










Research Article

Influence of Physico-Chemical Parameters on the Seasonal Dynamic of *Salmonella* spp Isolated from Urban Streams in Yaounde (Cameroon)

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Abstract

As water resources in urban areas are becoming increasingly degraded, due in large part to poor sanitation, a study has been conducted to examine the influence of physicochemical parameters and seasonal variation on the distribution of the enterobacteria *Escherichia coli* and *Salmonella* spp that have been isolated from the urban streams in the city of Yaounde. Bi-monthly water samples were collected from nine rivers during 12 months (April 2010 to March 2011). The isolation of bacterial germs was done according to the classical method. Physicochemical parameters were analyzed according to Standard methods. *Salmonella* spp was detected all over the studied year with a high prevalence of 49.4%. This prevalence varies from one season to another. *Escherichia coli* ranged between 2.5×10^3 to 67.1×10^3 UFC/100ml with highest prevalence observed during the long dry season. Physicochemical parameters revealed neutral to slightly alkaline waters (pH 6.7 – 8.8), with low mineralization (EC = 126 – 743 μ S/cm). Dissolved oxygen was generally less than 4 mg/l. Physicochemical parameters also showed temporal homogeneity in most of the variables (pH, EC, TDS, total hardness, alkalinity, Na, K, Mg, Ca). None of the physicochemical environmental variables analyzed had any specific influence on the presence of *Escherichia coli* or *Salmonella*. Furthermore, there was no significant correlation between the presence of *Escherichia coli* and *Salmonella* spp, as the sources of *Salmonella* spp contamination are probably different from those of *E. coli*. The observed pollution of rivers is related to the large anthropogenic activities in particular, the multiplicity of small farming closed to markets and houses, and husbandry activities along the streams which are important sources of organic matter. These rivers constitute a pool of *Salmonella* that can be easily disseminated in to different ecological systems and therefore represent a serious health risk for people who may come into direct or indirect contact with this pathogen.

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Keywords

Urban Streams, *Salmonella* spp, *E. coli*, Rivers Pollution, Yaounde

1. Introduction

Surface waters play a major role in assimilating or carrying off municipal waste water, industrial wastewater, runoff from agricultural activities, rainfall and run-off discharges. All these discharges greatly add nutrient load and make the rivers very susceptible to bacterial contamination. Studies have shown a strong relationship between urbanization and water quality of the surrounding surface water bodies [1, 2]. In particular, Chang (2008) showed that urban land cover was positively associated with increases in water pollution and identified as an important variable for the variations in water quality parameters [3].

Cities in developing countries generally host peri-urban settlements, which are characterized by high population density with inadequate basic service infrastructures for sanitation, drainage, waste disposal and piped water supply. This has commonly led to the reckless disposal of wastes and sewage on the ground surface and in to surface watercourses leading to the degradation of both surface and groundwater resources. In Cameroon, the degradation of water resources has been highlighted in several cities: Yaounde [4-8], Douala [9-11] and Bafoussam [12]. This degradation of water resources is in accordance with numerous studies, essentially associated with poor sanitation [13-16] and is a major cause of waterborne diseases [6, 17]. In Yaounde, the capital city of Cameroon, the risks of waterborne diseases are high throughout the city, both in urban and peri-urban areas, particularly in households located near streams and areas of stagnant wastewater. These have been shown to be the cause of about 15% of illnesses in households in the city of Yaounde and children under 5 years of age are the most affected and it represent 30% of cases recorded in all hospitals in the city [6]. According to the activity reports of Centre Pasteur du Cameroun (CPC), about 30% of diarrhea cases are caused by *Salmonella*, *Shigella* and enteropathogenic *Escherichia coli* [18]. The crucial role of urban rivers in the city of Yaounde as an important element in the *Salmonella* contamination cycle and the health consequences that could result has not been clearly established. We therefore set out to evaluate the prevalence of these pathogenic and potentially harmful bacteria in the rivers of the city of Yaounde, in a pollution context, and the possibly identifying the environmental factors that could affect their prevalence.

2. Materials and Methods

Study environment

The city of Yaounde is located between 3°45' and 3°59' North latitude, 11°20' and 11°40' East longitude, at an average altitude of 759 m. The city of Yaounde and its surroundings are subject to a particular climate described by Suchel (1972) as the 'Yaounde climate' [19]. It is a hot and humid equatorial climate with an average temperature of about (23 ± 2.5) °C, an average annual rainfall range between 1300 and 1500 mm per year. The climate is characterized by four seasons including a short rainy season (SRS) from March to June, a short dry season (SDS) from July to August, a long rainy season (LRS) from August to November and a long dry season (LDS) from December to March.

The hydrographic network is very dense and made up of streams which are mostly permanent, lakes and ponds. The River Mfoundi, the main river flowing through the city, is made up of several tributaries which flow into various places along the watercourse. Nine streams were studied. Eight of these rivers include the Mfoundi (Mf) and seven of its tributaries, namely the Ntem (N), Ekooza (Ek), Olezoa (O), Ewoue (E), Mingoa (Mi), Tongolo (T) and Abiergue-East (AE). The ninth river, Abiergue-West (AW), is part of the Mefou basin, which drains the western part of the city, currently experiencing rapid demographic growth. Figure 1. shows the study area and the locations of the sampling stations. Stations were chosen on the basis of their accessibility, the use of the watercourse by neighbouring populations, and potential or visible sources of pollution. Many pollution sources were identified near the stations: markets with their waste draining directly into the watercourse, latrines dug on riverbanks, toilets overflowing the river, domestic waste dumped on the river banks, and various anthropogenic activities (garages, vegetable gardens, laundry and horticulture). Some water points have only one pollution source, and others are affected by more than one. According to United States Central Intelligence Agency, the population of Yaounde is 3.066 million with a growth rate between 6% and 8% per annum [20].

The geology is made up of crystalline basement rocks such as paragneiss, migmatitic gneiss and schists of proterozoic age, metamorphosed in the pan-african orogeny at the northern margin of the Congo craton [21-23]. These medium to high grade metasediments are deeply weathered to a lateritic soil profile (ferralsols) of up to 20 m thickness [24, 25]. The bedrock is covered by alluvial hydromorphic clay and sand in the valleys [26] and ferralsols on the hillsides [24].

Sampling and analysis

Water samples were collected at thirteen selected sampling

points on the nine rivers from April 2010 to March 2011. The annotations 1 and 2 on some sampling points refer to two separate collection sites on the same river. Samples for physicochemical analysis were collected in 1 liter polyethylene bottles and those for bacteriological analysis in 500 ml sterile borosilicate glass bottles. The samples preserved in a cooler were quickly brought back to the laboratory for analy-

sis within 4 hours. Bacteriological analyses were performed at the Laboratory of Hydrobiology and Environment of the Faculty of Sciences of the University of Yaounde 1. The abiotic variables were measured at the Laboratory of Geochemical Analysis of Water in the Research Centre for Water and Climate Change / Institute of Geological and Mining Research.

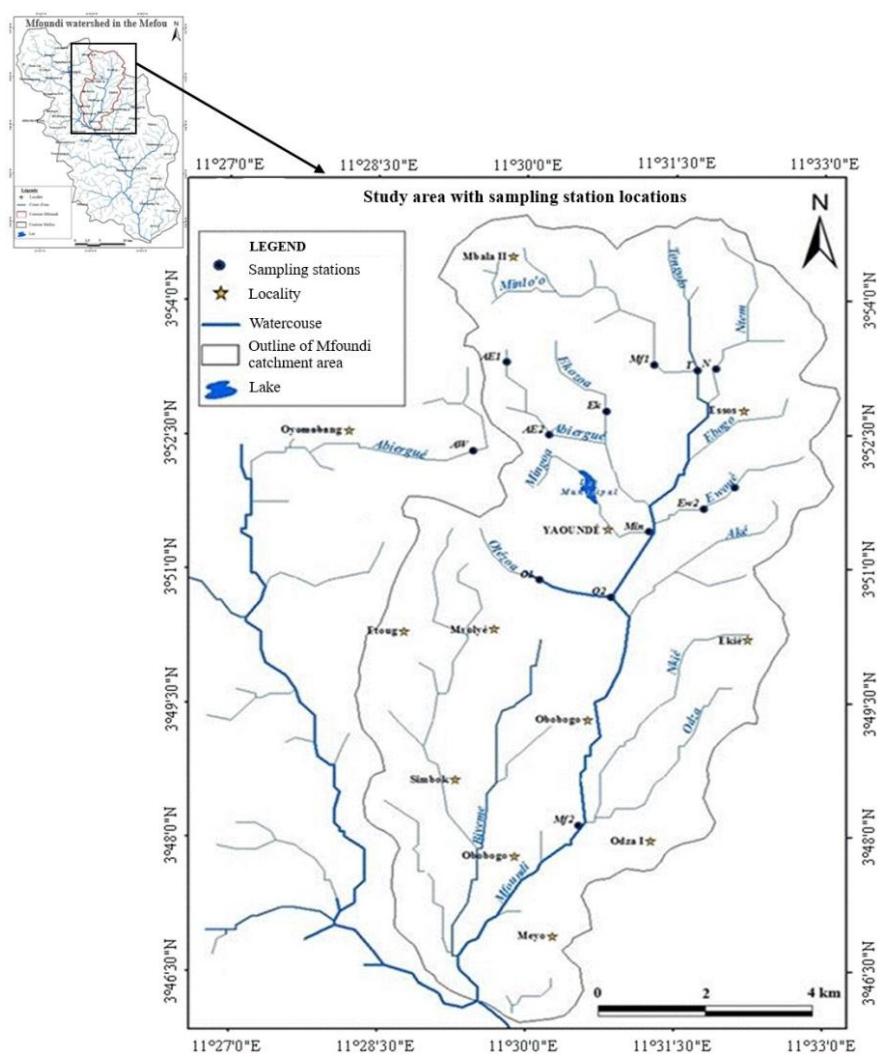


Figure 1. Study area with sampling station locations.

Hydrochemical parameters: Some physicochemical parameters were measured *in situ* with appropriate equipment: pH (pH meter WTW 315i), electrical conductivity and total dissolved solids (multiparameter conductivity meter WTW 330i) and dissolved oxygen (oximeter Hanna Instruments 9143). Total Suspended Solids (filtration and weighing), alkalinity (titration). Major ions were determined with non-suppressed ion chromatography (DIONEX France, ICS 90 and ICS 1100). Prior to ion chromatography analyses, samples were filtered with a 0.45 µm cellulose filter.

Bacteriology: The bacteriological analysis consisted of a quantitative investigation for *Escherichia coli* and a qualita-

tive investigation for *Salmonella* spp. The enrichment and isolation media were of the Biokar Diagnostics brand (France). The bacteria in our study were screened according to the recommended method of Rodier *et al.*, (2009) [27]. The isolation and enumeration of *E. coli* was carried out using the membrane filter technique, which consists of collecting by filtration through a sterile mixed esters of cellulose membrane from Millipore, France (porosity 0.45 µm; diameter 47 mm) all the bacteria in a specified volume of water to be analysed or a dilution of it. The membrane is then incubated on Endo agar (Biokar Diagnostics, France) at 44 °C during 18 to 24 hours of incubation after which the colonies are identified and

numbered using a colony counter. The number of colony-forming units (CFU) is then multiplied by the dilution factor and reported as CFU/100 ml of water according to the formula:

$$\text{CFU (abundance/100ml)} = \frac{\text{Number of colonies on Petridish}}{\text{Analyzed water volume (ml)}} * 100$$

Isolation and identification of *Salmonella* spp was performed based on the following protocol: pre-enrichment for 24 hours in double-concentration buffered peptone water (37 °C) prepared in the laboratory following Rodier *et al*, (2009), followed by enrichment for 24 hours in Müller-Kauffmann 1/10 (37 °C) and Rappaport-Vassiliadis 1/100 (43 °C) broths, then isolation for 24 hours at 37 °C on Hektoen enteric agar and Wilson-Blair Bismuth Sulfite Agar (BSA) and finally identification of suspected colonies. Enrichment broths and agar culture media were from Biokar Diagnostics, France. Biochemical profile of *Salmonella* spp was done using the Pasteur tube gallery for the identification of Enterobacteriaceae with media from Biorad and Biokar Diagnostics (France) to obtain the following profile: urease-, indole-, glucose+, gas+, lactose-, H₂S+, mannitol+, mobility+, citrate+, LDC+, ODC+, ADHA.

Data analysis: The graphs describing data were made with the Excel 2014 program. SPSS26 and XLSTAT 2007 were used for descriptive statistical analysis of data (mean, standard deviation, coefficient of variation), for calculation of correlations between variables and for principal component analysis to highlight similarities between different waters.

3. Results

Physicochemical characteristics

Results of physicochemical parameters are summarised in Table 1. The pH values range from 6.71 to 8.77 and vary slightly

over the year at most sites, with a standard deviation of 0.288.

Conductivity ranged from 126 to 743 µS/cm. The highest values were measured in Abiergue East 2 (408 to 743 µS/cm), Abiergue West (440 to 627 µS/cm) and Ewoue 2 (415 to 595 µS/cm). Its value increases during rainy seasons and decrease during dry seasons. The coefficient of variation (CV) of the electrical conductivity at each station is less than 20. Dissolved oxygen (DO) varies from 0.17 to 7.69 mg/l corresponding to 2.3% and 105% of DO respectively. Of the samples analysed, 23% are almost in an anaerobic state with a DO value below 1 mg/l. This situation is more observed in Ewoue 2, Olezoa 1 and Abiergue West. We also noticed that in Abiergue East 2, the anaerobic state is constant throughout the year. However, there are still 12% of the total samples who were of sufficient quality to support life in the Rivers and these samples were most collected from Mfoundi 1 and 2, Ekzoa, Ewoue 1, Olezoa 2 and Mingoa. Nitrate range from 0.7 to 130 mg/l. The highest nitrate concentrations were measured in Ewoue 2, Mfoundi 2, Abiergue East 2, Abiergue West, Ewoue 1, and the Ntem. The highest nitrate concentrations are observed from March to April, and then in July and October during the rainy seasons and the short dry season, while the lowest are in November and January during the long dry season. Orthophosphate levels vary between 0 and 3 mg/l and 90% of collected samples showed concentrations less than 0.5 mg/l. Chloride concentration in the water ranged from 6.97 to 79.84 mg/l. Highest concentrations were measured at the Abiergue East 2 and Ewoue 2 stations close to food markets, and also at Olezoa 1 and Abiergue West stations downstream of the densely populated areas. Overall, there is an increase in chloride from December to January at the peak of the long dry season and a decrease in October at the peak of the long rainy season. Concentrations of hydrogenocarbonate ions range from 25.1 to 276 mg/l with highest concentrations occurring in Abiergue East 2, Olezoa 1, Olezoa 2 and Ntem.

Table 1. Annual averages of physicochemical parameters at each site.

Stations		EC	SS	DO	pH	TDS	Alk	TH	Cl-	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	HCO ₃ ⁻	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺
		(µS/cm)	(mg/l)	(mg/l)	(UC)	(mg/l)	(mg/l)	(°F)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Mf1	Average	193.1	30.7	2.6	7.1	215.5	0.7	5.3	12.4	21.1	0.1	6.0	43.9	14.9	6.5	2.6	16.6
	SD	33.1	27.2	1.6	0.2	63.0	0.3	1.2	2.3	7.6	0.1	2.0	16.4	3.1	1.7	0.5	3.9
	CV	17.1	88.5	59.6	3.3	29.2	37.4	22.6	18.1	35.9	122.1	33.1	37.4	21.1	25.5	20.8	23.5
N	Average	400.6	54.7	1.6	7.2	405.1	1.8	8.8	30.5	36.7	0.6	5.9	112.5	36.1	15.9	4.6	27.7
	SD	50.9	44.8	1.1	0.2	53.6	0.4	1.8	10.9	23.4	1.0	3.8	24.0	9.4	4.7	1.1	5.6
	CV	12.7	81.9	66.9	2.4	13.2	21.3	20.2	35.7	63.7	173.4	65.3	21.3	25.9	29.3	23.2	20.3
T	Average	282.9	30.5	2.0	7.2	277.0	0.9	7.1	27.1	30.6	0.1	7.0	56.8	25.2	10.1	3.5	22.6
	SD	59.1	28.1	0.8	0.2	53.4	0.2	1.5	13.5	11.2	0.1	2.6	14.2	10.5	2.8	0.7	5.2

Stations		EC	SS	DO	pH	TDS	Alk	TH	Cl-	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	HCO ₃ ⁻	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺
		(µS/cm)	(mg/l)	(mg/l)	(UC)	(mg/l)	(mg/l)	(°F)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
EK	CV	20.9	91.9	40.7	2.7	19.3	25.0	21.4	49.7	36.6	170.8	37.2	25.0	41.8	27.8	19.3	23.0
	Average	347.8	24.4	3.2	7.3	356.4	1.3	10.04	27.4	34.9	0.2	9.9	79.1	26.0	9.3	5.1	31.6
	SD	35.0	11.8	1.5	0.2	32.5	0.4	1.30	4.3	7.9	0.3	2.9	21.6	3.4	1.0	0.6	4.7
AE1	CV	10.1	48.5	45.9	3.2	9.1	27.3	12.91	15.7	22.5	154.0	29.3	27.3	13.1	11.3	11.7	14.8
	Average	257.4	74.3	2.2	7.1	262.5	1.2	6.6	17.3	16.9	0.0	3.5	71.8	19.5	13.1	5.0	18.0
	SD	24.9	62.1	1.2	0.2	24.6	0.3	1.1	2.7	6.4	0.0	1.0	16.0	2.4	3.4	0.8	3.7
AE2	CV	9.7	83.6	55.1	3.1	9.4	22.3	17.4	15.7	38.0	129.5	28.1	22.3	12.2	26.2	16.8	20.6
	Average	624.4	49.6	0.9	7.3	648.3	2.7	11.1	55.3	47.9	0.3	11.1	165.0	48.2	23.6	7.0	32.7
	SD	88.4	28.6	0.7	0.1	56.8	0.8	2.6	15.2	34.9	0.4	5.3	48.3	13.7	7.2	1.6	8.0
EW1	CV	14.2	57.6	82.9	2.0	8.8	29.3	23.4	27.6	72.7	123.7	48.0	29.3	28.4	30.5	23.5	24.6
	Average	410.5	29.4	3.0	7.3	437.2	1.6	10.1	39.7	43.1	0.058	7.6	106.3	42.1	16.5	4.4	33.1
	SD	77.1	30.0	1.5	0.2	38.3	0.5	1.9	10.9	16.3	0.06	1.9	38.0	6.6	4.2	0.7	6.9
EW2	CV	18.8	102.0	50.4	2.9	8.8	33.1	19.1	27.3	37.9	101.2	24.9	35.7	15.7	25.5	15.6	20.8
	Average	500.3	36.6	2.0	7.2	488.4	1.7	9.33	40.6	55.8	0.1	9.4	95.3	43.7	18.8	4.7	29.5
	SD	50.5	37.8	1.4	0.2	44.4	0.6	2.42	13.4	33.1	0.1	2.5	33.4	8.5	4.3	1.0	9.0
Mi	CV	10.1	103.3	70.5	2.3	9.1	35.7	25.9	33.2	59.3	135.7	26.5	35.1	19.4	22.7	20.5	30.4
	Average	242.8	35.0	4.0	7.3	248.3	1.0	6.9	20.3	18.2	0.1	5.9	62.8	20.3	9.8	3.7	21.6
	SD	50.0	15.4	1.7	0.3	47.3	0.3	1.1	4.4	5.7	0.2	1.9	20.3	6.2	2.5	0.9	3.4
O1	CV	20.6	43.9	42.4	3.8	19.0	25.9	15.5	21.6	31.1	154.1	33.0	32.4	30.6	25.7	24.8	15.6
	Average	357.6	33.9	1.2	7.2	355.7	1.7	8.2	35.3	26.8	0.1	5.0	102.1	35.2	15.0	4.9	24.5
	SD	62.6	25.3	1.2	0.3	50.5	0.8	1.9	13.3	19.5	0.2	2.2	50.2	11.7	4.9	1.5	5.3
O2	CV	17.5	74.7	103.0	4.6	14.2	49.1	23.1	37.8	72.8	137.9	44.2	49.1	33.2	32.7	30.2	21.6
	Average	275.1	27.1	2.7	7.2	292.8	1.0	7.9	24.8	27.6	0.1	4.7	97.3	27.7	12.4	4.4	24.1
	SD	59.7	13.4	1.2	0.3	36.5	0.3	2.6	4.5	9.8	0.2	2.0	32.2	9.3	5.3	1.3	8.4
AW	CV	21.7	49.3	43.4	4.2	12.5	32.4	33.1	18.2	35.6	168.7	41.8	33.1	33.7	42.9	30.3	34.6
	Average	527.0	32.1	1.4	7.3	549.7	1.8	10.7	49.1	57.2	0.1	8.8	109.8	50.1	21.2	6.9	31.2
	SD	56.7	20.2	0.9	0.2	64.9	0.4	1.8	10.3	15.1	0.2	3.1	24.8	8.7	4.0	1.2	5.8
Mf2	CV	10.8	62.7	63.1	2.6	11.8	22.6	16.8	21.0	26.3	137.9	35.4	22.6	17.3	19.0	17.9	18.6
	Average	337.1	49.0	2.3	7.6	336.3	1.6	6.9	25.6	27.1	0.2	7.0	59.1	37.2	11.3	3.4	21.8
	SD	106.4	30.4	1.7	0.6	107.3	0.5	2.2	13.5	23.7	0.3	3.4	15.3	28.3	3.3	1.0	7.3
Mf2	CV	31.6	62.2	74.7	7.5	31.9	35.1	31.9	52.9	87.5	127.1	48.4	25.9	76.1	29.6	29.9	33.6

CV: coefficient of variation; EC: electrical conductivity; SS: suspended solids; DO: dissolved oxygen; Alk: alkalinity. TH: total hardness; TDS: total dissolved solid; SD: standard deviation.

The concentrations of the analysed cations vary between 8.82 and 109.74 mg/l for Sodium, 4.72 and 37.8 mg/l for Potassium, 2.01 and 9.40 mg/l for Magnesium, 5.22 and 51.61 mg/l for Calcium. Abiergue East 2, Ewoue 2 and Abiergue West were the

stations with highest concentrations of these ions.

The analysed waters were strongly dominated by bicarbonates for the anions ($\text{HCO}_3 > \text{Cl} > \text{NO}_3 > \text{SO}_4$). For the cations, a good equality between sodium and calcium was observed and

the ranking of dominance is $\text{Na/Ca} > \text{K} > \text{Mg}$. The projection of the chemical data on the Piper diagram (Figure 2) shows the samples located in the central zone indicating that, overall, they do not distinguish themselves in a dominant chemical facies and that their ionic composition is the result of a well-mixed and homogenised water source (rainwater, wastewater, runoff) and the absence of a major biogeochemical process. However, the

analysed waters tend to be equally shared between chloride facies (Mf1, T, Ek, Ew1, Ew2, Aw and Mf2) and bicarbonate facies (N, AE1, AE2, Mi, O1 and O2). These facies vary according to the seasons, with chloride facies dominating during the dry seasons and bicarbonate facies dominating during the wet seasons (Figure 3).

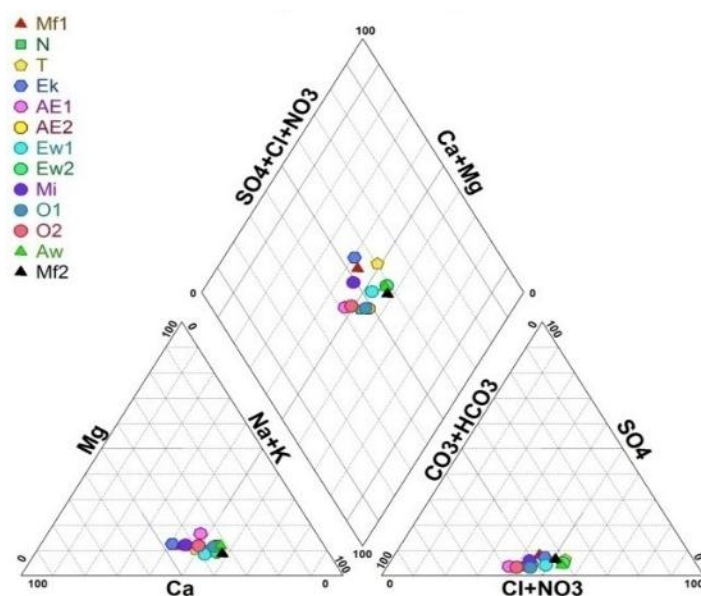


Figure 2. Hydrochemical facies of the analysed waters.

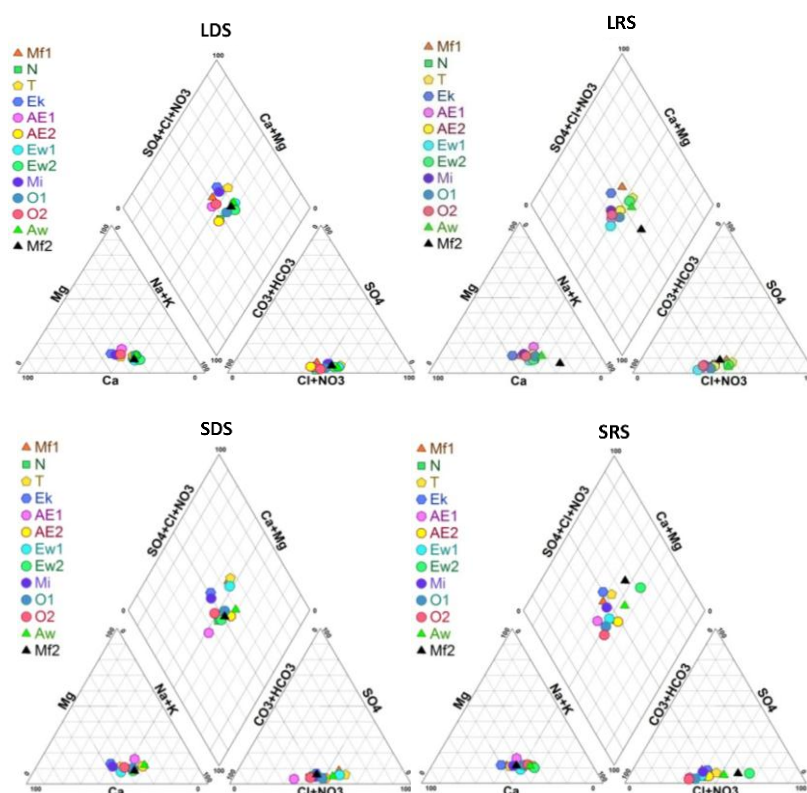


Figure 3. Seasonal trends in water facies at the stations.

Bacterial prevalence

Escherichia coli was isolated from all collected samples with highest concentration observed at Abiergue East 2 (250×10^3 CFU/100 ml), Olezoa 1 (150×10^3 CFU/100 ml), Ewoue 1 (150×10^3 CFU/100 ml) and Ntem (138 $\times 10^3$ CFU/100 ml), and lowest concentrations at Abiergue East 1, Mingoa and Olezoa 2 with less than 200 CFU/100 ml (Figure 4). *Salmonella* spp was isolated from 154 out of 312 samples, which

represents a global prevalence of 49.36%. The highest prevalence was observed during the long dry season (36.78%) followed by the long rainy season (26.63%) (Figure 6). The sites with the highest prevalence of *Salmonella* spp are located below food markets (Ewoue 2, Abiergue East 2, Ntem, Ewoue 1) and areas with high population density where considerable amounts of organic waste and faeces are produced (Olezoa 1, Mfoundi 1, Tongolo, Abiergue West).

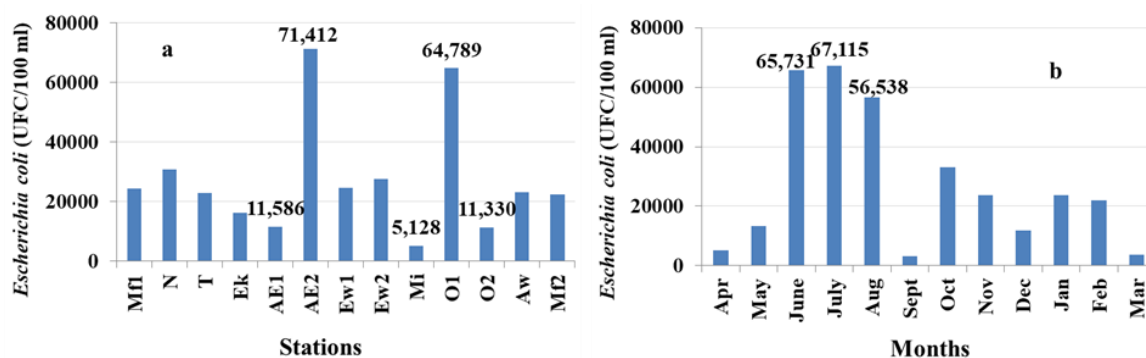


Figure 4. Spatial (a) and temporal (b) variations of *Escherichia coli*.

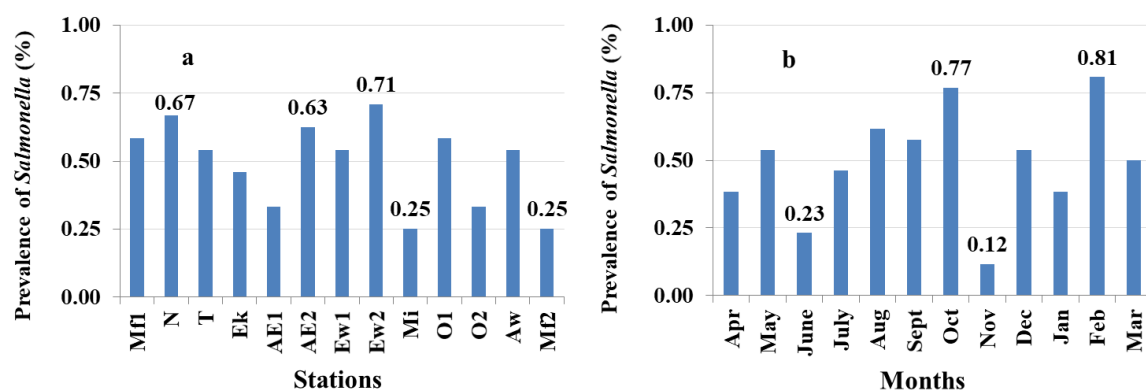


Figure 5. Spatial (a) and temporal (b) variation in the prevalence of *Salmonella* spp.

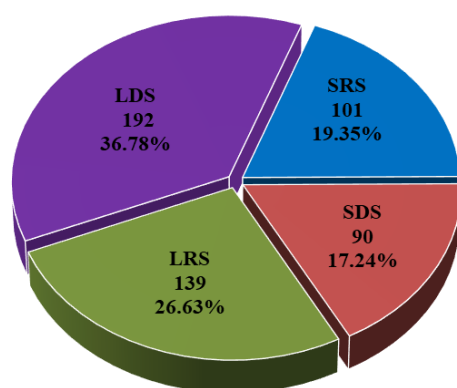


Figure 6. Seasonal distribution of *Salmonella* spp.

4. Discussion

Physicochemical characteristics

The pH values are within the range for natural surface water [28]. Soils in Yaounde are acidic [24] and this justifies the acidity of river water in sections not too much impacted by human activities, especially upstream [10]. The pH value evolves from neutral in the middle course to slightly alkaline in the lower course of the river. This evolution could be the result of a progressive mineralisation along the watercourse most importantly the dissolution of geologic materials which release ions in water as noted by Kuitcha *et al*, (2010) [5]. It could also result from external inputs from human activities most importantly domestic sewage which puts alkaline ions in to the river system [29, 30]. Concerning the electrical con-

ductivity, the high concentrations observed at Abiergue East 2, Abiergue West and Ewoue 2 could be due to that these streams flow through markets and densely populated areas from where they are loaded with nutrients and organic wastes drained directly into the streams. The decrease in conductivity in all stations during the rainy seasons could be the result of ion dilution in the water meanwhile evaporation during dry seasons may explain the increase in this parameter due to the mobility of ions in the water caused by the temperature rise. A similar situation has been observed by Jordao *et al.* (2007); Nougang, (2012); and Reggam *et al.* (2015) in analogous studies [31-33]. The low values of the coefficient of variation reflect that the conductivity at each station are fairly homogeneous, which is a sign that the factors influencing this parameter have the same trend throughout the year. On the other hand, on a spatial level, we noted considerable heterogeneity of the electrical conductivity showing that its concentration at each station depends mainly on external sources of pollution along the watercourses. The anaerobic situation mostly observed in Ewoue 2, Olezoa 1 and Abiergue West during the long dry season is due to the fact that the evaporation and the increase in temperature result in a reduction in the quantity of dissolved oxygen available in the environment. In the particular case of Abiergue East 2, we are dealing with serious pollution of this river exacerbated by the actions of the riverside populations and already highlighted by Foto (1989), Djuikom (1998) and Djuikom *et al.* (2009) who noted, among other things, the gradual deterioration in the water quality of this river from the upstream to the downstream [10, 34, 35]. The lack of oxygen leads to advanced degradation of the affected aquatic ecosystems, which can hardly support life in such conditions. But this situation is not completely out of control, because at some times during the year, the oxygen level increases significantly, leading to an improved water quality in the stations Mfoundi 1 and 2, Ekozoa, Ewoue 1, Olezoa 2 and Mingoa, who are located downstream of marshy areas situated along the course of rivers. Thus, the swamps serve to resorb the organic pollution generated upstream. This observation has already been made by Naah (2013) who showed that in the Mingoa River, for example, the marsh upstream from the Municipal Lake contributes significantly to the retention of contaminants [36].

Possible sources of high concentrations of nitrate in Ewoue 2, Mfoundi 2, Abiergue East 2, Abiergue West, Ewoue 1, and Ntem include human activities such as discharges from pit latrines and septic tanks, and a large input of organic matter which may produce nitrates through decomposition [37]. This could be explained by the fact that during the rainy season, the oxygen level in rivers is raised, which favours mineralising activity by micro-organisms, resulting in an increase in nitrates in the waters. Low concentrations of orthophosphates in the collected samples is corroborated by an observation made by INS-BGR (2013), which noted that although a large quantity of phosphorus (in the order of 600 tonnes of P/year) is produced by the urban and peri-urban population of Yaounde,

the contrast with the concentrations measured in water clearly shows that only small quantities of dissolved phosphorus (as phosphate anion (PO_4^{3-}) and its hydrolysed forms) are detected in the environment and in groundwater and surface water [38]. Free-pollution Rivers generally have chloride levels less than 25 mg/l [27], a value largely exceeded in 57% of the analysed samples. Sources of chloride in the urban environment are usually wood ash, household waste, domestic wastewater and mainly urine [38, 39]. Hydrogencarbonate ions in the rivers could result from meteoric water that leaches the surface of the soil, bringing carbonic acid that will be ionised into bicarbonates and carbonates. Another source of bicarbonate in these streams according to Kuitcha (2013) could come from the use of lime by the local population which subsequently flow through run-off and ends up in the rivers [40].

The highest concentrations of both sodium and potassium observed in the Abiergue East 2, Ewoue 2 and Abiergue West stations reflects the preponderance of their anthropogenic origin as these stations are located just below markets or downstream densely populated areas. Although potassium and sodium are natural elements that are important for the growth of living organisms with similar effects, the presence of potassium in water more than 2 or 3 mg/l is an indication of pollution by agricultural effluents (liquid manure, etc.) or food industry effluents [40]. The same evolution of magnesium and calcium in time and space, with an increase during the rainy seasons could be due to soils leaching and also from faeces because of inadequate sanitation [27, 40].

The preference for chloride facies at dry seasons could be explained by the fact that during this period, the concentration of mineral salts caused by evapotranspiration and discharges from various human activities contributes in increasing the conductivity and the dominance of chloride ions, which are very little involved in biological processes, thus leading to a dominance of the chloride facies. Conversely, during the rainy season, the dilution of mineral salts by rainwater and run-off helps to reduce the conductivity and increases the bicarbonate ions in the water (dissolution of atmospheric and organic CO_2), resulting in the ascendancy of bicarbonate facies.

Bacterial prevalence

The continuous occurrence of *Escherichia coli* in all samples is due to the fact that people use rivers to discharge their faeces, enriching them with organic matter and thus creating a favourable environment for the persistence and growth of this bacterial species [32]. This can be demonstrated by the large number of toilets (with barrels or on stilts) clearly visible alongside rivers, to which should be added domestic discharges and waste from various farms situated all along these streams. The high concentrations of *E. coli* found in all watercourses testify to their high content of biodegradable matter. This observation, already noted by Djuikom (1998), is characteristic of urban rivers, which pay a heavy price in terms of pollution due to anthropic pressure [35, 41]. On the other hand, low proportions of *E. coli* observed at Abiergue East 1, Mingoa

and Olezoa 2 were probably due to that these stations are located in the upstream section of the river (Abiergue East 1) or after the wet areas along the river's course (Mingoa and Olezoa 2), which have resorbed part of the pollutant load, thereby reducing the amount of elements which might boost the growth of *E. coli*. This once again underlines the importance of the marshy areas located between the pollution sources and the sampling points which resorb contaminants [36].

Although the high sunlight during the long dry season seems to have a bactericidal impact on microorganisms; it also warms waters to more favourable temperatures for their growth, which could explain the increase in *Salmonella* spp found during the long dry season. Haley *et al*, (2009) and Bertrand and Mattheus (2011) found a positive correlation between the warm season and the frequency of salmonellae [42, 43]. Similarly, the Food and Agriculture Organization report on Risk Assessment of *Salmonella* in Eggs and Broilers has noted seasonal variations in the incidence of human salmonellosis with a peak during warmer months [44]. Other authors have however observed a high prevalence of *Salmonella* spp in the rainy season [45, 46]. During these periods, run-off water drains waste and a considerable quantity of micro-organisms, including *Salmonella*, into the city's streams. The Yaounde's streams provide a favourable environment for the survival of salmonellae, as they receive all forms of waste from markets, homes and various activities, which produce organic matter that makes waters more suitable to their proliferation. This could explain the highest prevalence of *Salmonella* spp at the stations Ewoue 2, Abiergue East 2, Ntem, Ewoue 1, Olezoa 1, Mfoundi 1, Tongolo

and Abiergue West. Similar cases are presented by Jyoti *et al*, (2010), Bonadonna *et al*, (2006) and Lemarchand and Lebarron (2003) who observed an increase in the prevalence of *Salmonella* in watersheds strongly influenced by human activities [47-49]. Winfield and Groisman (2003) had observed very high *Salmonella*'s prevalence in poultry, livestock and plants compared to the prevalence in humans, showing that *Salmonella* is widespread in the environment [50]. The high prevalence of *Escherichia coli* and *Salmonella* in Yaounde's rivers presents a serious health risk, due to various activities that take place in the riverside area, such as illegal laundries, where water is used to clean cars, and where the people who work in these places can become infected. Another example is the vegetable crops cultivated alongside the rivers, which, if not disinfected and cooked properly, expose people to the risk of contracting salmonellosis.

Relationship between physicochemical and bacteriological variables

Globally, it can be seen that only pH is significantly correlated with *E. coli*'s abundance (Table 2). This could be due to the fact that the normal pH of faeces is slightly alkaline and, once in the environment, *E. coli* finds a pH in the receiving medium that is favourable to its growth and survival. This could explain the high levels of *E. coli* isolated throughout our study, up to 10^4 . The lack of correlation between *E. coli* and the other measured variables could have several causes, including the great spatial and temporal variability of this bacterium and the diversity of the sources of faecal contamination, which could mask any correlation with a specific parameter.

Table 2. Correlation between physicochemical and biological variables.

Variables	EC	SS	DO	pH	TDS	Alk	TH	Cl ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	HCO ₃ ⁻	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	<i>E. coli</i> S.spp
EC	1																
SS	0.086	1															
DO	-0.410	-0.079	1														
pH	0.222	-0.102	0.253	1													
TDS	0.934	0.077	-0.428	0.212	1												
Alk	0.711	0.173	-0.250	0.299	0.716	1											
TH	0.658	-0.121	-0.119	0.196	0.703	0.554	1										
Cl ⁻	0.770	-0.078	-0.349	0.150	0.775	0.565	0.700	1									
NO ₃ ⁻	0.478	-0.147	-0.154	0.081	0.490	0.272	0.427	0.514	1								
PO ₄ ³⁻	0.063	-0.051	0.049	0.113	0.068	0.165	0.156	0.105	-0.042	1							
SO ₄ ²⁻	0.337	-0.036	0.158	0.253	0.368	0.263	0.502	0.378	0.325	0.084	1						
HCO ₃ ⁻	0.627	0.069	-0.224	0.169	0.617	0.722	0.529	0.543	0.264	0.125	0.172	1					
Na ⁺	0.776	-0.046	-0.322	0.159	0.799	0.620	0.726	0.845	0.456	0.089	0.284	0.531	1				
K ⁺	0.718	0.058	-0.248	0.160	0.730	0.633	0.707	0.744	0.370	0.137	0.275	0.581	0.857	1			
Mg ²⁺	0.584	0.042	-0.237	0.020	0.612	0.510	0.784	0.658	0.384	0.098	0.244	0.506	0.703	0.785	1		

Variables	EC	SS	DO	pH	TDS	Alk	TH	Cl ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	HCO ₃ ⁻	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	<i>E. coli</i>	<i>S.spp</i>
Ca ²⁺	0.623	-0.142	-0.056	0.241	0.667	0.522	0.980	0.649	0.400	0.169	0.546	0.485	0.672	0.638	0.666	1		
<i>E. coli</i>	0.153	-0.056	-0.129	0.223	0.123	0.143	-0.036	0.050	0.073	-0.023	0.029	0.070	0.047	0.066	-0.147	-0.020	1	
<i>S. spp</i>	0.243	-0.102	-0.287	-0.060	0.243	0.159	0.215	0.199	0.147	0.014	0.135	0.193	0.140	0.207	0.139	0.214	0.079	1

Values in bold are significantly different from 0 at the significance level alpha=0.05

EC: electrical conductivity; SS: suspended solids; DO: dissolved oxygen; Alk: alkalinity. TH: total hardness; TDS: total dissolved solid.

The analysis of the correlations between *E. coli* and the physicochemical variables at each station (Table 3) shows that none of these characteristics has a significant influence on *E. coli* abundances, which seem to be more closely linked to the overall chemical state of waters resulting from the combined properties of the elements and indicated by the pH.

Concerning *Salmonella* spp, there was globally a significant

and positive correlation with electrical conductivity, TDS, alkalinity and total hardness, which are variables which reflect the mineralisation of water, also influenced by the concentration of dissolved ions (Table 2). It seems that the chemical properties of the rivers offer a good environment for the survival of these bacteria (high conductivity, slow water flow).

Table 3. Correlation between and *E. coli* and physico-chemical variables in each station.

Variables	Mf1	N	T	Ek	AE1	AE2	Ew1	Ew2	Mi	O1	O2	Aw	Mf2
EC	-0.347	-0.476	-0.364	-0.345	-0.531	-0.235	0.056	-0.522	0.018	0.280	0.186	-0.305	0.126
SS	0.018	-0.574	-0.081	-0.070	-0.238	-0.077	0.294	-0.280	0.172	0.158	0.337	-0.203	0.063
DO	0.543	0.000	0.214	0.486	0.256	-0.235	-0.056	0.469	-0.011	-0.225	0.168	0.175	-0.483
pH	-0.221	0.420	-0.354	0.500	0.448	0.473	0.441	0.308	0.473	-0.347	0.560	0.322	0.357
TDS	0.093	-0.438	-0.719	-0.458	-0.503	-0.067	-0.123	-0.277	-0.067	0.214	-0.147	-0.469	0.112
Alk	-0.375	0.161	-0.212	0.225	-0.259	-0.455	-0.385	0.200	0.147	0.291	0.130	-0.455	0.350
TH	-0.375	-0.364	-0.322	-0.178	-0.287	0.277	-0.385	0.236	-0.462	-0.315	-0.406	-0.700	-0.105
Cl ⁻	-0.039	-0.224	-0.277	-0.606	-0.434	0.357	0.045	-0.371	-0.357	-0.144	-0.522	-0.483	0.322
NO ₃ ⁻	0.032	-0.074	-0.371	0.346	-0.406	0.305	0.427	-0.123	-0.098	-0.277	-0.553	-0.014	-0.084
PO ₄ ³⁻	0.187	-0.173	0.413	-0.221	-0.258	-0.116	-0.189	0.296	0.092	-0.203	-0.617	-0.073	0.276
SO ₄ ²⁻	-0.046	0.070	-0.490	0.077	-0.650	0.263	-0.009	-0.109	0.039	-0.567	0.270	-0.273	0.063
HCO ₃ ⁻	-0.375	0.161	-0.212	0.225	-0.259	-0.455	-0.112	0.123	0.256	0.291	0.077	-0.455	0.105
Na ⁺	-0.336	-0.462	-0.445	-0.720	-0.217	0.256	-0.343	-0.364	-0.511	0.011	-0.480	-0.400	0.622
K ⁺	-0.340	-0.312	-0.207	-0.278	0.000	0.056	-0.168	-0.164	-0.193	-0.063	-0.210	-0.300	0.434
Mg ²⁺	-0.445	-0.560	-0.508	-0.720	-0.538	0.483	-0.657	-0.264	-0.371	-0.235	-0.658	-0.509	-0.028
Ca ²⁺	-0.389	-0.336	-0.350	-0.187	-0.105	0.368	-0.371	0.236	-0.301	-0.315	-0.392	-0.718	-0.140

Values in bold are significantly different from 0 at the significance level alpha=0.05

EC: electrical conductivity; SS: suspended solids; DO: dissolved oxygen; Alk: alkalinity. TH: total hardness; TDS: total dissolved solid.

Statistical analysis of the correlations between *Salmonella* spp and the physicochemical variables in each station shows individual correlations from one site to another (Table 4). This complexity of correlations may be due to the heterogeneity of pollution sources, which may vary in specificity, composition and load from one station to another. In addition, there could be

local environmental factors (inhibiting substances, predators, river hydrodynamics, etc.) that could influence the prevalence of *Salmonella* spp independently of the measured variables. Therefore, the occurrence of *Salmonella* spp in these environments is more likely to be linked to the presence of a wide range of human activities, in particular livestock farming, which sup-

plies faecal matter, and surrounding crops, which use it as fertiliser. The specific nature of these activities and their variability

throughout various sub-catchments of the city's hydro network are reflected in the prevalence of salmonellae.

Table 4. Correlation between and *Salmonella* and physico-chemical variables in each station.

Variables	Mf1	N	T	Ek	AE1	AE2	Ew1	Ew2	Mi	O1	O2	Aw	Mf2
EC	0.148	0.091	0.427	0.558	0.307	0.103	0.011	0.145	0.496	0.733	0.289	0.448	-0.051
SS	0.169	0.138	0.172	0.054	0.026	-0.057	-0.428	0.392	-0.436	0.517	-0.484	-0.155	-0.270
DO	-0.296	0.131	-0.688	-0.104	0.168	0.120	-0.666	-0.410	-0.465	0.092	-0.131	-0.456	-0.305
pH	-0.285	-0.087	-0.075	-0.082	0.479	-0.269	-0.027	-0.569	0.016	-0.202	-0.169	0.081	-0.012
TDS	0.360	0.025	0.108	0.769	0.161	-0.188	0.215	-0.099	0.422	0.557	0.430	0.382	0.020
Alk	-0.011	-0.546	-0.259	0.183	0.740	-0.159	0.050	-0.739	0.684	0.350	0.378	0.106	0.297
TH	0.106	-0.011	-0.100	0.764	0.161	0.396	0.480	-0.581	-0.137	0.559	0.727	-0.046	0.379
Cl ⁻	0.127	-0.222	0.065	0.375	0.232	0.358	0.084	0.057	-0.274	0.637	0.375	0.170	0.070
NO ₃ ⁻	0.116	-0.309	0.541	0.141	0.314	-0.018	-0.061	0.021	-0.629	0.386	-0.195	0.421	0.293
PO ₄ ³⁻	-0.220	-0.082	-0.476	0.427	-0.004	-0.220	0.440	-0.521	-0.035	0.363	0.074	0.374	0.138
SO ₄ ²⁻	-0.063	0.036	0.025	0.600	0.254	0.304	0.136	0.018	-0.340	-0.060	0.292	-0.124	0.207
HCO ₃ ⁻	-0.011	-0.546	-0.259	0.183	0.740	-0.159	0.061	0.357	0.176	0.350	0.311	0.106	0.387
Na ⁺	0.180	0.211	-0.032	0.337	0.150	0.142	-0.193	-0.134	-0.172	0.542	0.596	0.069	-0.227
K ⁺	-0.085	0.255	-0.301	0.661	0.404	0.503	-0.086	-0.498	-0.168	0.602	0.498	0.083	0.004
Mg ²⁺	0.137	0.167	0.108	0.314	0.138	0.464	0.161	-0.682	-0.277	0.535	0.660	0.083	0.145
Ca ²⁺	0.095	-0.036	-0.147	0.811	0.209	0.333	0.508	-0.581	-0.086	0.559	0.663	-0.032	0.496
<i>E. coli</i>	0.106	-0.180	-0.431	-0.108	-0.146	0.231	0.082	-0.189	0.074	0.209	-0.032	-0.481	-0.070

Values in bold are significantly different from 0 at the significance level $\alpha=0.05$

EC: electrical conductivity; SS: suspended solids; DO: dissolved oxygen; Alk: alkalinity. TH: total hardness; TDS: total dissolved solid.

In raw water, the presence of *Escherichia coli*, considered in several countries to be the most reliable indicator of faecal contamination, is not only a presumption of the presence of human or animal faecal matter, but also of all kinds of pathogenic micro-organisms that may be associated with it. The absence of any significant correlation between *Salmonella* spp and *E. coli* suggests that there are different sources of *Salmonella* contamination from those of *E. coli*. Several studies however shown a very weak correlations between bacterial bioindicators and pathogenic bacteria in surface waters [51].

Principal component analysis

The results of the principal component analysis (PCA) show 4 factors with an eigenvalue greater than or equal to 1

according to the Kaiser criterion, and representing 71.2% of the expressed variance (Table 5). Analysis of the correlations between the variables and factors (Table 6) shows that factor F1 is positively and strongly correlated with TDS, EC, K⁺, Cl⁻, TH, Mg²⁺, Na⁺, Ca²⁺, alkalinity, HCO₃⁻, NO₃⁻ and SO₄²⁻ and is considered to be the expression of mineralisation in the analysed waters. Factor F2, mainly correlated with dissolved oxygen, is considered to be the oxygenation axis of the water and indicates the ability of the environment to be self-purifying and to support life in the studied stations.

Factors 3 and 4, correlated with pH and TSS respectively, are the axis of the pH gradient and the axis of water solid pollution.

Table 5. Eigenvalues and percentages of the expressed variance.

Variables	F1	F2	F3	F4
Eigenvalue	7.430	1.519	1.312	1.131

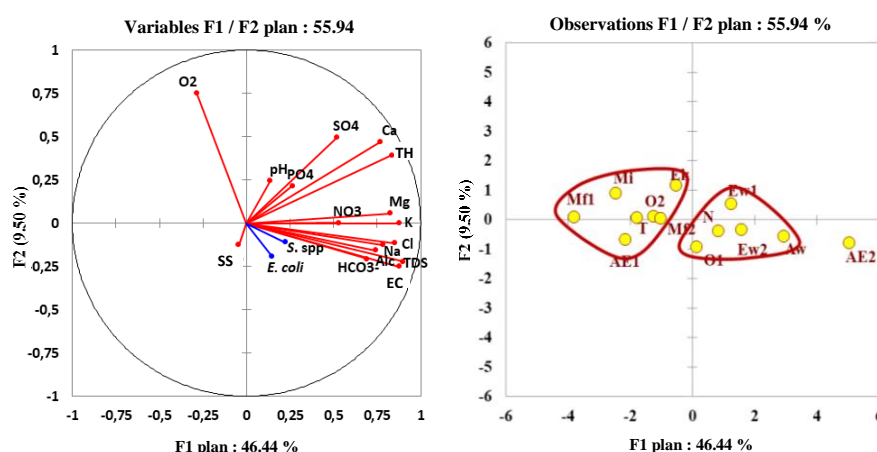
Variables	F1	F2	F3	F4
Variability (%)	46.440	9.497	8.199	7.072
Cumulated percentage	46.440	55.936	64.135	71.207

Table 6. Correlations between variables and factors.

Variables	F1	F2	F3	F4
EC	0.877	-0.252	0.139	-0.100
SS	-0.045	-0.126	0.513	0.619
DO	-0.285	0.751	0.286	0.016
pH	0.136	0.247	0.634	-0.516
TDS	0.900	-0.221	0.097	-0.077
Alk	0.742	-0.157	0.444	0.081
TH	0.836	0.392	-0.209	0.116
Cl ⁻	0.854	-0.116	-0.125	-0.148
NO ₃ ⁻	0.532	0.002	-0.252	-0.294
PO ₄ ³⁻	0.263	0.215	-0.074	0.475
SO ₄ ²⁻	0.520	0.497	0.141	-0.082
HCO ₃ ⁻	0.692	-0.207	0.303	0.146
Na ⁺	0.786	-0.125	0.045	-0.164
K ⁺	0.880	-0.002	-0.070	0.136
Mg ²⁺	0.826	0.057	-0.247	0.174
Ca ²⁺	0.771	0.470	-0.179	0.087
<i>E. coli</i>	0.147	-0.194	0.030	-0.082
<i>S. spp</i>	0.222	-0.109	-0.155	0.054

Values in bold are significantly different from 0 at the significance level $\alpha=0.05$

EC: electrical conductivity; SS: suspended solids; DO: dissolved oxygen; Alk: alkalinity. TH: total hardness; TDS: total dissolved solid.

**Figure 7.** The F1/F2 plan projection of the variables and stations.

The F1 - F2 plan, with 55.94% of the expressed total variance, was chosen as the one that significantly reflects the information expressed in the results (Figure 7). Plotting of the different stations in this factorial plan shows that the stations are positioned on the Factor 1 axis in the increasing mineralization direction from left to right and on the Factor 2 axis in the gradual oxygenation capacity direction from bottom to top (Figure 7). The stations were classified into three groups based on these environmental characteristics. Group I includes Mfoundi 1, Mingoa, Abiergue East 1, Tongolo, Olezoa 2, Ekozoa and Mfoundi 2, with low to medium mineralisation and poor oxygenation quality, indicating environments whose capacity to support life is under serious threat. Group II includes the Olezoa 1, Ntem, Ewoue 1 and Ewoue 2 Abiergue West stations, which are highly mineralised and of very low oxygenation quality (generally less than 2 mg/l), indicating heavily polluted waters in which the survival of most aquatic organisms is difficult, or even impossible. These environments are generally dominated by species that are tolerant to hypoxia. These are also the sites where the abundance of *Escherichia coli* is very high compared with Group I stations. Group III has only one station, Abiergue East 2, characterised by quasi-permanent anoxic conditions throughout the study period, significant mineralisation due to dissolved ion concentrations that are generally the highest, and faecal coliform values well above those of all the stations.

5. Conclusions

The results of this study show that water pollution in the Yaounde city is increasing due to higher anthropogenic pressure associated with dense housing and the proliferation of activities which are major sources of organic matter. Most of the analysed water is fairly low in oxygen and most of the physico-chemical variables increase during the rainy seasons, with a bicarbonate facies predominating. Water mineralisation is seasonally variable and is of both natural and anthropogenic origin, with anthropogenic sources dominating. The levels of this mineralisation depend on the pollution sources nearby the watercourse. However, wetlands downstream of pollution sources are important ecological areas that can absorb pollutants. *Salmonella* are present in Yaounde's rivers throughout the year, with a high prevalence. Yaounde's rivers are a reservoir for *Salmonella* strains, which can disseminate between different ecosystems. The level of contamination is high, and there are health risks for people who may come into direct or indirect contact with these bacteria.

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Data Availability Statement

The data are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

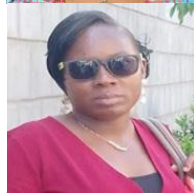


Henriette Ateba Bessa is a Hydrobiologist research officer at the Research Centre for Water and Climate Change (RCWCC) of the Institute of Geological and Mining Research (IGMR) since 2002. She completed her Master in Hydrobiology and Water quality in 2000 from the Yaounde I University and is currently completing a PhD thesis on Hydrobiology and Environment. She participates in research collaborations with the French Institute of Research for Development since 2012 within the frame of the CZO Multiscale Tropical Catchments. Ateba Bessa has been appointed since 2015 as the Chief of the Laboratory of Geochemical Analysis of Water of the Research Centre for Water and Climate Change. She has reviewed articles for various journals and has been invited as a Session Chair at many

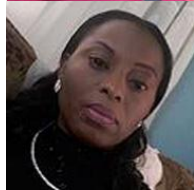
international conferences. She has been recently selected as Member of the Standing Committee on Measurements, Instrumentation and Traceability of WMO as expert from Cameroon.



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Bernadette Nka Nnomo is a Senior researcher at the RCWCC of the IGMR since 2017. She completed her PhD in Hydrology in 2016 from the Pierre et Marie Curie University of Paris, and her Msc in Water and Environment from the International Institute of Water and Environment Engineering of Ouagadougou in 2010. Dr. Nka Nnomo has participated in multiple international research collaboration projects in recent years. She has been recently selected as Member of Standing Committee on Earth Observing Systems and Monitoring Networks of the World Meteorological Organization as Expert from Cameroon. She has also been appointed as Co-Lead of the hydrology and freshwater observatory of the Congo Rainforest Alliance for Forest Training for Sustainable Development and has been invited as

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Blandine Pulchérie Tamatcho Kweyang is a Senior Lecturer at the Department of Microbiology of the University of Yaounde I. She completed her PhD in Microbiology from Yaounde I University in 2016, and her Master in Animal Biology in the same institution in 1996. He has participated in multiple research collaboration projects and has supervised numerous MSc research works in recent years. Dr. Tamatcho Kweyang currently serves as reviewer for many scientific articles in various journals and she has been invited as a Technical Committee Member in national conferences and a Session Chair at international conferences. She also serves as reviewer for many scientific articles in various journals.



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Thomas Njine is an Emeritus Professor of the University of Yaounde I and the former Dean of the Faculty of Science of the same university from 2005 to 2009. He has participated in multiple international research collaboration projects and supervised many PhD theses. He was also the founder of the Hydrobiology and Water Quality section of the Department of Animal Biology. He has served on the Editorial Boards of numerous publications and has been invited as a Keynote Speaker, Technical Committee and Judge at many international conferences. Pr. Njine is currently the Honorary Dean at PKFokam Institute of Excellence in Yaounde, Cameroon.

Research Field

Henriette Ateba Bessa: Hydrobiology and Water Quality, Water and environmental microbiology, Antimicrobial susceptibility, Biostatistics, Water Resources policies and management

Mireille Ebiane Nougang: Hydrobiology and Water Quality, Water and environmental microbiology, Antimicrobial susceptibility, Plant antimicrobial activity, Biostatistics

Ghislaine Madjiki Adjia: Hydrobiology and Water Quality, Ecohydrology, GIS and remote sensing, Flood trends and flood risk assessment, Water Resources policies and management

Gloria Eneke Takem: Hydrobiology and Water Quality, Hydrogeology, Water Resources policies and management

Bernadette Nka Nnomo: Statistical hydrology, Flood trends and flood risk assessment, Water Resources policies and management

Blandine Pulchérie Tamatcho Kweyang: Hydrobiology and Water Quality, Water and environmental microbiology, Antimicrobial susceptibility, Plant antimicrobial activity

Chrétien Lontsi Djimeli: Hydrobiology and Water Quality, Water and environmental microbiology, Antimicrobial susceptibility, Plant antimicrobial activity, Biostatistics

Olive Noah Ewoti: Hydrobiology and Water Quality, Water and environmental microbiology, Antimicrobial susceptibility, Plant antimicrobial activity

Jean Samuel Eheth: Hydrobiology and Water Quality, Water and environmental microbiology, Antimicrobial susceptibility, Plant antimicrobial activity, Biostatistics

Moise Nola: Hydrobiology and Water Quality, Water and environmental microbiology, Antimicrobial susceptibility, Plant antimicrobial activity, Biostatistics, Hydrogeology, Water Resources policies and management

Thomas Njine: Hydrobiology and Water Quality, Water and environmental microbiology, Antimicrobial susceptibility, Plant antimicrobial activity, Biostatistics, Hydrogeology, Water Resources policies and management