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Using Principal Component Analysis to Assess Water Quality from the Landing Stages in Coastal Region

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Abstract Principal component analysis (PCA) was used to comprehensively evaluate the relationship between physicochemical and bacteriological parameters of water on banks of Wouri. At each sampling station, the physicochemical analysis focused on Water temperature, pH, dissolved oxygen, dissolved CO_2, electrical conductivity, suspended solids, nitrates, ammonium ions, orthophosphates, color, salinity, and turbidity. The bacteriological analysis consisted of the isolation of heterotrophic aerobe bacteria (HAB), faecal bacteria, and some pathogenic bacteria. PCA showed that two factorial axes F1 (49.48%) and F2 (25.18%) explained 74.67% of the total inertia. pH, Suspended Solids, electrical conductivity and color are significantly and positively correlated with each other and also significantly and positively correlated with the F1 axis. HAB, faecal bacteria, *Shigellae*, dissolved CO_2 and salinity are significantly and positively correlated with each other and, are also significantly and negatively correlated with the F1 axis and with the previous group of variables. The F1 axis discriminates in the negative coordinates of the Youpwe 1 and 2 stations, characterized by a high content of orthophosphates, ammonium ions, and low oxygenation. There is also a high concentration of bacteria such as HAB, faecal coliforms and *Salmonella*. The calculation of FC/FS ratio reflects exclusively contamination of animal origin in all the sampled stations.

Keywords: *water, bacteriological analysis, physicochemical analysis, principal component analysis*

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1. Introduction

Water is a primary resource for life because all living things on earth use water for life activities [1]. The microbiological quality of coastal water is a determining factor in the economic, social and tourist life of all societies that have to provide for water quality needs. Infact, the landing stages which represent the areas of the estuary where people, goods and more commonly sea products are disembarked and embarked. The landing stages are more subject to human disturbances given the speed and intensity of the exchanges that take place there every day and the large flow of people who transit through them. Estuaries and coastal zones are therefore areas with high strategic stakes for the economies of the bordering territories and for the environment [2]. Coastal waters are also receptacles for large quantities of anthropogenic wastes rich in nutrients and organic matter. The coastline is a receptacle for urban, industrial and agricultural discharges containing a wide variety of contaminants [2]. River contamination release management is of critical for surface water conservation in all the countries [3]. They are vulnerable to the extremely variable conditions of coastal environments such as tides, storms and low water levels [4,5]. This is the case of the Wouri River hydrographic network, which is subjected to anthropogenic pressures due to the anarchic proliferation of industrial and urban activities and tidal phenomena [5]. The contamination of surface water by pathogens is a pollution problem that goes back a long way in time. During the twentieth century, water borne diseases were responsible for large epidemics of dysentery, typhoid fever, cholera, among others [6].

Microbiological indicators are considered among the most important water parameters for domestic use. They

correspond to pathogenic germs that originate from the discharge of domestic or industrial wastewater directly into watercourses and / or from soil leaching [7].

There is little information about the sources of contamination at the Youpwe, Akwa North, Essengue and Sandaga port of the city of Douala. Few data are available on the dynamics of the abundance of faecal contamination bacteria in wharf water. In addition, the influence of physicochemical parameters on this abundance dynamic has not been addressed very much. The multivariate statistical method is used by researches to assess the quality of water environments. Among them, Principal component analysis, is widely used to search the relationship between the original indicator variables and transform them into independent principal components [8]. During past Decade, this analysis method has been widely used to understand the temporal and spatial changes in surface water and groundwater quality [9,10]. This work aims to perform PCA based on the results to identify the physicochemical indicators affecting the abundance of bacterial indicators at the landing stages of the Wouri River, Douala (Littoral Region, Cameroon).

2. Materials & Methods

2.1. Study Area and Sampling Stations

The study took place from February to July 2019 in the city of Douala, economic capital of Cameroon and capital of the Littoral Region. It is geographically located in the Golf of Guinea at the intersection of the parallel 04°03 North latitude and the 09°04 meridian East longitude. The climate is equatorial, Cameroonian type, coastal sub-type, with monomodal rainfall characterized by heavy rainfall (between 2596 mm and 5328 mm) and an average ambient temperature of 28 °C [11].

Concerning the metrological data for the city of Douala during the study period, the air temperature varied from 26.1 to 27.6 ° C, the relative humidity as for it varies between 74 and 78 %. The values of insolation and rainfall reach 190 KWh / m^2 / d and 592.2 mm respectively.

The vegetation, initially of the humid dense forest type, is completely degraded nowadays. The very dense hydrographic network is made up of the Wouri and Dibamba rivers and their tributaries which irrigate almost the entire city. At the petrographic level, the soils consist mainly of sandy and clayey-sandy formations [12]. This port city is made up of thirteen sub-watersheds with an urbanized area of approximately 153.76 km^2 and an estimated population of 2,755,011 habitants in 2010 [13,14]. In order to have a clear idea of the location of the different study sites, the geographical coordinates of all the sampling stations were determined using a Garmin Etrex 30 brand GPS. Those coordinates are given in Table 1 below. Figure 1 shows the geographical location of the study area and the sampling stations.

The choice of sampling stations was made on the basis of their accessibility, their economic importance and their proximity to market places. These different stations serve as clearinghouse for the landing of sea products of various species (shrimp, fish, skate), and the risks of contamination of the landing stages is high. A total of five stations were chosen including two stations at the Youpwe landing stage (Youpwe 1 and Youpwe 2), one station at the Essengue and Akwa North landing stages and a last station at the Sandaga port.

At each site, water sample was collected in a 500 mL sterile glass bottle labeled **A**, and in a 1000 mL clean polyethylene bottle labeled **B**. Both samples were transported to the laboratory in a cooler with icepacks (7±2°C) for further analyses. The sample in bottle **A** and that in the polyethylene bottle **B** were for the assessment of the bacterioplankton cells and for some physico-chemical analyses respectively.

2.2. Measurement of Environmental Variables

At the level of each sampling station, the physicochemical analysis focused on 12 variables. The analysis of these parameters was carried out according to the recommendations of APHA and Rodier [15,16]. Water Temperature (°C), pH (CU) and dissolved oxygen (% of saturation) were measured *in situ*, respectively using a mercury column thermometer graduated to 1 / 10th, a pH-digital meter model SCHOTT GERATE CG 818 and an oximeter from HANNA, model HI 9146. Similarly, the electrical conductivity of water (µS / cm) and salinity were measured using a TDS / Handheld conductivity meter from HANNA series HT 8733 and a multi parameter from HANNA / HI9829 respectively.

The Suspended Solids (mg/L), Water color (Pt.Co) and turbidity (FTU) were measured in the laboratory directly using a HACH DR / 2000 spectrophotometer. Readings were done at wavelengths 810 nm, 455 nm and 450 nm respectively. At the same time, nitrates (mg/L), orthophosphates (mg/L of PO_4^{3-}) and ammonium ions (mg/L of NH_4^+) were analysed by colorimetry using a DR / 2000 spectrophotometer of HACH brand: readings were taken at wavelengths 570 nm, 880 nm and 425 nm respectively. Dissolved CO_2 content of the water was measured in the laboratory by titration in an acidic medium (N/10 hydrochloric acid), after fixing the CO_2 on the field using sodium hydroxide (NaOH N/20) and 2 to 3 drops of phenolphthalein.

2.3. Bacteriological Analysis

The quantitative analysis of bacteria consisted of the isolation and counting of heterotrophic aerobe bacteria (HAB), Total and Faecal coliforms, faecal streptococci, bacteria of the genus *Salmonella* sp. and *Shigella* sp. The analysis technique used was that of surface spreading on Agar culture media poured into Petri dishes. HABs were isolated on ordinary agar medium, incubated at 22°C for 5 days. Endo culture medium was used for the isolation of total and faecal coliforms, incubated at the temperature of 37°C and 44°C respectively for 24-48 hours; while faecal streptococci was seeded in Bile Esculin Azide (BEA) Agar at the temperature of 37°C for 24 hours. Salmonella-Shigella agar was used for the isolation of *Salmonella* sp. and *Shigella* sp., incubated at the temperature of 37°C for 24-48 hours. The count of the germs isolated was carried

out using an OSI brand colony counter. Bacterial abundances are expressed in decimal logarithmic units Colonial Forming Units (CFU) per 100 mL of water sample.

2.4. Data Analysis

Data was typed using Microsoft Excel and imported into the programme SPSS version 25.0 for analysis. The Kolmogorov-Smirnov test was first applied to check the normality of the distribution before comparing environmental parameters and abundances of bacteria isolated. The Kruskal – Wallis test and Mann – Whitney test were then performed with SPSS 25.0 to verify significant differences between stations considering each environmental parameter. The Principal Component Analysis made it possible to characterize the areas sampled in the landing stages on the basis of the distribution of the concentration of bacteria in relation to the physico-chemical parameters of the water. The objective of this descriptive analysis method is to present in graphic form the maximum amount of information contained in a large data table [17].

Figure 1. Map of the study area showing sampling stations

3. Results & Discussion

3.1. Environmental Variables

The minimum and maximum values, the mean values and standard deviations of the physicochemical parameters measured at each landing stage studied are presented in Table 2. The results of the comparison tests of the Kruskal Wallis test have also been presented.

The water temperature and dissolved CO_2 contents varied from 28 to 31.44°C and from 17.5 to 190.8 mg/L respectively. The average temperature values fluctuated between 29.03 ± 1.33 and 30.57 ± 0.91°C with a high value recorded in March at the Essengue landing stage. Dissolved CO_2 content varied with mean values between 52.89 ± 12.80 and 91.06 ± 63.62 mg/L. No significant difference was observed among the stations (Kruskal-Wallis H test; $p > 0.05$) for these two parameters. The same is true for the pH values, which also showed no significant difference between the different landing stages. The average pH values were between 7.81 ± 1.02 and 9.14 ± 0.99 CU. The lowest pH value was recorded in February at Youpwe 2 and the highest value in June at Akwa North landing stage.

Water salinity showed relatively stable spatial fluctuations during the study period. However, the highest salinity concentration was obtained in March in Essengue (12.28 psu) and the lowest in July at the Akwa North landing stage (0.29 psu) with average values between 0.38 ± 0.07 and 10.05 ± 1.58 psu. Variations in salinity were significant between all the stations (Kruskal-Wallis H test and Mann-Whitney U test; $p < 0.05$), except between the Youpwe 1 and Essengue docks where there is no significant difference ($p > 0.05$). Dissolved oxygen saturation rate had mean values between 60.93 ± 9.65 and 70.85 ± 8.37%, the greatest value being observed at the Sandaga landing stage. The same statistical results are observed for the water content of nitrates and phosphates (Kruskal-Wallis H test; $p > 0.05$). The lowest nitrate content in the water was obtained in Sandaga in April (1.8 mg/L) while the highest nitrate concentration was 13.22 mg/L. This value was recorded in Essengue in June. The highest levels of phosphates reached the value of 1.591 mg/L, observed at the Youpwe 1 wharf.

Suspended solids contents were relatively high at most stations throughout the sampling period. The mean values ranged from 14.33 ± 3.14 mg/L to 49.50 ± 30.7 mg/L. The evolution of suspended solids content showed significant differences (Kruskal-Wallis H test; $p < 0.05$), in particular between the Youpwe 1 and Sandaga wharves, between Youpwe 2 and Akwa North, and between Essengue and Akwa North (Mann-Whitney U test; $p < 0.05$). As for electrical conductivity, it oscillated between 10.1 µS/cm and 767 µS/cm at the landing stages of Essengue and Akwa North respectively. A significant difference was recorded ($p < 0.05$), in particular between the Youpwe 1 and Akwa North wharves, between Youpwe 2 and Akwa North.

Turbidity contents ranged from 10 to 153 NTU. The lowest values were obtained at the Sandaga stations, and the highest in March at the Akwa North station. Water color fluctuated between 17 and 447 Pt.Co during the study. The variation profile of these two parameters does not show any significant difference between the different stations studied ($p > 0.05$). Regarding ammonium ions, significant differences ($p < 0.05$) were observed with mean values between 0.13 ± 0.08 and 0.49 ± 0.27 mg/L. The differences observed were between Youpwe 1 and the other landing stages except those of Youpwe 2 and Akwa North ($p < 0.05$).

The results of the physicochemical parameters show temporal variations. Overall, the water taken from the landing stages had temperatures that vary very little around an average of 29.94 ± 0.98°C. These temperatures are compatible with the activity of isolated microorganisms which are all mesophilic and promote the dissolution of gases and salts in water. In fact, the surface water in the city of Douala is significantly warmer, this could be explained by the fact that the city of Douala is close to the sea and there is a high concentration of industrial activities and a strong urbanization of the watershed which exposes the water to solar rays. These observations are similar to those of some authors in the same Wouri River [18].

Regarding water pH, it varied from one campaign to another, increasing slightly between May and July. The slightly basic tendency of the pH was same in all the stations studied. The absence of significant differences in pH between the different stations studied would reflect the nature of the pedological substratum of the coastal region, which is the same everywhere. Indeed, the characteristic soils of this region are acidic and rich in iron hydroxide and alumina [19]. However, the monthly fluctuations of this parameter would probably be due to the influence of precipitations, industrial and urban discharges. Furthermore, the concentration of dissolved carbon dioxide in all the sites was relatively high. These high dissolved CO_2 contents should normally lead to acidic waters due to the formation of carbonic acid following the reaction of CO_2 with water [20].

The low basicity and the high salinity contents of the sampled water. The average salinity obtained for all the months and for all the stations was 5.69 ± 0.64 psu) would therefore be due to a compensation of these contents by carbonic acid formed. In addition, regions subjected to relatively high temperatures experience water losses through evapotranspiration, which indirectly influence the salinity content of their waters [21].

The data obtained for oxygen content showed relatively high oxygen saturation percentage values (65%) in June corresponding to the rainy month. During heavy rains, passive diffusion at the air-water interface by agitation of the water promotes its reoxygenation [22]. In addition, these variations would be directly linked to the seasonal variations of water temperature which condition the process of oxygen solubility. Suspended solids contents were relatively high at most stations throughout the sampling period. In fact, during the rainy season, pollutants and debris removed by dredging on the watersheds are washed away by runoff [2]. The average of this parameter for all stations is 28.97 ± 14.86 mg/L. Surface water with a Suspended Solids concentration between 14 and 24 mg/L is of questionable quality [23]. This doubt of the quality of the water in these landing stages is reinforced by the results of the survey carried out among residents. Indeed, it results from this survey that an average quantity of 1 tonne 563 kg of waste is produced

and dumped by the respondents per day in the waters of the said landing stages. Turbidity remained almost constant in all the stations during the first four months of the study and dropped sharply in June significantly ($p \leq 0.05$). This drop would be due to the dilution of the water in the landing stages by the heavy rains recorded between the end of May and the beginning of June.

Turbidity, Suspended Solids and color values were significantly correlated throughout the study period. Water is more turbid and colored when the density of the particles in suspension is higher [2,16]. More, water color entirely results from the extraction of the organic matters in decomposition, as well as the dissolution of some ions as iron, the manganese and the copper [24,25].

The average phosphate obtained for the entire sample was 0.52 ± 0.43 mg/L. Organic pollution is perceptible when the orthophosphate content is greater than 0.5 mg/L. On the basis of this, it can be affirmed that the waters of the landing stages are polluted [16]. The ammonium ions contents were generally high. The average content of this parameter was 0.30 ± 0.15 mg/L for this study. Ammonium ion contents of the order of 0.5 to 1 mg/L of NH_4^+ in surface waters suggests sources of pollution located upstream and concentrations greater than 0.3 mg/L of NH_4^+ testify to significant organic pollution [16]. The nitrate values for the whole sampling period ranged from 2 to 13.22 mg/L with an average of 7.92 ± 3.28 mg/L. The high levels of mineral nitrogen (NH_4^+ and NO_3^-) and orthophosphates in the water at the various stations reflect the strong mineralization of the water and the anthropized nature of the Wouri watershed, which is distinguished by its significant input of allochthone organic matter, nitrogenous and / or phosphorus metabolic waste emanating from human activity.

Table 1. Geographic coordinate of the sampling stations

Geographic coordinate	Sampling stations				
	Youpwe 1	**Youpwe 2**	**Akwa North**	**Essengue**	**Sandaga**
Altitude (m)	0	0	11	3.6	25
Latitude	04°01`26,7``	04°01`35 ``	04°04`58``	04°2`267``	04°03`43,3``
Longitude	09°40`0,6``	09°40`02``	09°42`41``	09°40`06``	09°41`57,7``

Table 2. Physical and chemical metric for different stations studied

Metric	Stations					K-W test
	Youpwe 1	Youpwe 2	Akwa North	Essengue	Sandaga	
Temperature (°C)	28 – 30.5 29.58 ± 0.92^{a}	29 – 31 30.25 ± 0.76^{a}	29 – 31 30.26 ± 0.99^{a}	29 – 31.44 30.57 ± 0.91^{a}	28 – 31.2 29.03 ± 1.33^{a}	H = 6.944 P = 0.139
Dissolved CO_2 (mg/L)	17.5 – 167.2 68.35 ± 70.24^{a}	44 – 190.8 91.06 ± 63.62^{a}	34.44 – 68.3 52.89 ± 12.80^{a}	21.28 – 190.1 57.49 ± 65.37^{a}	32.08 – 93.56 67.51 ± 23.07^{a}	H = 5.454 P = 0.244
pH (C.U)	6.2 – 9.3 7.94 ± 1.21^{a}	4.82 – 9.2 7.87 ± 1.68^{a}	7.4 – 10.7 9.05 ± 1.51^{a}	6.47 – 9.04 7.81 ± 1.02^{a}	7.37 – 10.09 9.14 ± 0.99^{a}	H = 6.190 P = 0.185
Salinity (ps.u)	7.02 – 9.59 8.67 ± 0.88^{a,b,c,e}	6.98 – 8.01 7.41 ± 0.45^{b,c,d,e}	0.29 – 0.47 0.38 ± 0.07^{c,d,e}	8.2 – 12.28 10.05 ± 1.58^{d,e}	1.6 – 2.13 1.96 ± 0.21^{e}	H = 25.948 P = 0.000
Dissolved oxygen (%)	45 – 74.4 63.4 ± 11.01^{a}	49 – 77.1 60.93 ± 9.65^{a}	46.1 – 71 61.80 ± 9.61^{a}	67.1 – 73 69.58 ± 2.55^{a}	55.8 – 79.1 70.85 ± 8.37^{a}	H = 5.929 P = 0.205
Nitrates (mg/L NO^{3-})	2 – 12.1 8.37 ± 4.49^{a}	3.8 – 10 7.03 ± 2.84^{a}	2.1 – 12 7.5 ± 3.29^{a}	6.2 – 13.22 10.54 ± 2.63^{a}	1.8– 11.23 3.17 ± 3.14^{a}	H = 5.786 P = 0.216
Suspended solids (mg/L)	9 – 33 17.33 ± 8.31^{a,d}	5 – 32 23.50 ± 9.75^{a,b}	13 – 100 49.50 ± 30.7^{b,c}	11 – 20 14.33 ± 3.14^{c}	18 – 70 40.17 ± 22.43^{d}	H = 12.815 P = 0.012
Conductivity (µS/cm)	13.28 – 16.8 15.13 ± 1.32^{a,b}	13.21 – 166 58.2 ± 68.89^{a,b}	137 – 767 336.83 ± 300^{b}	10.1 – 194 64.42 ± 84.48^{a}	11.12 – 384 107.1 ± 144.8^{a}	H = 10.135 P = 0.038
Tubidity (NTU)	53 – 104 78.67 ± 20.57^{a}	38 – 78 66.17 ± 17.01^{a}	28 – 153 85.17 ± 57.24^{a}	21 – 58 41.17 ±13.41^{a}	10 – 147 56.50 ± 63.47^{a}	H = 6.709 P = 0.152
Color (Pt-Co)	17 – 179 101.5 ± 66.64^{a}	36 – 149 63.67 ± 42.79^{a}	26 – 447 204 ± 200.2^{a}	30 – 99 61.67 ± 32.86^{a}	100 – 355 163.67 ± 97.0^{a}	H = 5.393 P = 0.249
Phosphates (mg/L $P0_4^{3-}$)	0.22 – 1.59 0.66 ± 0.51^{a}	0.14 – 1.56 0.67 ± 0.65^{a}	0.08 – 1.32 0.52 ± 0.46^{a}	0.12 – 0.9 0.34 ± 0.29^{a}	0.21 – 0.86 0.42 ± 0.23^{a}	H = 2.034 P = 0.729
Ammoniun ions (mg/L NH_4^+)	0.09 – 0.76 0.43 ± 0.24^{a,b,c}	0.06 – 0.75 0.49 ± 0.27^{a}	0.1 – 0.49 0.32 ± 0.14^{a}	0.03 – 0.22 0.13 ± 0.08^{b}	0.06 – 0.17 0.13 ± 0.04^{c}	H = 12.502 P = 0.014

Values represent Min – Max & mean ± standard deviation. Kruskal–Wallis (K–W) tests were used to evaluate differences among the four groups. In the same row, values followed by different superscripts (a,b,c,d,e) are significantly different (Mann-Whitney test).

Table 3. Summary of Spearman correlation between bacterial abundances and environmental variables; values in bold show significant correlations at the level $p \leq 0.05$

Bacteriological Variables	Environmental variables											
	Temp	DCO_2	pH	Sali	DO	NO_3^-	SS	Cond	Turb	Col	NH_4^+	PO_4^{3-}
HAB	-0.1	**0.9**	-0.6	**0.6**	-0.4	0.1	**-0.6**	**-0.7**	-0.2	**-0.7**	**0.6**	**0.6**
Total Coliforms	**-0.7**	0.3	0.3	0.3	**0.8**	-0.2	-0.3	-0.4	-0.5	-0.1	-0.3	-0.3
Faecal Coliforms	-0.2	**0.8**	-0.5	**0.7**	-0.2	0.3	**-0.7**	**-0.9**	-0.1	-0.6	0.5	0.5
Faecal Streptoccoci	0.2	**0.7**	**-0.8**	**0.7**	-0.3	0.2	**-0.7**	**-0.6**	-0.5	**-0.9**	0.3	0.3
Salmonella sp.	**0.1**	**0.6**	**-0.6**	0.5	**-0.1**	-0.1	-0.5	-0.3	**-0.7**	**-0.8**	0.1	0.1
Shigella sp.	0.2	**0.7**	**-0.8**	**0.7**	-0.3	0.2	**-0.7**	**-0.6**	-0.5	**-0.9**	**0.3**	0.3

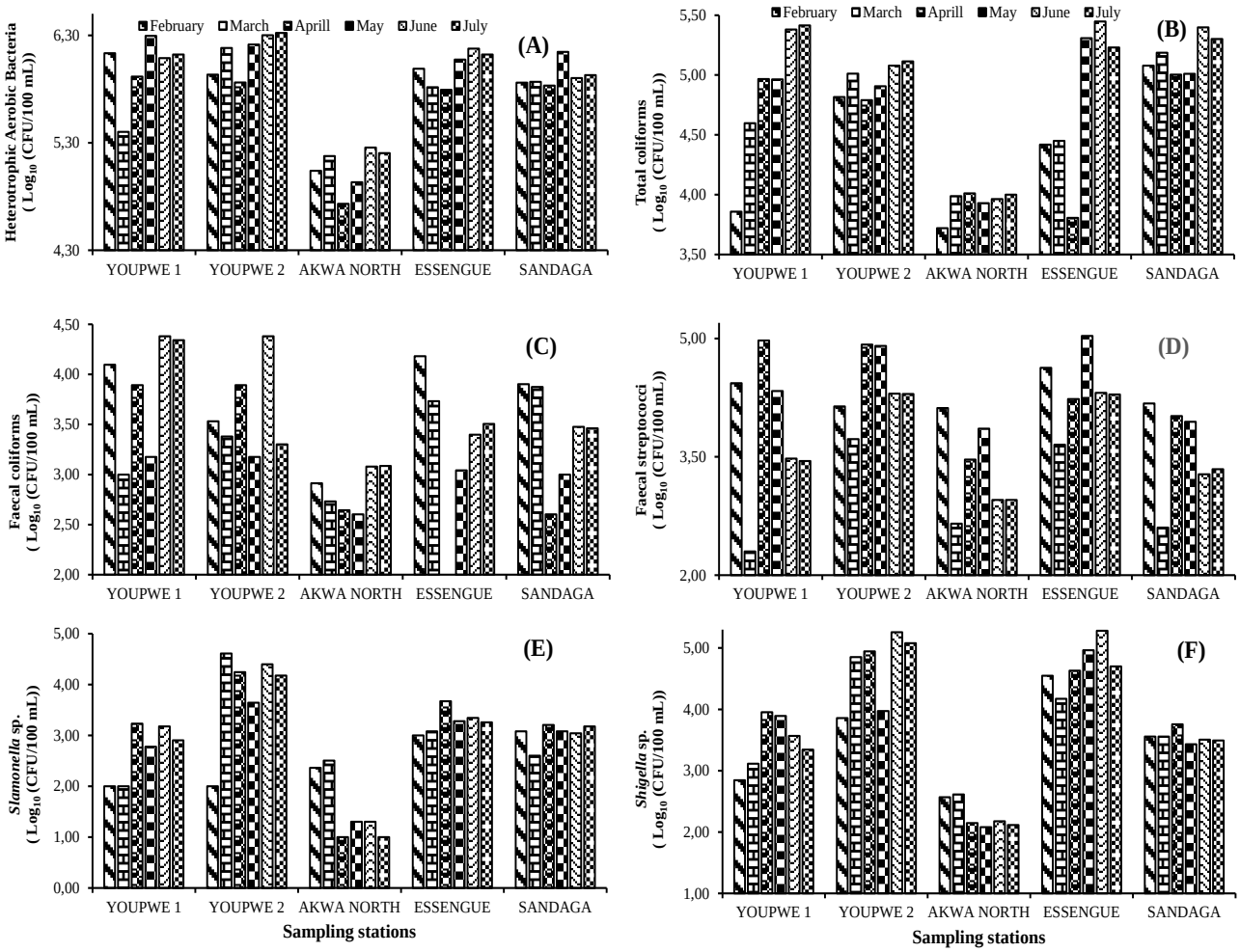

Figure 2. Spatio-temporal variations in cell abundance of Herotrophic Aerobe Bacteria (**A**), Total Coliforms (**B**), Faecal Coliformes (**C**), Faecal Streptococci (**D**), *Salmonella* sp. (**E**), and *Shigella* sp. (**F**)

3.2. Bacteriological Variables

The spatiotemporal variations in the abundances of bacterial germs are presented on Figure 2. These are HAB, total and faecal coliforms, faecal streptococci, the genera *Salmonella* sp. and *Shigella* sp.

The abundances of HAB cells, expressed in decimal logarithmic units (CFU/100 mL), ranged from 4.73 to 6.32. The lowest value was observed in March at Akwa North wharf and the highest abundance at Youpwe 2 wharves in April and July respectively (Figure 2A). Cell concentrations of total and faecal coliforms fluctuated from 3.72 Log10 units (CFU/100 mL) to 5.45 Log10 units (CFU/100 mL) and from 2 to 4.38 Log10 units (CFU/100 mL), respectively (Figure 2 B & Figure 2 C). The abundances of faecal streptococci were between 2.30 and 5.03 Log10 units (CFU/100 mL). The densities of *Salmonella* sp. ranged from 1 to 4.61 Log10 units (CFU/100 mL). As for *Shigella* sp., its cell density fluctuated from 2.08 to 5.28 Log10 units (CFU/100 mL) (Figure 2F).

Bacteriological analysis of this water near the landing stages revealed that it is not hygienic for human use or primary contact according to the water quality standards established by the WHO. The results of the study showed that the frequency of aerobic mesophilic heterotrophic bacteria reached an average value of 5.82 ± 0.43 Log_{10} units (CFU/100 mL), total coliforms had the value of 4.74 ± 0.47 Log_{10} units (CFU/100 mL), faecal coliforms 3.39 ± 0.36 Log_{10} units (CFU/100 mL), faecal streptococci 3.89 ± 0.47 Log_{10} units (CFU/100 mL), *Salmonella* sp 2.88 ± 0.84 Log_{10} units (CFU/100 mL) and *Shigella* sp 3.73 ± 1.01 Log_{10} units (CFU/100 mL) which varied from one sampling station to another. The strong presence of germs indicative of faecal contamination in the sites studied can be explained by important punctual inputs of urban waste and fishery products. In fact, port and industrial activities and the discharge of urban effluents into the waters of the Wouri are believed to be the cause of the strong bacterial contamination of these waters [26].

The origin of faecal pollution is related to the quantitative ratio of faecal coliforms to faecal streptococci (FC/FS). According some authors, when this CF/SF ratio is < 0.7, pollution is mainly or entirely of animal origin and animal droppings seem to play a predominant role in the contamination of the water [27]. The calculation of this ratio for this study gives ratios of 0.46 at Youpwe 1, 0.18 at Youpwe 2 and for Akwa North landing stages, the ratio was 0.13 at Essengue and 0.59 at Sandaga. These values which are still below 0.7, reflect exclusively contamination of animal origin.

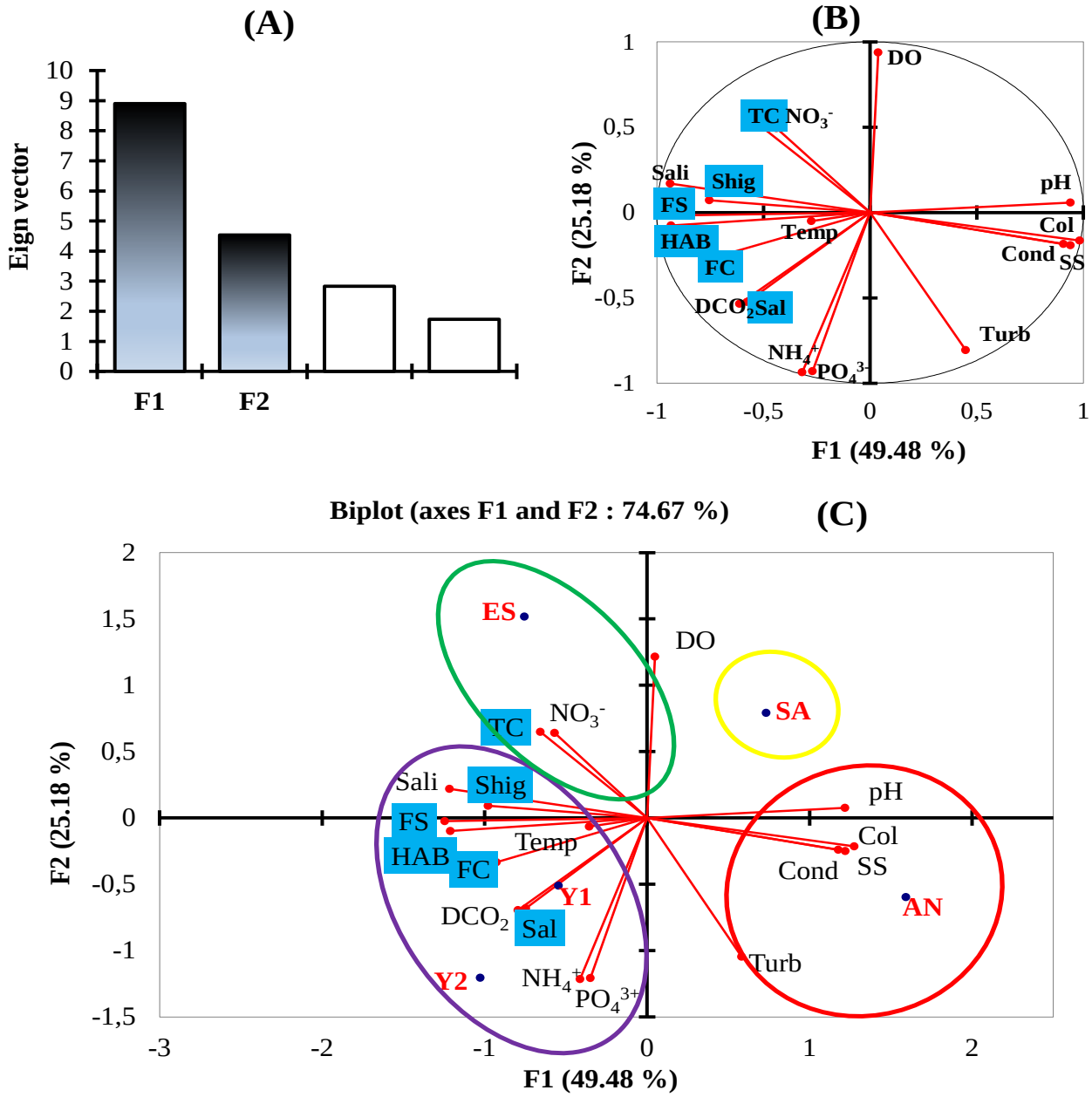

Figure 3. Result of the Principal Component Analysis (PCA) carried out on the physicochemical and bacteriological variables measured in the different stations during the study period: (**A**) Histogram of the eigen vector; (**B**) Correlation circle between variables and factorial axes F1 and F2; (**C**) Biplot showing the distribution of the stations with respect to their physicochemical and bacteriological characteristics in the factorial plane F1 X F2

3.3. Relationships between Bacterial Abundance and Abiotic Factors

The factorial map obtained from the Principal Component Analysis (PCA) is presented on Figure 3. Table 3 presents a correlation matrix of the variables studied during the study.

The Principal Component Analysis (PCA) carried out, using the physicochemical and bacteriological parameters, helped to characterize the different groups formed. The analysed matrix is a table of 18 columns corresponding to the environmental parameters measured and 5 lines representing the samples taken at the 5 sampling stations during the 6 months of study. The bulk of the total variance is provided on the first two factorial axes F1 (49.48%) and F2 (25.18%) which explains 74.67% of the total inertia (Figure 3 A). The correlation matrix is presented on Table 3. The correlation circle (Figure 3B) shows that, pH, SS, conductivity and color are significantly and positively correlated with each other and also significantly and positively correlated with the F1 axis. Likewise, HAB, Faecal Colilforms (FC), Faecal Streptococci (SF), *Shigellae* (Shig), dissolved CO_2 (DCO_2) and salinity (Sali) are significantly and positively correlated with each other and, are also significantly and negatively correlated with the F1 axis and with the previous group of variables. Dissolved oxygen (DO) is significantly and positively correlated with the F2 axis. On the other hand, orthophosphates (PO_4^{3-}), ammonium ions (NH_4^+) and turbidity appeared to be significantly and

negatively associated with the F2 axis. Moreover, temperature (Temp), nitrates (NO_3^-), salinity (Sali) and total coliforms (TC) are not significantly linked to these two axes.

The factorial map (Figure 3 C) shows a distribution of the 5 sampling stations with respect to their physicochemical and bacteriological characteristics. Four major groups of stations emerge in this factorial plane. The F1 axis discriminates in the negative coordinates the Youpwe 1 (Y1) and Youpwe 2 (Y2) stations, characterized by a high content of orthophosphates, ammonium ions and low oxygenation. There is also a high concentration of bacteria such as HAB, faecal coliforms and *Salmonella*. The F1 axis also isolates, but in its positive axis, the Akwa North station (AK) characterized by a strong mineralization, a high content of suspended matter and a low oxygenation of the water.

The objective of PCA was to extract the primary information representative of the typical characteristics of the water environment from a database and represent it as a new set of independent variables of the principal component [28]. Principal Component Analysis suggests that physicochemical and biological variables interact in a complex way, reflecting the complex processes occurring in the natural environment.

These results show that the first axis clearly demonstrated that Youpwe 1 (Y1) and Youpwe 2 (Y2) stations were characterized by high content of orthophosphates, ammonium ions, low oxygenation, high concentration of bacteria such as HAB, faecal coliforms and *Salmonella* sp., faecal streptococci. Indeed, parameters such as ammonium ions, orthophosphates and dissolved oxygen significantly influenced the distribution of bacteria indicating faecal contamination [29].

The lowest levels of faecal pollution indicators were noted in the other landing stages, particularly at Akwa North station, characterized by high electrical conductivity and color. Salinity as well as the DCO_2 positively influenced the multiplication of HAB, Faecal Colilforms (FC), Faecal Streptococci (FS), *Shigella* and *Salmonella*. The strong correlations observed with salinity and DCO_2 would be the consequence of an environmental condition favorable to bacterial metabolism.

4. Conclusion

The physicochemical and bacteriological quality of the water from the wharves on the banks of the Wouri River (Douala-Cameroon) was studied and the analysis of the abiotic and bacteriological parameters showed that the water at the wharves is polluted and harbour a varied microbiological flora. The water of the landing stage is highly mineralized and have very little temperature variation around an average of 30°C. They are rich in organic matter as shown by physicochemical parameters such as orthophosphates, ammonium ions, nitrates and suspended matter which indicate a consequent pollution. These waters are of poor ecological quality because they are highly mineralized, hot, colored, relatively saline, hypoxic and very turbid, reflecting intense bacterial activity in the water body. The principal component analysis was presented as an important multivariate analyses method to explain the variance of all parameters through a smaller set of independent variables. PCA presented some potentially informative results for understanding mechanisms of water quality in the area.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Opoku - Kwanowaa, Y., Furaha, R K., Yan, L. and Wei, D. (2020). Effects of Planting Field on Groundwater and Surface Water Pollution in China CLEAN-Soil, Air, Water 48, Issue 5-6.

[2] Koji, E., Noah, E O., Onana, F M., Tchakonté, S., Lontsi D C., Tamsa, A A. ; Bricheux, G., Sime-Ngando,T. and Nola, M. (2017). Influence of Anthropogenic Pollution on the Abundance Dynamics of Some Freshwater Invertebrates in the Coastal Area of Cameroon, Journal of Environmental Protection, 8, 810-829.

[3] Jiang, J., Ri, T., Pang, T., Wang, Y. and Wang, P., (2019). Water quality management of heavily contaminated urban rivers using water quality analysis simulation program. Global J. Environ. Sci. Manage 5(3), 295-308.

[4] Gonzáles, H E., Giesecke, R., Vargas, C A., Pavez, M., Iriarte, J L., Santibáñez, P., Castro, L., Escribano, R. and Pagès. F. (2004). Carbon cycling through the pelagic foodweb in the northern Humboldt Current off Chile (23°S). ICES Journal of Marine Science, 61, 572-584.

[5] Tchakonté, S., Ajeagah, G A., Nyamsi, T N., Camara, A I., Diomandé, D. and Ngassam, P. (2015). Stream's water quality and description of some aquatic species of Coleoptera and Hemiptera (Insecta) in Littoral Region of Cameroon. Biodiversity Journal, 6, 27-40.

[6] George, I. and Servais, P. (2002) Sources et dynamique des coliformes dans le bassin de la Seine. Centre National de la Recherche Scientifique.

[7] Saab, H.B., Nassif, N., El Samrani, A.G., Daoud, R., Medawar, S. and Ouaïni, N. (2007). Survey of bacteriological surface water quality (Nahr Ibrahin River, Lebanon). Journal of Water Science, 20, 325-424.

[8] Arslan, O. (2013). Spatially weighted principal component analysis (PCA) method for water quality analysis. Water Resources, 40, 315-324.

[9] Neta, G., Goldman, L R., Barr, D., Sjodin, A., Apelberg, B J., Witterand, F R. and Halden, R U. (2010). Distribution and determinants of pesticide mixtures in cord serum using principal component analysis. Environ. Sci. Technol, 44, 5641-5648.

[10] Zeinalzadeh, K. and Rezaei, E. (2017). Determining spatial and temporal changes of surface water quality using principal component analysis. J. Hydrol. Reg. Stud. , 13, 1-10.

[11] Suchel, J B. (1972). Le climat du Cameroun. Thèse de Doctorat 3eme cycle, Université de Bordeaux III, (186 pages).

[12] Giresse, P., Megope-foonde, J., Ngueutchoua, G., Aloisi, J. and Kuete, M. (1996). Carte sédimentologique du plateau continental du Cameroun. Rapport de l'Institut Français de recherche scientifique pour le développement en coopération. ORSTOM (ed).

[13] CUD. (2007). Communauté Carte des bassins versant de la ville de Douala en 2007. Urbaine de Douala-Cameroun, Service de cartographie et des plans urbains.

[14] Bucrep. (2010). 3ème recensement général de la population et de l'habitat : la population du Cameroun en 2010.

[15] APHA. (2009). Standard Methods for the Examination of Water and Wastewater. America Public Health Association, APHA-AWWAWPCF (Eds.), Pennsylvania, Washington.

[16] Rodier, J., Legube, B., Marlet, N. and Brunet, R. (2009). L'analyse de l'eau. 9e édition, DUNOD, Paris.

[17] Thillai, R T., Rajkumar, M., Sun, J. and Ashok, V P. (2010). Seasonal variations of phytoplankton diversity in the Coleroon coastal waters, southeast coast of India. Acta Oceanol. Sin. 29, 97-108.

[18] Tchakonté, S., Ajeagah, G A., Diomandé D., Camara A I., Konan, K M. and Ngassam, P. (2014). Impact of anthropogenic activities on water quality and Freshwater Shrimps diversity and distribution in five rivers in Douala, Cameroon. *Journal of Biodiversity and Environmental Sciences*, 4, 183-194.

[19] Asaah, V A., Abimbola, A F. and Suh, C E. (2006). Heavy Metal Concentration and Distribution in Surface Soils of the Bassa Industrial Zone 1 Douala Cameroon. Arabian Journal for Science and Engineering, 3, 147-158.

[20] Panda, P K ; Dash, P K and Panda R B. (2020). The Study of Water Quality of the River Salandi by Using Modified Canadian Council of Ministers of the Environment Water Quality Index Method, Bhadrak, Odisha, India. *American Journal of Water Resources*. 8(5), 237-245.

[21] NOAA. (2014). Oil Spills in Mangroves: Planning and Response Considerations (Maryland : Office of Response and Restoration).

[22] Ginet, R. and Decou, V, (1997). Initiation à la biologie et à l'écologie souterraines.

[23] Hébert, S. and Légaré, S. (2000). Suivi de la qualité des rivières et petits cours d'eau. Direction du suivi de l'état de l'environnement, ministère de l'Environnement, Québec, envirodoq No ENV-2001-0141, rapport N° QE-123.

[24] Olanezuk-Neyman, K. and Bray, R. (2000). The Role of Physico-Chemical and Biological Processes in Manganese and Ammonia Nitrogen Removal from Groundwater. Polish Journal of Environmental Studies, 9, 91-96.

[25] Signe, J M., Lontsi, C D., Njoya, A M., Eheth, J S., Tchakonté, S., Tamsa, A A., Ateba, H B., Bricheux, G., Nola, M. and Sime-Ngando, T. (2015). Assessment of the potential effect of somme streams properties on the isolated *Aeromonas hydrophila* strains susceptibility against some β-Lactams and Sulfamids. Research in Biotechnology, 6, 33-44.

[26] Abologo, A L., Essomba N C., Banock L L. and Bilong, B C. (2016). Qualité microbiologique des eaux des fleuves Nyong et Wouri (Cameroun) et impact potentiel sur la santé des populations riveraines. International Journal of Biological Chemical Sciences 10(3), 1235-1249.

[27] Larif, M., Soulaymani, A., Hnach, M. and El Midaoui, A. (2013). Contamination spatio-temporelle d'origine hydrique de l'oued Boufekrane dans la région de Meknès-Tafilalt (Maroc). Int. J. Biol. Chem. Sci. 7, 172-184.

[28] Abdi, H. and Williams, L J. (2010). Principal component analysis. Wiley Interdiscip. Rev. Comput. Stat. 2, 433-459.

[29] Djuikom, E., Jugnia, L B., Nola, M., Foto, S. and Sikati, V. (2009). Physicochemical water quality of the Mfoundi River watershed at Yaounde , Cameroon, and its relevance to the distribution of bacterial indicators of faecal contamination. Water Science & Technology, 9, 2841-2849.