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Hydrochemical And Microbiological Study of Urban River Waters In The Agglomeration of Brazzaville (Republic of Congo)

M. Ngouala Mabonzo

Laboratory of Geography, Environment and Planning (LAGEA), Faculty of Letters, Arts and Human Sciences, University Marien Ngouabi, B.P. 69 Brazzaville, Republic of Congo.

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Abstract *- To study the waters of the urban rivers of Brazzaville in the Republic of Congo for environmental needs, it was necessary to determine the various parameters influencing the quality of the water in these urban rivers. Their physicochemical elements were monitored throughout the hydrological cycle of 2020 in all of these rivers. The results of the chemical analyzes were processed by hydrochemical and statistical methods. The spatial distribution of the elements shows the same evolutionary pace as that observed for anions and cations. It appears that the waters of these rivers are characterized by low contents of dissolved salts. This could be explained by the importance of surface feeding. The Principal Component Analysis and the Ascending Hierarchical Classification indicate that the mineralization of these waters is controlled by two major phenomena: mineralization which results in the pluvi-leaching of soils for surface water and, anthropogenic activities in the production of waste pollutants. This study also shows that the waters of these rivers are contaminated by total germs, fecal and total coliforms which are the consequence of recent anthropogenic pollution.*

Keywords *- Congo, Brazzaville, urban rivers Principal Component Analysis, Ascending Hierarchical Classification.*

I. INTRODUCTION

Population growth accompanied by rapid urbanization causes numerous disturbances to natural environments (Ghazali et al., 2013). The urban environment thus concentrates populations and activities on a confined territory, which must support many flows (Host *et al.*, 2014). The agglomeration of Brazzaville is crossed by many urban rivers which all flow into the Congo River. With the demographic growth that this agglomeration has experienced in recent years, people care little about the quality of the environment, in particular the rivers which carry large quantities of both domestic and industrial waste. Surface waters, which constitute an ecosystem where many aquatic species live, are the most exposed to this threat since these rivers have become major receptors of wastewater, waste and household refuse (Tchoumou et al., 2017). Thus, a qualitative assessment of rivers turns out to be interesting in order to follow the evolution of environmental pollution with a view to controlling physicochemical and chemical parameters, a quality aimed at preserving the health of populations against various diseases water origin. This work represents a first study, the aim of which is to assess the quantitative and qualitative importance of the physico-chemical parameters of urban river water. This is a contribution, not only to water quality control in the rivers of the Brazzaville agglomeration, but also to updating the knowledge acquired on water quality.

A. General framework of the study

The agglomeration of Brazzaville is the political and administrative capital of the Republic of Congo. It stretches from southwest to northeast between latitudes 4°10" and 4°30" S, and longitudes 15°20"and 15°40" East. It is bounded to the north by the sub-prefecture of Ignié, to the south and west by the sub-prefecture of Ngoma-Tsétsé and to the east by the Congo River (Figure 1)

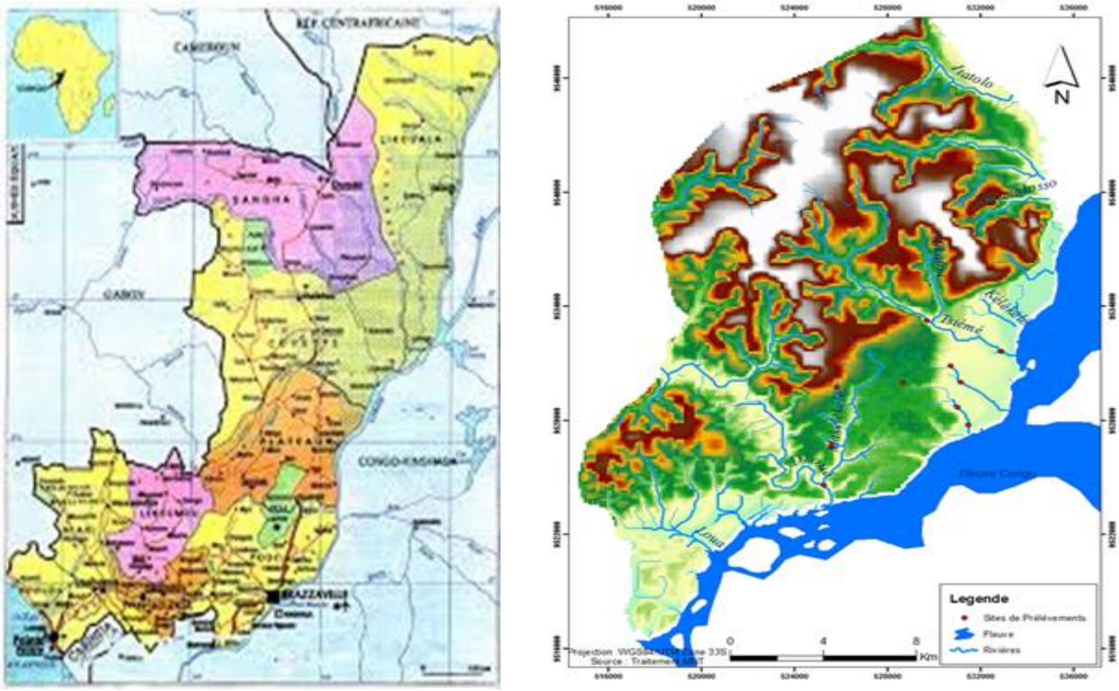

Figure 1: Map of Congo specifying the study area

From a geological point of view, the agglomeration of Brazzaville consists of three (3) large sedimentary series. This is from the summit to the base of: the sandy series of the Batéké plateaus (Ba); the Stanley-Pool (Sp) sandstone series and the Inkisi (I) sandstone series (Cosson, 1955; Le Marechal, 1966; Dadet, 1969). These soils belong to three distinct classes: podzolized soils, ferrallitic soils and hydromorphic soils (Nzila, 2001). This agglomeration is covered by Pentaclethra eetveldeana formations on the desaturated soils of hills and dry valleys and savannas in Loudetia with Annona arrenaria and Hymenocardia acida which grow on the slopes and tops of hills with mostly sandy soils and low retention capacity of water (Koechlin, 1961; Makany, 1976). The Bas-Congolese type climate has two seasons: a long rainy season from October to May, marked by a period of rainfall respite from January to February and a large dry season from June to September (Samba-Kimbata, 1978).

II. MATERIAL AND METHODS

Eleven (11) sampling campaigns were organized between January 2019 and July 2020 for the performance of this study (Figure 1). The water samples were taken during the great seasons (dry and rainy) and focused on the waters of the various urban rivers in the agglomeration of Brazzaville.

During the sampling campaigns, the water samples collected were placed in polyethylene bottles with a capacity of 500 ml, previously washed with distilled water. In the field, before filling the bottles, they were washed three times with the water to be sampled. The bottles were filled to the brim and then the cap screwed on to avoid any gas exchange with the atmosphere. The water samples were then transported in a 4°C cooler to the laboratory for analysis within one hour of collection. During sampling, physical water parameters such as temperature, pH, and electrical conductivity (EC) were measured in situ in these rivers. The equipment used in the field consists of a pH meter for measuring pH, a conductivity meter for measuring electrical conductivity (EC), temperature. The elements assayed in the laboratory are Ca^{2+}, Mg^{2+}, K^{+}, Cu^{2+}, Al^{3+}, NH_4^{+}, Fe^{3+}, Cr^{3+} for the cations and Cl^{-}, SO_4^{2-}, HCO_3^{-}, NO_3^{-}, F^{-} for the anions; turbidity; MES. A total of 132 samples were taken for chemical analyzes. A Garmin Map 60 GPS was used to take the geographic coordinates of the sampling points. The collected data was processed using a combination of multivariate statistical methods and hydrochemical method.

A first approach uses Principal Component Analysis (PCA) on reduced centered variables. Statistical analysis makes it possible to highlight the similarities and the graphic position that two or more chemical variables would present during their evolution. The purpose of this analysis is to follow the chemical evolution of the waters. Indeed, PCA is a descriptive multidimensional statistical method that can be used as a tool to aid in the interpretation of a data matrix. This analysis makes it possible to synthesize and classify a large amount of data in order to extract the main factors that are at the origin of the simultaneous evolution of the variables and their reciprocal relationships.

The second approach is based on the use of Ascending Hierarchical Classification (CHA) analysis for the study of the phenomena at the origin of water mineralization. The Ascending Hierarchical Classification (CHA) is a powerful tool for analyzing water chemistry data and for formulating geochemical models (Yidana et al., 2008; Hamzaoui et al., 2012). It is a classification system that uses Euclidean distance for similarity measures and the tutorship for bond method that produces the most distinctive classification where each member in a group is more like his colleagues than any other. Which member outside the group (Mina et al., 2007; Güler et al., 2002). PCR and CHA have 7 descriptors and 13 variables which are: electrical conductivity (EC), pH and ions such as HCO3-, SO42-, Cl-, Na+, K+, Ca2+, Mg2+, NO3-, NO2-, NH4+ and Fe3 +. In this study, all the different statistical analyzes of the data were performed using the STATISTICA version 6.0 software.

The hydrochemical method required the use of the triangular Piper diagram for the hydrochemical classification of the waters of the region. The results of the microbiological analyzes were compared with the guideline values of the World Health Organization (Majdoub et al., 2014; OMS, 2008) in the context of drinking water, not influenced by human activities.

III. RESULTS

The results of the chemical analyzes of the water of urban rivers in the agglomeration of Brazzaville are shown in Table.

Table 1: Results of the physico-chemical analyzes expressed in mg/L.

Paramètres	Min	Maxi	Moyenne	Ecart - type
pH	4,57	7,61	6,75	0,47
T◦C	23,1	31,1	26,57	1,84
CE (µS/cm)	20	130	46,57	20,3
Ca^{2+} (Mg/l)	1	29	11,19	6,31
Mg^{2+} (Mg/l)	2	26	10,91	5,06
K^{+} (Mg/l)	1	10	4,37	1,96
Cl^{-} (Mg/l)	0,22	10,1	5,16	2,21
NO_3^{-} (Mg/l)	0,1	12	1,8	2,77
SO_4^{2-} (Mg/l)	2	36	10,01	6,89
SiO_2 (Mg/l)	0,1	9	2,1	1,23
NO_2^{-} (Mg/l)	0,032	1,16	0,36	0,22
PO_4^{3-} (Mg/l)	0,07	0,9	0,25	0,22
Cu^{2+} (Mg/l)	0,02	0,9	0,32	0,27
Al^{3+} (Mg/l)	0,1	0,9	0,34	0,28
NH_4^{+} (Mg/l)	0,1	0,9	0,35	0,18
Cr^{3+} (Mg/l)	0	0,5	0,04	0,051
Fe^{3+} (Mg/l)	0	0,09	0,02	0,019
F^{-}(Mg/l)	0,1	0,9	0,23	0,157
Mn^{2+} (Mg/l)	0,001	0,21	0,03	0,035
Turb	0	16	4,8	3,79
CaCO3 (Mg/l)	1	49	24,02	15,2
MES	0,1	15,2	4,6	3,21

The temperature of the rivers in the agglomeration of Brazzaville varies between 23.1 and 31, 1°C, with an average of 26, 57°C. Regarding the pH of the water, it varies between 4, 57 and 7, 61 for an average of 6, 75, which indicates that the water is acidic. The waters of this agglomeration are weakly mineralized. The electrical conductivity varies between 20 and 130 µS.cm-1, with an average value of 46, 57 µS.cm-1. High conductivity waters are those of PUBMa6 (130 µS.cm-1) and of PUBC1 and PUBFo (120 µS.cm-1). This reveals that the waters are generally less loaded. These waters also have low nutrient salt contents including nitrogen compounds, with contents of 12 Mg.L-1, 1, 16 Mg.L-1 and 0, 9 Mg.L-1 respectively for nitrates, nitrites and ammonium. Regarding the heavy metals object of this work (copper, iron and manganese), the maximum levels observed in the water of urban rivers are, respectively, 0,9 Mg.L-1, 0,09 Mg. L-1 and 0,21 Mg.L-1. The classification of the results of chemical analyzes obtained from the triangular Piper diagram makes it possible to identify two major families of water in the whole of this region (Figure 2):

- Calcium chloride water,
- Calcium sulphate waters. In the agglomeration of Brazzaville, the waters of these urban rivers are therefore characterized by a predominance of sulfate ions over calcium and chloride ions, which are practically weak in these waters. Calcium is the most important cation, followed by Mg2+ and K+.

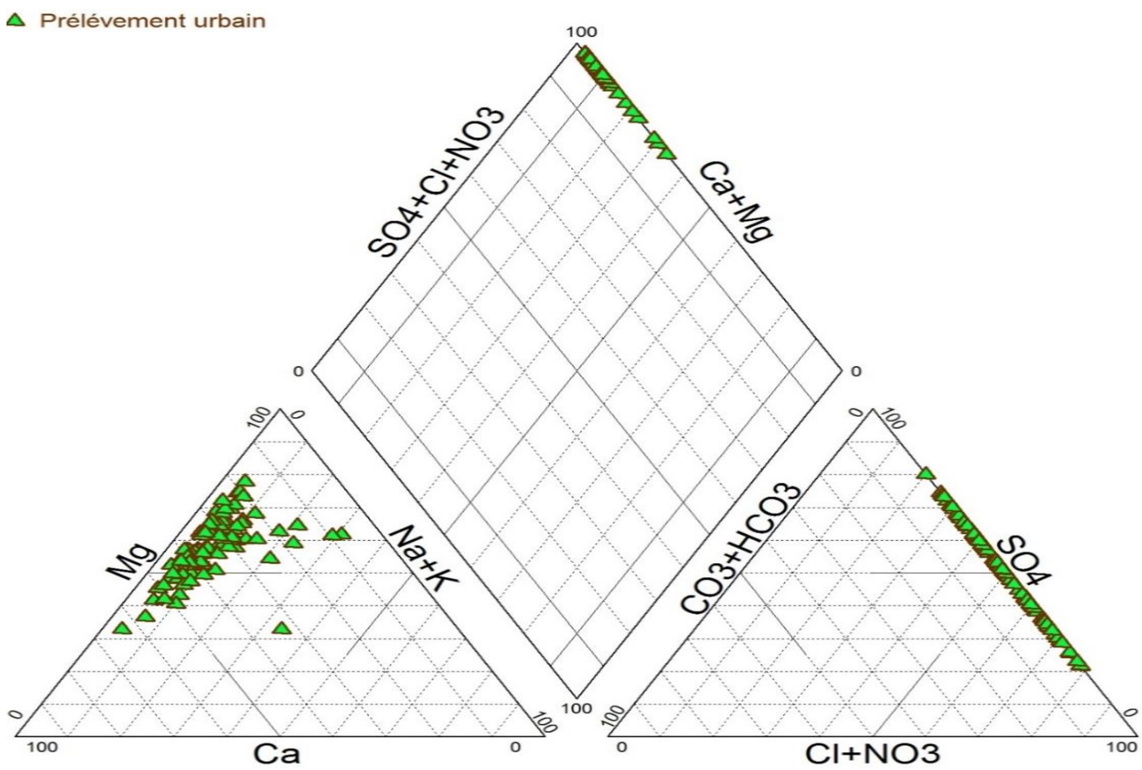

Figure 2: Piper diagram of river waters in the Brazzaville watershed

The correlation coefficient of the different parameters in the definition of the main factors is given in Table 2. These factors are defined by a certain number of parameters essential in the demonstration of the mechanism of water mineralization. This table shows that, the most important is defined by Cl- (r = 0, 53), Mg2+ (r=0, 37), K+ (r = 0, 36). The significant links which exist between the different parameters are given in figure 3. These links are reflected by the different correlations which exist between the variables studied. There is an important correlation between SO42- and K+ (r = 0, 36), Mg2+ (r = 0, 14), PO43- (r = 0, 12). This correlation is also observed between Al3+ and NO2- (r = 0, 28). The elements that define these factors come from a long duration of solution following the water-rock contact of this environment.

Table 2: The correlation coefficients of chemical elements in the waters of rivers in the Brazzaville watershed

Paramètres	Coefficient de corrélation (r^2)
Ca^{2+} (Mg/l)	0,06
Mg^{2+} (Mg/l)	0,14
K^+ (Mg/l)	0,13
Cl^- Mg/l)	0,29
NO_3^- (Mg/l)	0,01
SO_4^{2-} (Mg/l)	0,13
SiO_2 (Mg/l)	0,13
NO_2^- (Mg/l)	0,08
PO_4^{3-} (Mg/l)	0,12
Cu^{2+} (Mg/l)	0,009
Al^{3+} (Mg/l)	0,08
NH_4^+ (Mg/l)	0,03
Cr^{3+} (Mg/l)	0,001
Fe^{3+} (Mg/l)	0,07
F^-(Mg/l)	0,003
Mn^{2+} (Mg/l)	0,02
Turb	0,12
CaCO3 (Mg/l)	0,002
MES	0,22

A. Principal Component Analysis (PCA)

The statistical study from the Principal Component Analysis (PCA) gives many results which are presented in Table 1. In this table are recorded the eigenvalues, the variances expressed for each factor and their accumulations. The factor F1, with an expressed variance of 27, 98%, is the most important of all, followed by the factor F2, with respectively 21, 17% of the expressed variance. These two factors reflect the bulk of the information sought and make it possible to represent the scatter plot significantly because the sum of the variance expressed by these factors is equal to 49,15% (Figure 3).

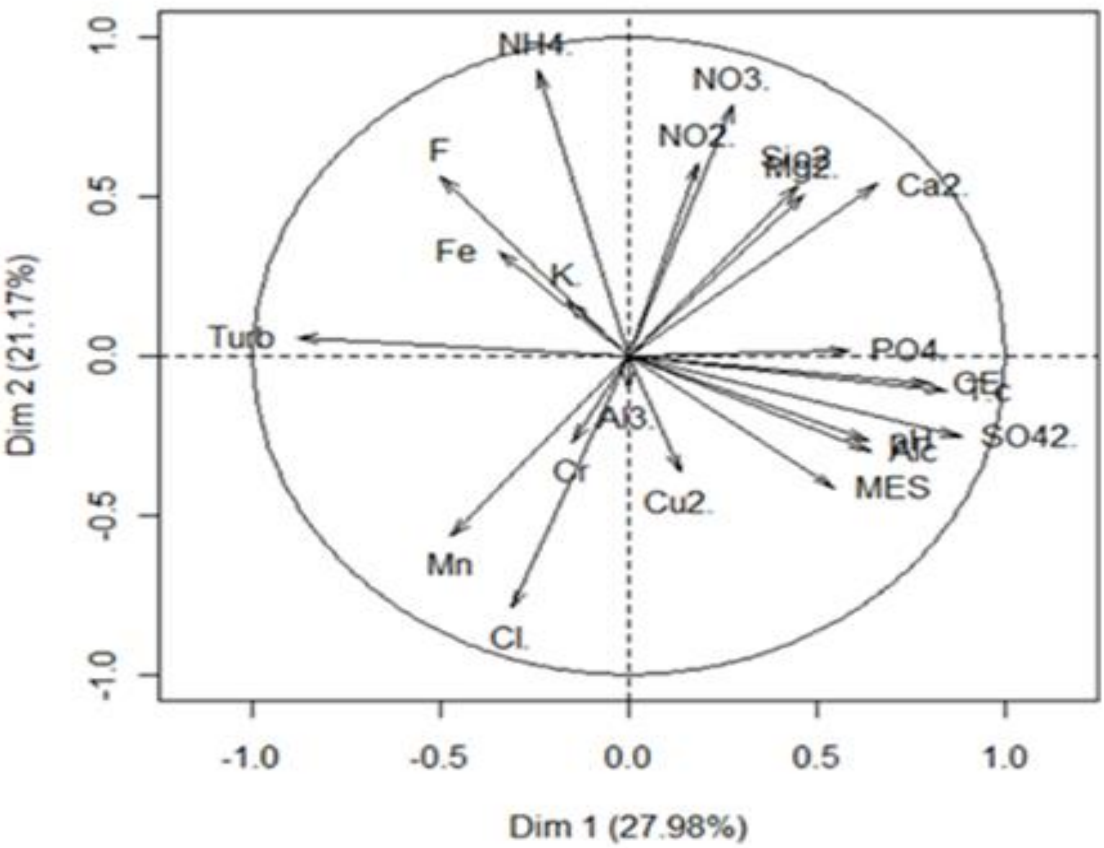

Figure 3: Principal component analysis of the waters of the Brazzaville watershed in the F1-F2 factorial plane

These factors also explain the inertia of the representative point cloud of structures which can be determined by NO2-, NH4+, Cr3+, and Al3+. This plan highlights the superficial exchanges that take place between runoff from precipitation and soil drainage. These exchanges highlight the phenomenon of pluviolessivage of the grounds.

B. Interpretation of the classification of observations

The statistical treatment of observations by this method reveals three classes of mineralization (Figure 4):

- a low mineralization class (1) with a conductivity less than or equal to 50 µS.Cm-1 of points PUBFi12, PUBTs5, PUPFo9. This concerns water with a low charge compared to all the samples analyzed,
- a class (2) of medium mineralization with a conductivity of the order of 61 µS.Cm-1 of points PUBTi11, PUBFi10, PUBMa7 and PUBTs2. This class is characterized by fairly high concentrations of SO42-, CaCO3, Ca2+, Mg2+ and MES,
- a class (3) of high mineralization with a conductivity corresponding to the extreme values measured (> 100 µS.Cm-1) of the points PUBc1, PUBFo8 and PUBMa6. The waters of this class are very heavy.

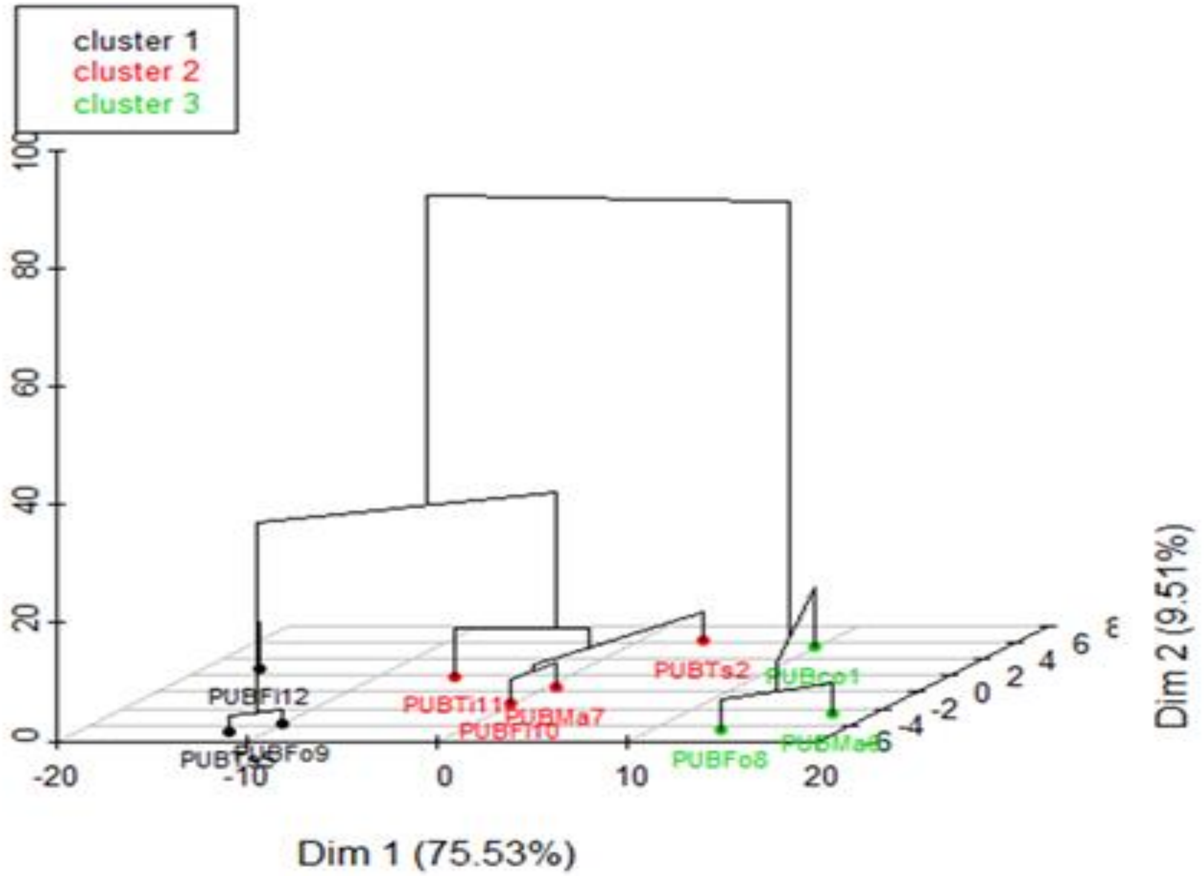

Figure 4: Ascending hierarchical classification of observations (C.A.H.)

Observation of this Figure (4) shows that class (1) is close to both class (2) and class (3). While the gap between class (2) and (3) is important. This difference confirms the significant variability between the maximum and minimum values of water mineralization.

C. Microbiological analyzes

The results of the microbiological analyzes are contained in Table 3. The analyzes show the presence of bacteria of the total germ, total coliform and fecal coliform types in the water of Mfilou, Mfoa and Tsiémé corresponding to the water of these urban rivers. The levels of total germs in the water of the Mfilou river are respectively 406 and 376 per 100 ml of water; Mfoa (302); Tsiémé (408) and dome (398). Total coliforms and fecal coliforms are also present in large quantities (403 and 412) in the water of the Tsieme. In all the rivers of this agglomeration, the presence of total germs, fecal coliforms and total coliforms can be explained by the discharge of cake by the oil mill factory, fecal products from animals and humans (Figure 5).

Table 3: Results of some microbiological elements in the waters of rivers in the Brazzaville watershed.

Points de mesures	Germes totaux	Coliformes totaux	Coliformes fécaux
Mfilou (Amont)	406	390	298
Mfilou (Aval)	376	399	386
Mfoa	302	378	307
Tsiémé	408	403	412
Coupole	398	389	388

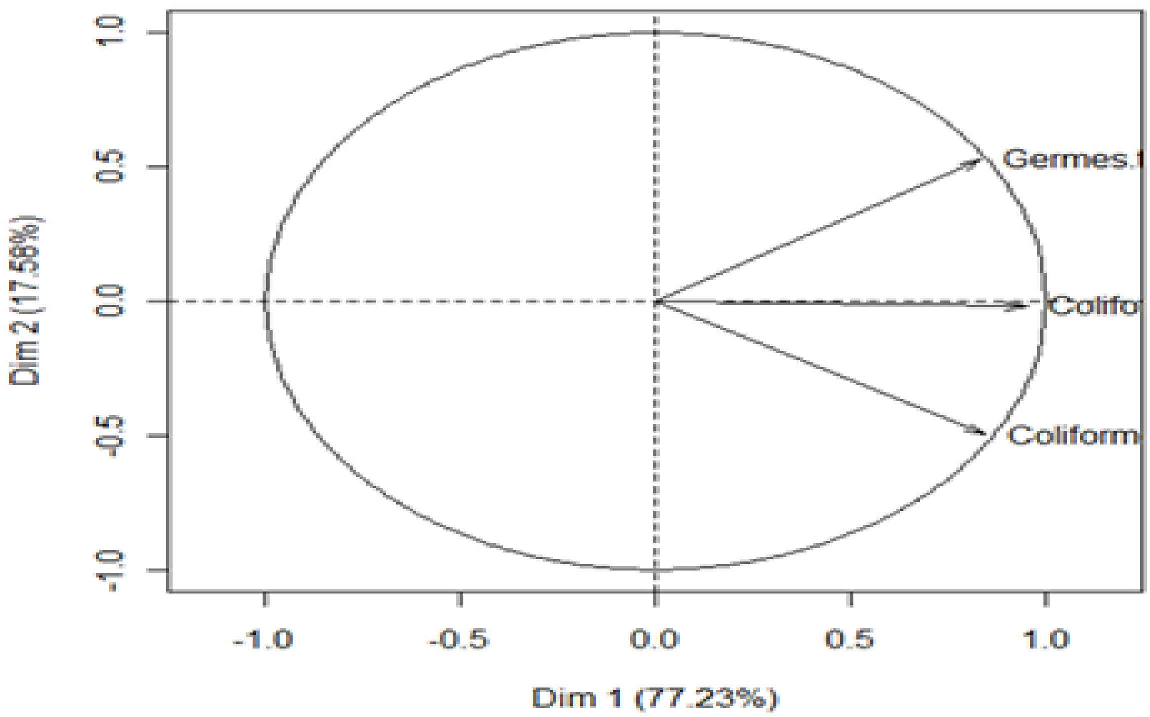

Figure 5: Principal component analysis of the waters of the rivers of the Brazzaville watershed in the factorial plane F1-F2

This shows that the waters of this urban river are subject to anthropogenic influence. Indeed, the indicative value for the bacteriological quality proposed by the World Health Organization (WHO) is zero coliforms per 100 ml of water, or levels higher than this value have been observed in the waters of all urban rivers from Brazzaville.

IV. DISCUSSION

The results of this study are presented roughly in Tables 1 and 3. The latter serves as a basis for this part of the discussion. The analyzes carried out on the water of urban rivers in the agglomeration of Brazzaville show that the average water temperature, which is 26.57 °C, fits very well within the range of water temperature variation in the Republic of Congo by comparison with the work of (Kouassi et al., 2011 ; Moukandi - N'kaya, 2012). These temperatures correspond to seasonal variations in ambient atmospheric temperatures. According to (Ngouala Mabonzo, 2016), indicates the functioning of the hydrological system of these rivers, that the sources of contamination located on the surface and would be more dangerous than other sources of pollution such as latrines and sumps. The waters of these urban rivers are less mineralized, with a maximum conductivity of 130 µS/cm. The waters are acidic, with an average pH of 6.75 for the waters of these rivers. The acidity of the water is one of the essential characteristics of the waters in the Republic of the Congo. Indeed, according to (Moukolo, 1993; Tapsoba, 1995), the acidity of water in humid tropics is mainly linked to the decomposition of plant organic matter, with the production of CO_2 in the first layers of the soil. Does the presence in water of CO_2 from soils facilitate the hydrolysis of silicate minerals. The waters of these rivers contain total germs, fecal coliforms and total coliforms. This shows that the waters are subject to recent bacteriological pollution. Indeed, all of these urban rivers lack an adequate sanitation system. Surface water is used by the populations as collectors of household refuse and waste of all kinds. This explains the presence of faecal coliforms and faecal streptococci in well water by contamination of faecal origin and therefore the possibility that dangerous pathogens are present in the water. Pathogens are indicators of faecal pollution and are largely of human origin. The presence of these microbes confirms the influence of the waters of the urban rivers of Brazzaville by human activities. Also the faecal origin of the pollution of the water resources of the Republic of Congo has been highlighted by several authors such as (Matini et al., 2009; Mbilou et al., 2016) in the groundwater of the outlying districts of the southern zone of Brazzaville and (Ngouala Mabonzo, 2016) at groundwater level in the Pointe-Noire sedimentary basin. In addition to this bacteriological pollution, there is a metallic pollution marked by the presence of Trace Metal Elements in the water of urban rivers in the agglomeration of Brazzaville. The waters of this geographic space are subject to anthropogenic influence.

V. CONCLUSION

The physicochemical and microbiological characteristics of the waters of the rivers of the Brazzaville watershed in the Republic of Congo have been the subject of an environmental assessment, by analyzing the physicochemical quality parameters: temperature, conductivity, chromium, manganese, iron, copper, aluminum, ammonium, nitrates, nitrites, phosphates. The mineralization of the waters of these rivers, during two to three years of sampling, shows that the contents of dry residue and major elements vary little from one season to another. The spatial distribution of the major ions indicates that the waters of all the measuring stations are more or less loaded with dissolved salts. This could be explained by the importance of the surface recharge which is done mainly from runoff water along the rivers of this watershed. The results obtained by the Principal Component Analysis (PCA) indicate that the variables which control the salinization of water are cations and anions. The results of the Ascending Hierarchical Classification (ACH) showed the existence of three water groups with the classification of the different measuring points. Compared to European and Moroccan standards, these results reveal the highly polluted state of the rivers in the Brazzaville region. The causes of the pollution of this river result from the activities and behavior of the communities that inhabit the Communes through which the river crosses as well as from the industrial activities installed and which the effluents carry daily. Finally, self-purification cannot be achieved easily because these rivers receive polluting discharges from their sources to the outlet with the Congo River and the Djoué. Overall, the results of the microbiological analyzes obtained show that the waters of the rivers of the Brazzaville watershed are contaminated by Total Coliforms, Fecal Coliforms and Total Germs. This contamination increases as rivers flow through inhabited areas, indicating that this pollution is due to poor waste management. The use of this unsafe water by the population could be correlated with the increase in cases of water-borne illnesses, especially diarrheal illnesses, which are the basis of many deaths. Sustainable waste management and environmental sanitation would be a step in the right direction.

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