted of all seasonal bacterial loads of Lake A.

Second class included all bacterial loads of all the seasons of Lake B and the bacterial loads of all the seasons of Lake C. The third class consisted of all seasonal bacterial loads of lake D and all seasonal bacterial loads of lake E. Turbidity, dissolved organic carbon (DOC), pH, *E. coli* and thermotolerant coliforms were higher at Lake D and Lake E, and decreased at Lake C and Lake B and then at Lake A (Figure 13C). These parameters evolve according to the direction of the water flow of the lacustrine system. In contrast, dissolved oxygen (O2) is more abundant at Lake A while Lake D and Lake E have the lowest levels of dissolved oxygen (O2).

Discussion

This work was undertaken to understand the dynamic of bacterial pollution within Yamoussoukro lakes and assess the risks related to the contamination of vegetable crops watered by lake waters. During all climatic seasons, very high bacterial loads were obtained in the lake waters and on vegetable crops compared to the recommended international standards of 100 *Escherichia coli* per 1000 mL of water (AFNOR, 1999b). They were similar to those generally found in most contaminated surfaces waters (Ishii et al., 2014; Mathai et al., 2018). Furthermore, it was found that the bacterial loads within Yamoussoukro lake increased according to the flow gradient of the waters. At Lake A, located further upstream of the system, pollution was the lowest followed by Lake B.

Table 2. Pearson matrix (n) between coliforms and different lake characteristics during 2015-2016 climate seasons

Variables	Thermotolerant Coliforms	*E. coli*	F1	F2
Thermotolerant Coliforms	1	0.8995	-0.9491	0.0898
E. coli	0.8995	1	-0.9063	0.0531
pH	0.4095	0.3377	-0.5191	-0.6462
Turb	0.7407	0.7718	-0.8482	-0.3133
O2	-0.8720	-0.7792	0.9414	-0.1379
T°C	0.3273	0.2563	-0.2989	0.8712
COD	0.8594	0.7834	-0.9339	0.0831

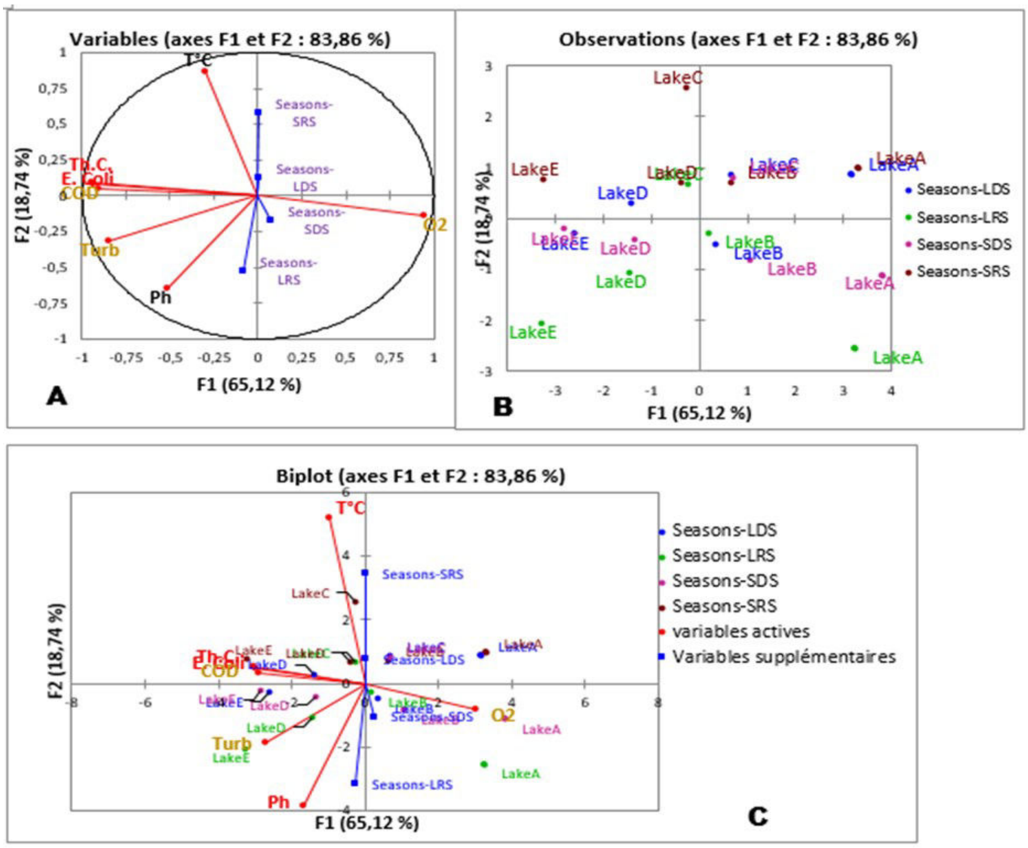

Figure 12: Principal component analysis of physicochemical parameters and bacterial populations in different lakes during 2015-2016 (F1 and F2 axes: 83.86%), *A: Figure: Variables, B: Figure: Observations, C: Figure: Biplot*

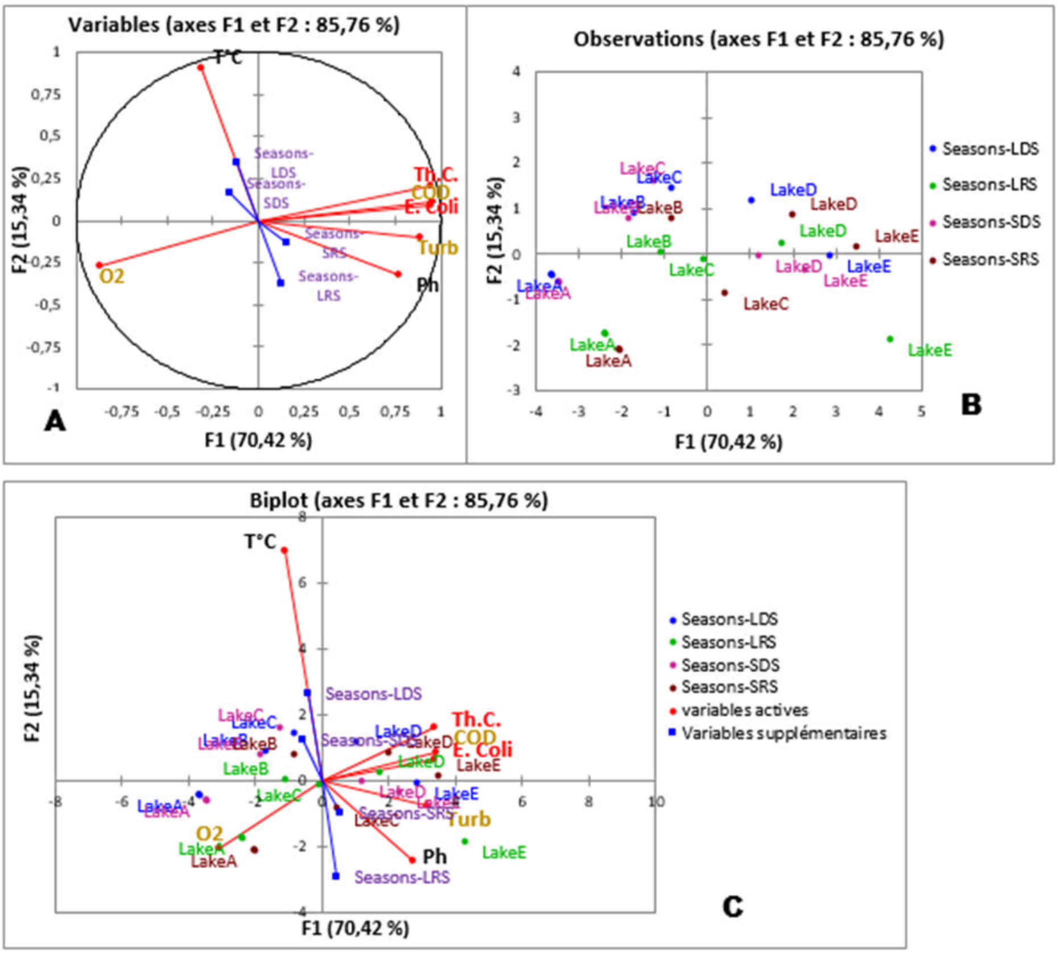

Figure 13: Principal component analysis of physicochemical parameters and bacterial populations in different lakes during 2016-2017. (F1 and F2 axes: 85.76%), *A: Figure: Variables, B: Figure: Observations, C: Figure: Biplot*

Table 3. Pearson matrix (n) between coliforms and different lake characteristics during the 2016-2017 climate seasons

Variables	**Thermotolerant**	***E. coli***	**F1**	**F2**
Thermotolerant	1	0.9305	0.9412	0.2083
E. coli	0.9305	1	0.9458	0.0857
pH	0.6723	0.7511	0.7693	-0.3178
Turb	0.7309	0.7520	0.8900	-0.1031
O2	-0.8477	-0.7501	-0.8690	-0.2721
T°C	-0.1167	-0.958	-0.3121	0.9083
COD	0.9093	0.9219	0.9552	0.1111

At Lakes C and D in the center of the lacustrine system, bacterial loads were intermediate in all the waters and vegetables. Lake E downstream of the lacustrine system had the highest bacterial loads. This was due to the location of Lake E downstream of the lake system. Indeed Lake E was the receptacle for others Lakes. Bacterial loads in lake waters were higher during rainy seasons while bacterial loads on vegetables were higher during dry seasons. Surface water pollution is usually more pronounced during the rainy season. Due to rainfall, runoff carries suspended solids that promote surface water bacterial pollution (Naidoo and Olaniran, 2014, Tornevi et al., 2014). During rainy seasons, the lakes were generally more loaded with bacteria and during dry seasons, vegetables were generally more loaded with bacteria. The reasons of this result could be in the cultural habits of gardeners (Callejon et al., 2015). In fact, lake waters were more used during dry seasons. This cultural practice is common in Africa. In Rwanda, about 60 % of farmers irrigated their vegetables during the dry season, while the rest entirely relied on rainfall (Ssemanda et al. (2018). Consequently during seasons, polluted water used for watering contaminated the vegetable crops. Lakes turbidity and dissolved organic carbon (DOC) evolved in the same direction with microorganisms, while dissolved oxygen (O2) evolved in opposite sense. Indeed, it is known that one of the important factors in the survival and growth of bacteria is the source of carbon (Ishii and Sadowsky, 2008).

Dissolved organic carbon content can provide information on the quantity of nutrients available in the environment and is as such a variable that allows bacterial abundances when it is high (Abdo et al. 2010).

This was also confirmed by our results. Bacterial loads from lake waters were also positively correlated with turbidity as previously obtained elsewhere (Smith et al., 2008; El-Amier et al., 2015, Taylor et al. 2011). In this study, it can be noticed that turbidity and dissolved organic carbon levels evolved in the same direction. In Yamoussoukro lakes, turbidity is due to particles rich in organic carbon (Abril et al., 2004). In surface water, turbidity is usually created by suspended solids such as debris of organic matter, living microorganisms, inorganic particles such as silt and clay (Bilottaa and Brazier, 2008). If the percentage of dissolved organic carbon is important in suspended solids, then bacterial loads can be positively correlated with turbidity (Taylor et al. 2011). In this study, dissolved oxygen was negatively correlated with the contents of DOC. Dissolved oxygen is proportional to the rate of degradation of organic matter which includes dissolved organic carbon according to Petitjean et al. (2004).

Thus dissolved oxygen is always negatively correlated with the contents of DOC. High levels of dissolved oxygen have a negative influence on the bacterial load. It has been also noted that the physicochemical properties for each of the lakes evolved according to climatic seasons. Jang et al., (2017) showed that load evolution of *E. coli* is influenced by its environmental conditions of survival. The fluctuation of bacterial loads (*E. coli* and thermotolerant coliforms) in the lakes is linked to the turbidity, dissolved organic carbon (DOC), climatic seasons and lake spatial position. During the rainy seasons, erosion phenomena accumulate pollutants from lakeside areas in the lakes by the phenomena of runoff which transports pollutants from upstream to downstream (Menon et al. 2003; Baral et al., 2018). It is therefore important, according to these results, to carry out sensitization campaigns among the population (Havelaar et al., 2015) in order to avoid, in the future, the proliferation of infectious diseases such as typhoid fever,
bacillary dysentery and cholera (Painter et al., 2013; Batz, 2014).

Conclusion

This study clearly showed that bacterial loads in Yamoussoukro lake waters evolved with seasons, lake spatial positions, turbidity and dissolved organic carbon (DOC). The bacterial loads in lake waters were higher during rainy seasons while the ones on vegetables were higher during dry seasons. At lakes upstream of the lake system, *E. coli* and thermotolerant coliforms pollution was the lowest. Lakes below the lake system had the highest bacterial loads. The lakes contained thermotolerant coliform strains of which *Escherichia coli* represented more than 85%, in waters and on the vegetables. The waters in Yamoussoukro lakes were not suitable for vegetable crop irrigation

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