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(RESEARCH ARTICLE)

Evaluation of the microbiological quality of the water distribution network of the Boma center in Kongo Central/DR Congo

Live Loki MAVEMA [1], Déogratias Schie' Nkung' MUTAMBEL'HITY [2], Yvonne Bomangwa IBEBEKE [3], Jean-Claude Tshijik KAMB [2] and Edouard Mbungu SISA [2,*]

[1] *Laboratory of Biology and Chemistry, Higher Pedagogical Institute of Boma (ISPB) B.P. 151 Kongo Central, DR Congo.*
[2] *Laboratory of Hydrobiology, National Pedagogical University (NPU) B.P. 8815 Kinshasa I, DRC.*
[3] *Laboratory of chemical, National Pedagogical University (NPU) B.P. 8815 Kinshasa I, DRC.*

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Abstract

The present study on the evaluation of the microbiological quality of the water distribution network of the Boma center in Kongo Central in the Democratic Republic of Congo was carried out in 12 sampling stations during the rainy season. The city of Boma where insalubrity is emerging on all avenues, bacteriological analyzes have focused on the search for Escherichia coli, fecal coliforms, total coliforms and fecal streptococci; analyses of the physical and chemical quality of the network's waters mainly concerned pH, residual free chlorine and turbidity in accordance with the WHO requirement. Hydrogen potential (pH) has a seasonal average of 91.7% of the sample compliance rate with the 2011 WHO recommendations, residual free chlorine has 66.7% and 66.7% for turbidity.

Bacteriologically: 48 samples (66.7%) out of 72 were compliant with WHO recommendations (2011) for Escherichia coli, 42 samples (58.3%) were compliant for faecal coliforms and 30 samples (41.7%) were compliant for total coliforms. As for faecal Streptococci, 54 samples (75%) comply with a high pollution rate at E.RDP and E.VBA stations and a low rate recorded at E.km8 station. The presence of all these bacteria of faecal origin and the non-compliance of certain physico-chemical parameters in the distribution network could be due to intermittent distribution, the obsolescence of the piping (χ = 245 leaks/month of which 220 repaired) and the insalubrity of the network. In view of the results obtained during this period, this distribution network provided water which, upstream as well as downstream, contained some germs indicative of faecal pollution.

Keywords: Microbiological quality; Distribution network; Water; Boma

1. Introduction

Water is the most abundant resource on the planet, covering about three-quarters of its surface area. However, the fresh water on which our lives depend constitutes only 2.5% and that most of this water is blocked in ice caps and glaciers, therefore not directly accessible [1]; a significant fraction (97.5%) cannot directly be consumed, used for irrigation, or even used for industrial purposes, due to its high salt content.

Sustainable Development Goal (SDG) 6.3 adopted in 2015 by the United Nations General Assembly is precisely titled as follows: "By 2030, improve water quality by reducing pollution, eliminating dumping of waste and minimizing emissions of chemicals and hazardous materials, halving the proportion of untreated wastewater and significantly increasing global recycling and safe reuse of water," it is far from being reached in the DRC [2].

* Corresponding author: Edouard Mbungu SISA
Laboratory of Hydrobiology, National Pedagogical University (NPU) Kinshasa, DRC.

Indeed, the DRC faces both financial and logistical difficulties to serve its population with drinking water despite the fact that it has significant water potential to supply all of Africa. To date, many cities are facing a shortage of drinking water.

According to statistics published by the Ministry of Energy and the United Nations Environment Programme (UNEP), the national service rate, which was 69% in 1990, fell to 22% in 2005, before rising to 26% in 2013 [3] ; an estimate well below the average of 60% for sub-Saharan Africa as a whole.

The distribution network in the center of the city of Boma, uses six reservoirs, two of which are in communicating vessels, two catchment points from the Congo River and two water treatment plants. This distribution network has a certain defect noted by water leaks on certain avenues (245 leaks / month on average). This defect is aggravated by erosions and anarchic constructions that characterize some neighborhoods and municipalities of Boma. In addition, users of this valuable product observe colored water coming out of their tap, which may be due to the infiltration of sand and other household waste into the piping, especially when it rains [4].

To date, the DRC in general and the city of Boma in particular are facing this difficulty of qualitative and quantitative insufficiency of drinking water. Boma's water distribution network distributes only 20 000 000 litre of water per day for an estimated population of 372 962 inhabitants [5]. Epidemiological data recorded in Boma Health Zone, growing demographics, unsanitary conditions and water scarcity in Boma remain fundamental questions [6].

This study reveals the bacteriological profile of germs indicative of faecal pollution in the network and alerts the public authorities to be able to take appropriate measures to guarantee the health of populations. It is an assessment of the water quality of the distribution network of the Boma Center in Kongo Central/DRC. It has set itself the following specific objectives:

- analyze the physical and chemical quality of the water in the distribution network;
- isolate bacteria indicative of faecal water pollution from the network;
- identify whether or not the water in this network complies with WHO standards [7].

2. Study environment

The port and historic city of Boma is a city crossed by the national n°1 of the DR Congo. It is located 125 km from the port city of Matadi, 114 km from the city of Muanda, 140 km from Tshela and 470 km from the city province of Kinshasa. It is located at 05° 50′ 55" South and 13° 03′ 22" East and covers an area of 4,332 Km^2.

It is bounded by:

- In the north, by the Angolan province of Cabinda and the territory of Lukula;
- In the South, by the Republic of Angola;
- To the East, through the territory of Seke-Banza;
- To the West, by the Atlantic Ocean.

Boma stretches on both sides of the Kalamu River which is the backbone of the city's hydrography. It is bounded to the west and east by two hill ranges. The city of Boma is full in its western part of the heavily enclosed torrents which, during the rainy seasons, supply the Kalamu River considerably with water and thus makes it very aggressive for the floods that the city fears. According to the annual report of the Boma City Council [8], this city of Boma has an estimated population of 368,148 inhabitants.

The coordinates of the water sampling stations in Boma's distribution network in Kongo Central are given in Table I.

Table 1 Geographic coordinates of water sampling stations

Stations	Localization	Longitude	Latitude	Altitude
E. BRA	Bralima water station	E 13° 04’ 49.4’’	S 05° 51’ 32.4’’	42 m
E. KM8	Water station of kilometer 8	E 13° 02’ 35.4’’	S 05° 47’ 56.3’’	24 m
E. MBA	Mbangu Water Station	E 13° 03’ 30.5’’	S 05° 48’ 55.0’’	28 m
E. RAU	Water station of the reservoir of the old factory	E 13° 03’ 29.2’’	S 05° 50’ 56.5’’	61 m
E. RDP	Rond-Point water station	E 13° 03’ 26.3’’	S 05° 49’ 40.3’’	34 m
E. RKIK	Kikiaka Reservoir Water Station	E 13° 02’ 55.4’’	S 05° 49’ 44.0’’	146 m
E. RKIS	Kisantu Reservoir Water Station	E 13° 03’ 14.6’’	S 05° 50’ 06.9’’	96 m
E. SKA	Water station in the Seka-Mbote district	E 13° 02’ 50.1’’	S 05° 51’ 10.6’’	28 m
E. VBA	Lower town water station	E 13° 03’ 41.0’’	S 05° 51’ 11.6’’	19 m
E.TRF	Discharged treated water station and flare-up	E 13° 03’ 40.6’’	S 05° 51’ 33.5’’	18 m
E.TRSF	Discharged treated water station without flare-up	E 13° 03’ 40.6’’	S 05° 51’ 33.5’’	18 m
E.TST	Treated and stored water station	E 13° 03’ 41.1’’	S 05° 51’ 34.3’’	17 m

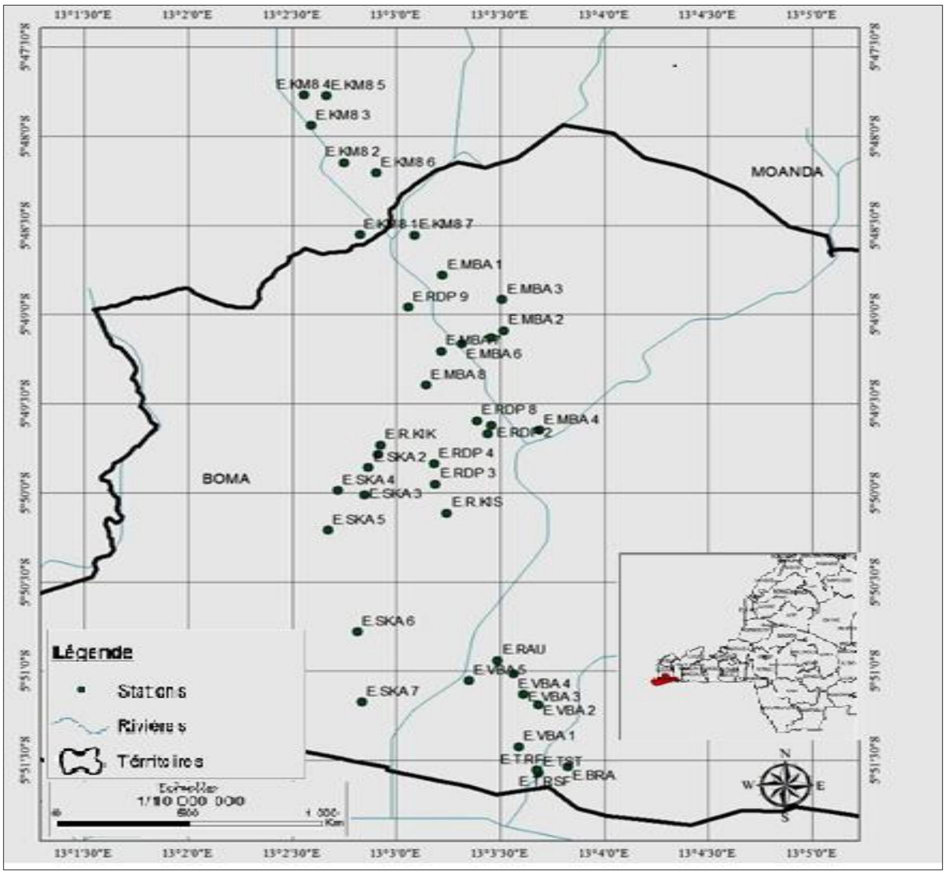

Figure 1 Geospatial map of the water distribution network of the boma centre

3. Methods

3.1. Water sampling

Each month is a sampling campaign; twelve samples are collected at the rate of one sample per station during six months of the rainy season all parameters were analysed in each sample.

Water samples were taken according to the usual precautions [9]. These are:

- Turn on the tap for one minute using a 75% ethyl alcohol burner;
- Take the water from borosilicate glass vials (500 ml) with emery stopper and close tightly;
- Label the vials containing the samples with indication of the place, date, time and temperature of the water to be analyzed;
- Pack in aluminum foil, place in a cooler at 4 °c and send to the laboratory.

3.2. Analysis of the physical and chemical parameters of water

Physical and chemical parameters included pH, temperature (°C), turbidity (NTU), conductivity (µs/cm), dissolved oxygen (mg/L), permanganate oxidizability (mg/L), residual free chlorine (mg/L), biological oxygen demand (mg/L). pH, temperature, turbidity, conductivity and dissolved oxygen were measured in situ using an OAKTON PCD650 multi-parameter probe.

3.3. Bacteriological analyses of water

Bacteriological analyses focused on the search for Escherichia coli, faecal coliforms, total coliforms and faecal streptococci in distribution waters, according to the rules given by [9]:

Several culture media were used to isolate each type of bacteria. These are:

- Mac Conkey (MCc) to analyze coliforms;
- Brilliant Green Bile Broth 2% (BGBB) for coliform confirmation;
- Nutrient agar 2% or Nutrient Agar AT 2% for the analysis of total germs;
- Simmons citrate agar used for Escherichia coli.

Depending on the availability of the equipment in the laboratory, sowing in petri dishes is the only procedure that has been used with strict compliance with some rules given by Rodier [9]:

- The equipment used such as: petri dishes, pyrex test tubes, graduated pipette, beaker have been previously sterilized in the oven (170 °C) for 60 minutes;
- The petri dishes were placed on the table by numbering them according to the different types of water samples to be analyzed ;
- On a table with flame, the culture media previously prepared and sterilized in the autoclave for 15 minutes at 121 ° C were poured into the different petri dishes and 1 ml of each sample was distributed in each petri dish;
- After waiting five minutes to let the culture medium solidify, these boxes were put in the incubator at the upturned position to avoid wetting the medium;
- The results were read 24 hours after at 37 °C for coliforms and 48 hours after at 44 °C for faecal *streptococci*.

As for colony identification, Eschericia coli was presented as red colonies with metallic reflection or pink colonies on MacConkey medium, red colonies for faecal coliforms, white colonies for total coliforms and small red colonies arranged in chains represented fecal streptococci.

3.4. Data Analysis

For the analysis, data were analyzed using student's "t" test (ANOVA 1), Principal Component Analysis (PCA) and Hierarchical Ascending Classification (HFA) were used.

3.4.1. Principal Component Analysis (PCA)

To establish the relationship between the abiotic variables of the water sampling stations and the micro-organisms, we used the Principal Component Analysis (PCA) [10].

Principal Component Analysis is a multivariate analysis widely used in the processing of ecological data. It allows a simplified expression of the information contained in a multivariate array from a reduced number of variables [11; 12].

In this work, Principal Component Analysis was used to establish a distribution in the two-dimensional plane of all sampling stations according to all the environmental factors studied, standardized and centered reduced [11].

All data were first normalized (LOG (X+1)), then centered reduced; the purpose of standardization is to transform the distribution of raw data into a normal distribution. The transformed data is centered reduced to standardize the different environmental factors that are not expressed in the same order of magnitude.

Past software (Paleontological Statistics version 2.16) [13; 14; 15; 16; 17] was used to determine the correlation between abiotic and biotic variables. For the interpretation of the axes, variables whose contribution is exclusively higher than the average contribution ($> 1/\sqrt{p}$, p denoting the number of variables) were used [18].

3.4.2. Hierarchical Ascending Classification (HFA)

CAH consists of gradually aggregating individuals according to their resemblance, measured using an index of similarity or dissimilarity. This classification method is intended to produce groupings described by a number of variables or characters [19].

It actually proceeds to the construction of classes (packets) by successive agglomeration of objects two by two, which provide a hierarchy of partition of objects.

There are several methods of CAH and several choices for calculating the distance between two objects, two classes or an object and a class [20]. The Bray-Curtis index was used, with the technique of average agglomerative grouping [10].

Speaking in terms of individuals and variables, assuming that "n"n individuals are characterized by the "p" variables or characters then the tree is constructed such that for the elements that are in the same group, each has several characters in common with the others and each character is possessed by the members of the group [21].

The algorithms that build these trees are known as "hierarchical bottom-up classification."

The most used is Ward's algorithm or the method of moments of order 2 [21].

In automatic classification, there are no a priori groups. The method looks in the point cloud for dense areas that will form groups that will remain to be interpreted later

4. Results

5. Physical parameters of tap water

The highest average pH value (7.3) was measured at E.RAU station and the low value (6.4) at E.SKA station.

The highest average turbidity value (6.7NTU) was observed at E.TST, E.TRF and E.TRSF stations and the lowest in the network (1.3 NTU) was observed at E.SKA station.

The highest average turbidity value (6.7U NTU) was observed at E.TST, E.TRF and E.TRSF stations and the lowest in the network (1.3 NTU) was observed at E.SKA station. Conductivity had the highest mean value (87.4 µS/cm) at E.TST, E.TRF and E.TRSF stations and the lowest value (60.1 µS/cm) at E.RKIS station.

The average temperature values taken during the year 2017, these are not within the range set by the European Union Directive of 1998 (15-25 ° C) and therefore, they do not comply with these values.

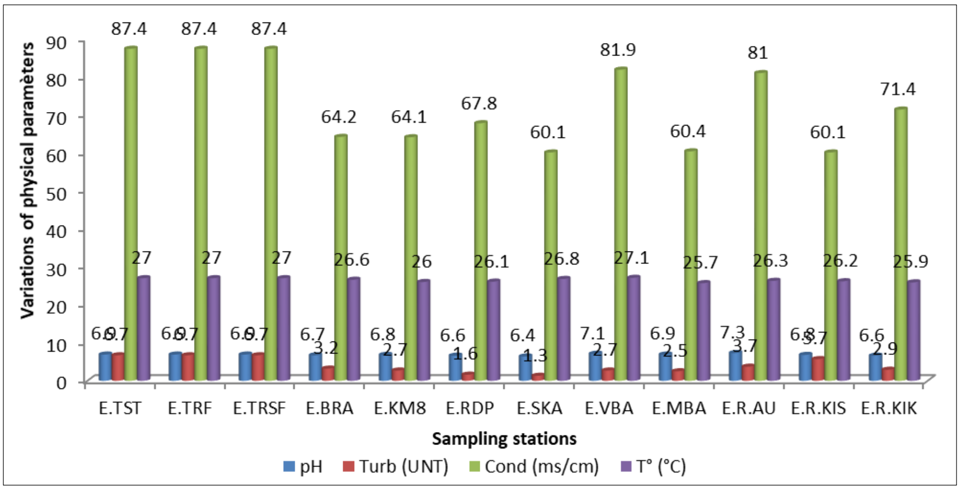

Figure 2 Variations in the average values of the campaigns of the physical parameters of the water analyzed in the 2017 rainy season

5.1. Chemical parameters of the drinking water of the city of Boma

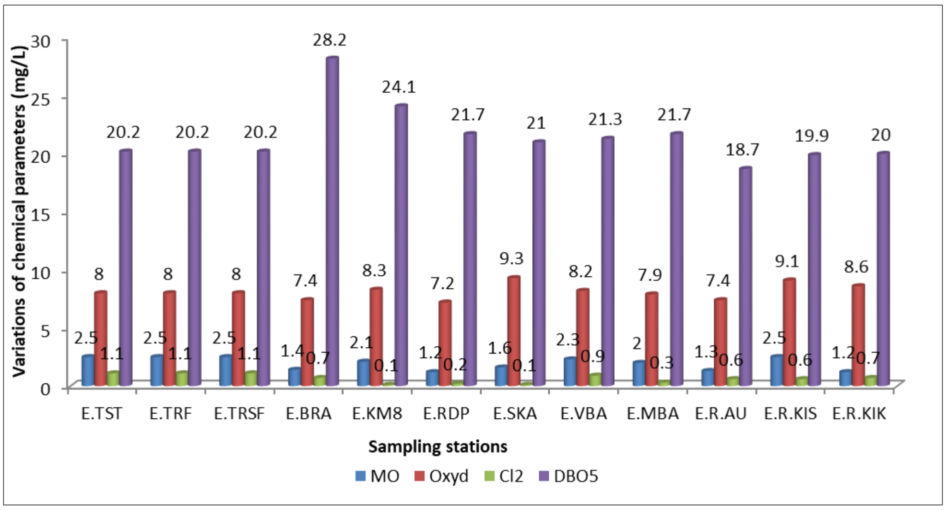

Figure 3 Variations in the average values of the campaigns of the chemical parameters of the water analyzed in the 2017 rainy season

The highest average permanganate oxidizability (or oxidizable material) value (2.5 mg/L) was recorded at E.TST, ETRF, E.TRSF and E.RKIS stations; unlike the lowest value (1.2 mg/L) analysed at E.RDP and E.RKIK stations (fig.3).

During this study year, the low mean dissolved oxygen value is observed at the E.RDP station (7.2mg/L) and the highest value (9.3mgl) was calculated at the E.SKA station.

The low mean of residual free chlorine (0.1 mg/L) was recorded at stations E.km8 and E.SKA and the highest average (1.1 mg/L) at stations E.TST, E.TRF and E.TRSF.

The highest biological oxygen demand (BOD5) (28.2 mg/L) is at E.BRA station and the lowest (18.7mg/L) at E.RAU station.

5.2. Bacteriological parameters of the tap water of the city of Boma

Out of 72 samples analyzed: 48 samples (66.7%) comply with the 2011 WHO recommendations and another 24 samples (33.3%) are non-compliant with a high Escherichia coli pollution rate at E.km8 station, followed by E.SKA, E.MBA and E.TRF stations (fig.4).

For faecal coliforms, 42 out of 72 samples (58.3%) comply with the 2011 WHO recommendations and 30 (41.7%) other samples do not comply with these recommendations. The highest pollution rate was recorded at E.km8 station and the lowest rate at E.TRSF station.

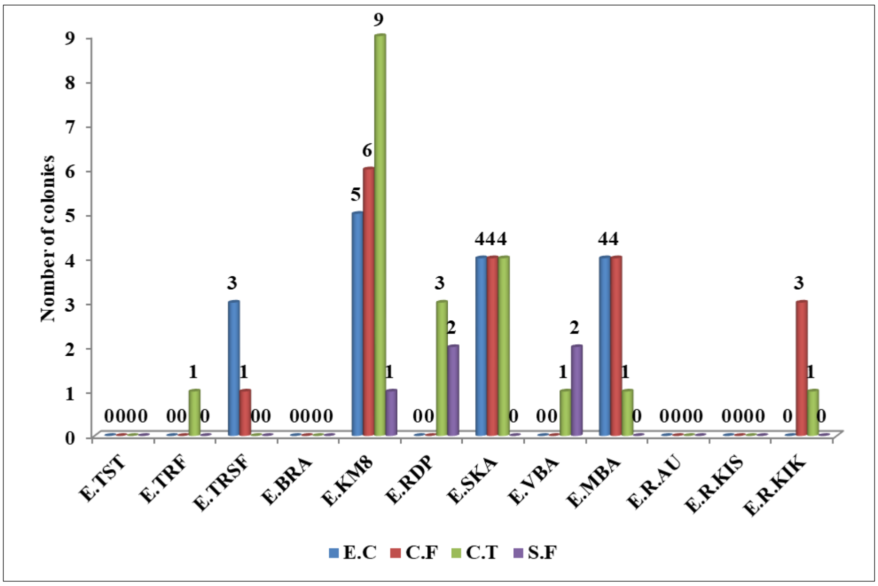

Figure 4 Variations in the average values of the campaigns of the bacteriological parameters of the water analyzed in the 2017 rainy season

For total coliforms, 30 samples (41.7%) comply with the same recommendations (WHO, 2011) and 42 samples (58.3%) are non-compliant. The highest pollution rate is at E.km8 station and the lowest was recorded at E.TRF, E.VBA, E.MBA and E.R.KIK stations.

As for faecal Streptococci, 54 samples (75%) comply with the 2011 WHO recommendations and another 18 samples (25%) do not comply with the highest pollution rate at E.RDP and E.VBA stations and the lowest rate recorded at E.km8 station.

5.3. Statistical Analysis

5.3.1. Correlation between bacteriological, physical and chemical parameters of the tap water of the city of Boma

Two main axes (axis 1 and axis 2) were selected because they explain 96.8% of the dispersion of the variables; Axis 1 showed 91.3% of the total variance and axis 2 showed 5.5%.

With regard to the correlations between axis 1 and isolated bacteria, it was established that no bacterial species correlated positively with axis 1.

Axis 1 positively correlated with the following physical chemical parameters: pH (r=0.45031), turbidity (r=0.025365), color (r=0.94584), conductivity (r=2.136), temperature (r=1.3994), dissolved oxygen (r=0.56485) and BOD5 (r=1.56485).

Positive correlations were observed between the following microbial species: Escherichia coli, faecal coliforms and total coliforms and parameters TA, MO, THt, TAC and between the faecal streptococcal species and the following physico-chemical parameters: MO and Cl2 (fig.5).

The following microorganisms: Escherichia coli, faecal coliforms, total coliforms and faecal streptococci correlated negatively with physico-chemical parameters: pH, turbidity, colour, conductivity, temperature, dissolved oxygen and BOD5.

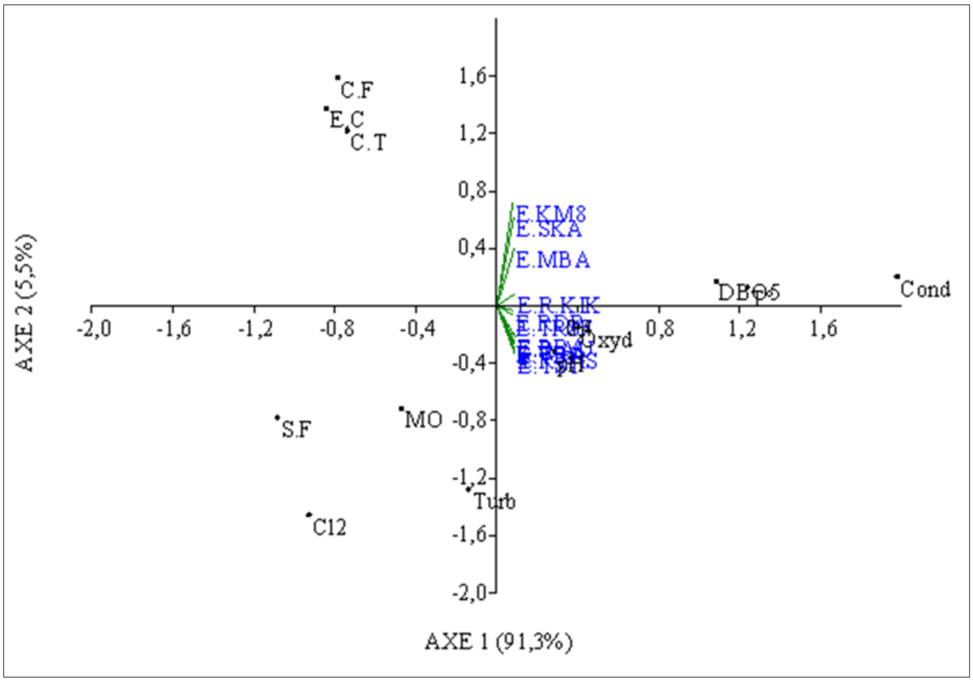

Figure 5 Correlations between bacterial presence and physico-chemical parameters in Boma's water distribution network in the rainy season in 2017

5.3.2. Hierarchical Ascending Classification (HFA)

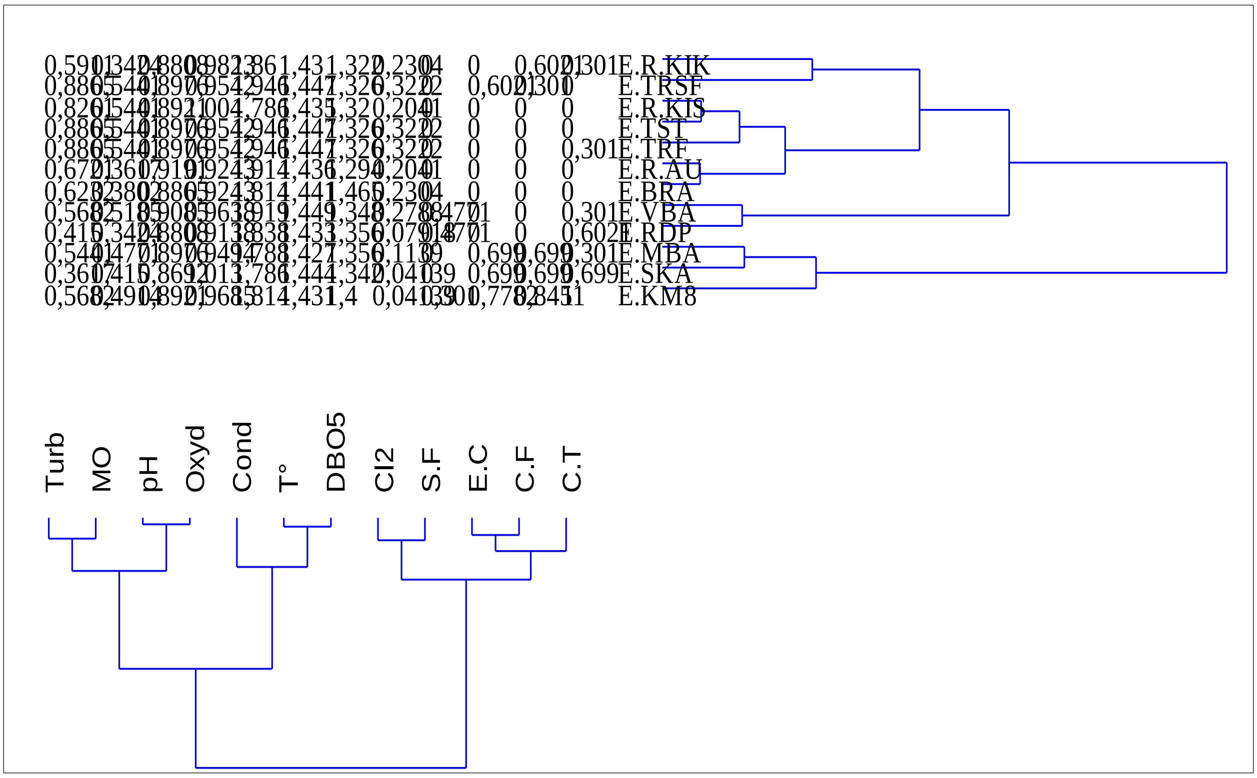

Figure 6 Dendrogram of reconciliation of stations and physical, chemical and bacteriological parameters of the tap water of the city of Boma in 2017

Two groups of parameters were identified (fig.6), turbidity, oxidizable materials, pH, dissolved oxygen, conductivity, temperature and biological oxygen demand were close. The second group is that of Chlore, S.F, E.C, C.F and C.T which have come together (fig.6B). The residual free chlorine content determines the population of bacteria (fig.6).

The comparisons were also observed between two groups of stations. The E.KM8, E.SKA and E.MBA stations are very close and distant from the parameters of the mains water at the E.RKIK, E. TRSF, E.RKIS, E. ISL, E. IRF, E. RAU, E. BRA, E.VBA and E. RDP stations.

6. Discussion

The pH has average values that are slightly acidic (6.73±0.43) in the rainy season with a compliance rate of 91.7% of the samples with the 2011 WHO recommendations. These results are similar to those presented by [22] in Chad (pH 6.848±0.82), for treated water in the network. The results obtained showed highly significant differences in pH (pH** 0.0006776).

The residual free chlorine in Boma's water distribution network has averages (0.61±0.48) with a sample compliance rate of 66.7% in the rainy season. These averages of the concentrations in the network (0.1 to 1.13 mg/L) appear to be the same as those found by [23] in Montreal (0.1 to 1 mg/L); these seasonal mean values show no significant difference for residual free chlorine (0.8376).

During the season, turbidity has average values (3.86±1.39) whose compliance rate with the WHO [7] recommendations reached 66.7%. The results obtained in this study are different from those found by [22] (turbidity 0.116±0.08).

The recorded turbidity values were well above the WHO-prescribed limit (5 NTU) with a considerable increase at plant exit at the three TST-TRFS-TRSF stations as shown in Figure 2. This high turbidity was probably due to the presence of finely divided suspended solids such as clays and silts [24]. It should be noted that high turbidity can promote the proliferation of microorganisms that can attach to suspended particles that have a protective effect of these microorganisms against disinfection [25]. Thus, these waters were all cloudy and their bacteriological quality was therefore suspect at the TRF and TRSF stations.

Since the WHO did not set recommendations for the temperature of the treated water in the distribution network, however, the European Union set in 1998 an interval between 15 and 25°C. Thus, the average temperatures recorded (X±SD) in all samples of the season in 2017 do not comply with these aforementioned standards. These values can be explained by the fact that Boma's water distribution network is in tropical areas where the ambient temperature can influence that of the water, especially when the pipes are not protected by a layer of soil, as a result of erosion.

The results obtained showed that the average values of the bacteria found show differences in the levels of (%) compliance of the samples with the WHO [24] recommendations: Escherichia coli [66.7%]; Fecal coliforms [58.3%]; Total coliforms [41.7%] and fecal streptococci [75%]. It appears from this study that out of 72 samples analyzed: 33.3% are unsatisfactory due to the presence of Escherichia coli, 41.7% are non-compliant due to the presence of faecal coliforms, 58.3% of samples are satisfactory due to total coliforms and 25% non-satisfaction due to faecal streptococci.

These results, whose rates are higher, are different from those found by [26] in Dakar and [25] in Mbanza-Ngungu.

Out of 72 samples analyzed: Escherichia coli, 48 samples (66.7%) comply with the WHO [24] recommendations and 24 other samples (33.3%) are non-compliant with high pollution levels at station E.km8, followed by stations (E.SKA, E.MBA and E.TRF). Fecal coliforms, 42 samples out of 72 (58.3%) are compliant and another 30 samples are non-compliant with these recommendations.

The highest pollution rate was recorded at E.km8 station and the low rate at E.TRSF station. The total coliforms, 30 samples (41.7%) comply with these recommendations and another 42 (58.3%) are non-compliant. The highest pollution rate is at E.km8 station and the lowest was recorded at E.TRF, E.VBA, E.MBA and E.R.KIK stations. Fecal streptococci, 54/72 (75%) samples are compliant and another 36 samples (25%) are non-compliant with a high pollution rate at E.RDP and E.VBA stations and a low rate recorded at E.km8 station.

The poor quality of this water could be explained not only by the lack of hygiene but also by poor sanitation [27], to which can be added the intermittent distribution of water. Most of these polluted stations are located in places with a high level of pollution from damaged latrines, garbage cans. This implies that they undergo an infiltration of microorganisms from water leaks observed in the network. Similarly, runoff is thought to be responsible for the presence of bacteria in these waters [28]. Positive correlations between Escherichia coli, faecal coliforms and total coliforms; Escherichia coli, faecal coliforms, total coliforms and faecal streptococci (Figure 5) indicate the common origins of these microbes.

7. Conclusion

Although the Boma water distribution network is a structure to ensure the supply of drinking water throughout the city, the results of the physical, chemical and microbiological analyses obtained show that the water samples taken from end-to-end the network and analyzed in the laboratory have some average values that exceed the limits set by WHO throughout the 2017 rainy period.

During this period, this distribution network supplied water which, upstream (water production and treatment plant) as well as downstream (water consumers), contained some germs. The presence of these so-called fecal contamination indicators of faecal contamination is synonymous with certain health risks because their survival in drinking water seriously suspects that of pathogenic germs.

This state of affairs, which is a problem for water quality, can be justified by: inefficient treatment, intermittent distribution, dilapidated piping (245 leaks/month on average), and unsanitary conditions in the distribution system.

In terms of health, the non-compliance of 33.3% of samples with WHO recommendations in this distribution network means the lack of effective treatment of the water distributed or the lack of permanent maintenance throughout the network.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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