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Research Article

Physico-chemical and Bacteriological Characterization of Surface Waters in the City of Dolisie, Republic of Congo

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Abstract

Surface water quality in Dolisie (southwest of the Republic of Congo) is strongly impacted by human activities, particularly domestic wastewater discharge, agriculture, and livestock farming, leading to progressive degradation of water resources and posing risks to public health as well as domestic and agricultural uses. This study assessed water quality through analysis of physico-chemical and bacteriological parameters at several sites representative of domestic and agricultural areas. Physico-chemical analysis showed that pH ranged from 5.5 (Ninja Lake) to 9.9 (marsh near the Orthodox Church), with a mean of 6.58 ± 1.18. Water temperature varied from 25.36°C (upstream of the Loubomo River) to 28.5°C (Tahiti fish ponds), with an average of 26.83 ± 0.93°C. Electrical conductivity ranged from 115.66 to 315.33 µS/cm (mean 213.65 ± 73.18 µS/cm), while total dissolved solids (TDS) varied from 57 to 210.5 ppm (mean 112.52 ± 46.70 ppm). Three heavy metals were detected: cadmium (0.049–0.070 ppm, mean 0.057 ± 0.005 ppm), copper (0.0217–0.0509 ppm, mean 0.037 ± 0.010 ppm), and zinc (0.0004–0.00311 ppm, mean 0.004 ± 0.008 ppm). Microbiologically, total mesophilic aerobic flora (TMAF) ranged from 1,000 to 6,000 CFU/100mL (mean 3,333 ± 1,670), total coliforms from 69 to 193 CFU/100mL (mean 133 ± 43), and fecal coliforms from 32 to 102 CFU/100mL (mean 64 ± 21), exceeding WHO standards and indicating significant fecal contamination. Fecal streptococci ranged from 30 to 72 CFU/100mL, *Staphylococcus* spp. from 14 to 97 CFU/100mL, *Salmonella* from 40 to 110 CFU/100mL, *Shigella* from 19 to 77 CFU/100mL, and *Pseudomonas aeruginosa* from 15 to 62 CFU/100mL. Correlation analyses revealed significant relationships: temperature correlated with total coliforms (r = 0.69) and fecal coliforms (r = 0.63), electrical conductivity correlated with TDS (r = 0.91), and several bacterial groups showed positive correlations among themselves. Principal component analysis associated the F1 axis (42.24% of variance) with microbiological parameters and the F2 axis (20.7%) with physico-chemical parameters. These findings reveal progressive deterioration of surface water quality in Dolisie and emphasize the urgent need for sustainable management measures, public awareness, and wastewater control to preserve water resources and protect public health.

Keywords

Surface Water, Physico-chemical Parameters and Bacteriological, Dolisie, Republic of Congo

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1. Introduction

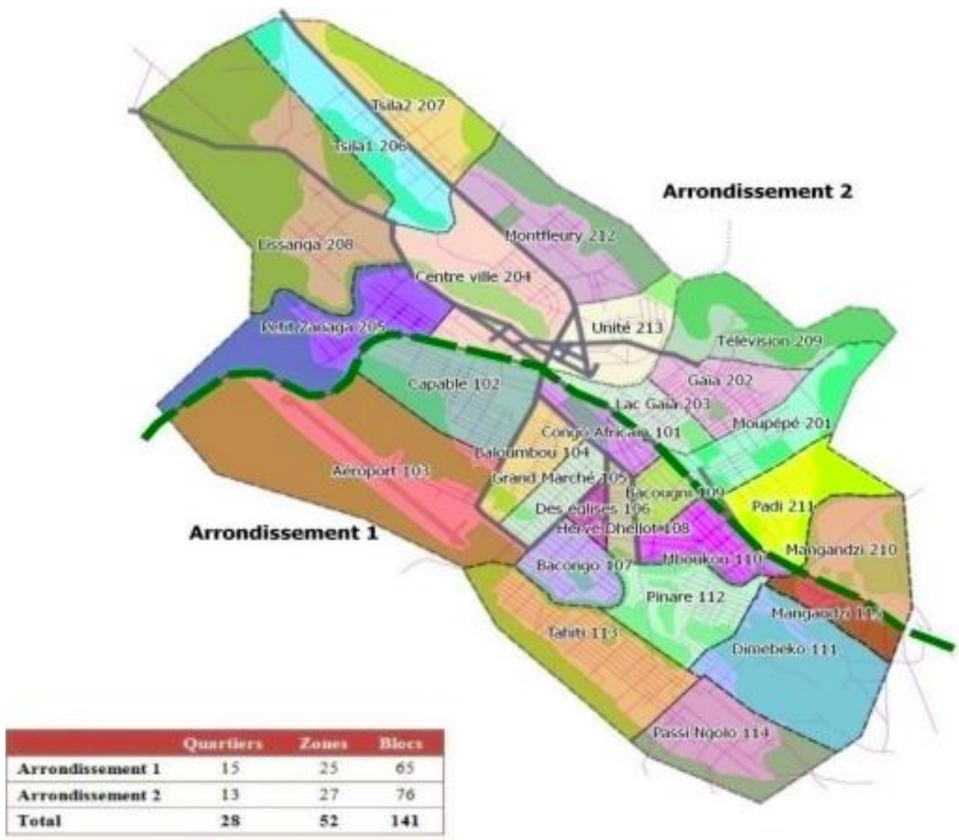
Water plays a crucial role in life, health, and human dignity [1]. All living beings have a vital need for water to survive. As an irreplaceable resource, water is not only an essential nutrient but also participates in numerous fundamental physiological functions, such as digestion, nutrient absorption, body temperature regulation, and waste elimination [2]. The quality of water intended for human consumption is evaluated based on its physico-chemical and bacteriological properties. The use and ingestion of polluted or contaminated water are among the main causes of numerous human diseases [3]. Every year, 300 million children die from waterborne diseases such as cholera, diarrhea, typhoid fever, hepatitis A, poliomyelitis, and schistosomiasis [4]. These diseases are primarily transmitted via the fecal-oral route, through ingestion of polluted water, consumption of contaminated food, or contact with unsafe water during bathing or recreational activities [3].

In the Republic of Congo, access to safe drinking water remains a major challenge. Daily water supply in Congolese cities involves constant movement, 25-liter jerrycans, and tanker trucks labeled “Potable Water.” These scenes illustrate the difficulty of accessing quality water in many urban and rural centers of the country [5]. The city of Dolisie, the capital of the Niari Department, is no exception. It faces significant challenges in sanitation and access to drinking water. The population of Dolisie, estimated at 83,802 inhabitants in 2007 [6], was assessed at 178,172 inhabitants in 2023 [7], corresponding to an annual growth rate of 7%. This rapid population growth has led to unplanned urbanization and precarious socio-economic conditions.

In some neighborhoods, the availability of potable water is limited, and daily shortages force residents to rely on natural springs, river water, wells, or lakes. However, the quality of these waters is often assessed solely on visual criteria (clear water), without consideration of anthropogenic contamination risks. These water sources are therefore not immune to chemical and bacterial pollution. It is in this context that the present study was conducted, aiming to characterize the bacteriological and physico-chemical quality of river and lake waters in the city of Dolisie.

2. Materials and Methods

2.1. Presentation and Location of the City of Dolisie



	Quartiers	Zones	Blocs
Arrondissement 1	15	25	65
Arrondissement 2	13	27	76
Total	28	52	141

Figure 1. *Boroughs and Districts of the City of Dolisie [9].*

This study was conducted in the city of Dolisie, which covers an area of 90-100 km^2 with an average altitude of approximately 300 m [8]. Dolisie is located in the southwest of the Republic of Congo, within the Niari Department. It is the third largest city in the country and the departmental capital, with a population estimated at 178,172 inhabitants in 2023 [7]. The administrative structure of Dolisie is divided into 2 boroughs and 15 districts (Figure 1); Borough 1 comprises 15 districts, while Borough 2 is subdivided into 13 districts [9].

2.2. Sample Collection

Water samples were collected following the procedures described by Rodier [10]. Sampling was performed manually in water bodies (Figure 2). Before each collection, polyethylene bottles were first emptied of their initial contents (mineral water) and then labeled using adhesive tape indicating the location, date, and sample number. The bottles were carefully rinsed several times with the water to be analyzed to prevent contamination. Once rinsed, the bottles were immersed to a depth of 10–15 cm, filled, tightly sealed, and immediately placed in a cooler containing ice packs to minimize any chemical or biological alterations. Figure 2 shows the locations of the sampling points.

Figure 2. *Presentation of Water Bodies.*

3. Analytical Methods

3.1. Physico-chemical Analysis Methods

3.1.1. In Situ Measurement of Physico-chemical Parameters

In situ measurements were performed for physico-chemical parameters such as temperature, pH, electrical conductivity, salinity, and total dissolved solids (TDS) using a multi-parameter probe. First, the device was turned on, and the probe was rinsed with water from the sampling site to prevent cross-contamination. The condition of the sensors (temperature, pH, conductivity, and TDS) was then checked. The probe was fully immersed in the water contained in a vessel at a depth of approximately 10–15 cm below the surface. Once the sensors stabilized (typically within 30 seconds to 1 minute), the displayed values for each parameter were recorded. After measurements, the sensors were rinsed with water and gently wiped with a clean tissue.

3.1.2. Heavy Metal Analysis

Samples intended for chemical analyses, particularly for the detection of six (6) heavy metals-copper (Cu), zinc (Zn), cadmium (Cd), lead (Pb), chromium (Cr), and nickel (Ni)-were sent to the AMTECH EXPERTISES Chemistry Laboratory in Pointe-Noire. Trace metal analysis was performed using a Flame Atomic Absorption Spectrometer (FAAS). The principle of flame atomic absorption spectroscopy involves nebulizing the water sample into a flame, which excites the metal atoms. As these atoms return to their ground state, they emit light at a wavelength characteristic of the element, with an intensity proportional to its concentration. Total trace metal concentrations were expressed in parts per million (ppm).

3.2. Bacteriological Analyses

To determine the bacterial composition of the water samples, the membrane filtration method was employed using sterile membranes with 0.45 µm pores and 47 mm diameter. The operation was performed using a three-station filtration manifold (Figure 3) mounted on a metal stand. The procedure involved selecting a sterile membrane with sterile forceps and placing it on the perforated plate of the manifold, gently shaking the bottle containing the water sample, and aseptically pouring 100mL of the sample into the filtration funnel. The valve was then opened to allow water to pass through. Once the membrane was dry, the reservoir was removed, the membrane was grasped at the edge with sterile forceps, and carefully placed onto a culture medium, ensuring that no air bubbles were trapped under the membrane.

Figure 3. *Water samples to be analyzed.*

3.3. Sample Processing

QGIS software was used to design the sampling map, while

Word and Excel, as well as STATISTICA software, were employed for data entry and processing. Tables and graphs were used to present the collected data. The results were then compared to international standards for surface water quality in order to draw conclusions and make specific recommendations.

4 Results and Discussion

4.1. Results

4.1.1. Physico-chemical Parameters

a. pH

The pH values recorded in this study are presented in Figure 4. They ranged from 5.5 in the waters of Ninja Lake (NINJA) to 9.9 in the marsh near the Orthodox Church (ORTH), with an overall mean of 6.58 ± 1.18 across all sampling points.

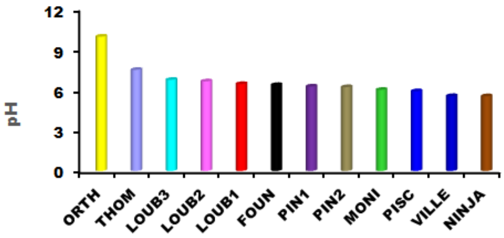


Figure 4. pH variation at the sampling points.

b. Temperature

Figure 5 shows that water temperature during this study ranged from 25.36°C upstream of the Loubomo River (LOUB1) to 28.5°C in the Tahiti fish ponds (PISC), with an overall mean of 26.83 ± 0.93°C.

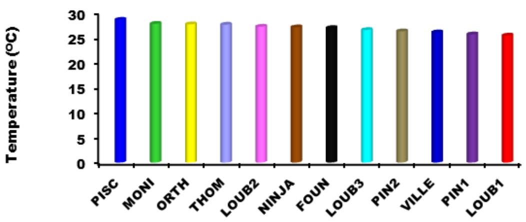


Figure 5. Temperature variation at the sampling points.

c. Electrical Conductivity

Electrical conductivity measurements varied between 115.66 µS/cm in Ninja Lake (NINJA) and 315.33 µS/cm at the downstream point of the river (LOUB3), with an overall mean of 213.65 ± 73.18 µS/cm (Figure 6).

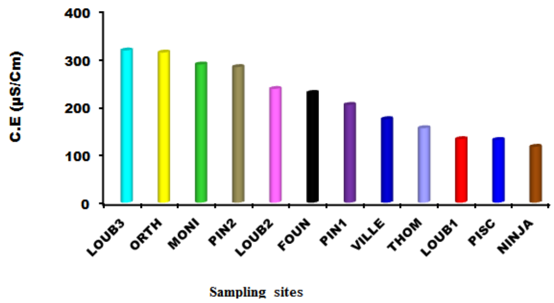


Figure 6. Variation of Electrical Conductivity.

d. Total Dissolved Solids (TDS)

TDS/salinity values recorded in this study ranged from 57 ppm in the middle course of the Pinaret River (PIN2) to 210.5 ppm in Ninja Lake (NINJA), with a mean of 112.52 ± 46.70 ppm (Figure 7).

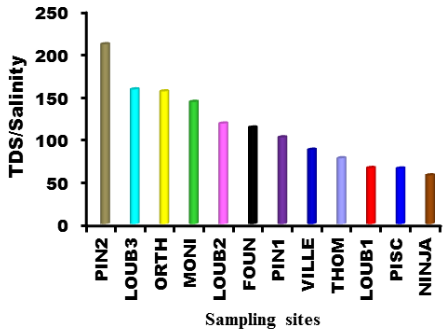


Figure 7. Variation of TDS/Salinity.

4.1.2. Heavy Metals

Out of six (6) elements analyzed (Cu, Zn, Pb, Ni, Cd, Cr), three (3) were detected in all samples: cadmium (Cd), copper (Cu), and zinc (Zn).

Cadmium (Cd)

Cadmium concentrations recorded in this study ranged from 0.049 ppm in the waters of Thomas Lake (THOM) to 0.070 ppm in the middle course of the Pinaret River (PIN2), with a mean of 0.057 ± 0.005 ppm (Figure 8).

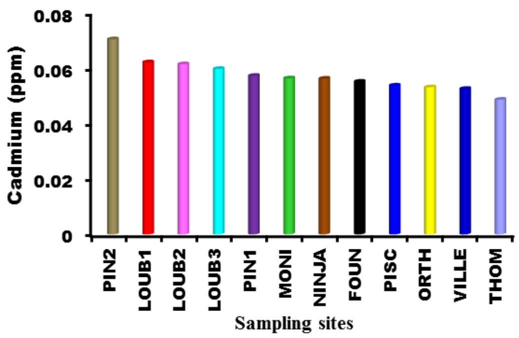


Figure 8. Cadmium concentration variation.

Copper (Cu)

Copper concentrations (Figure 9) varied from 0.0217 ppm in the marsh near the Orthodox Church (ORTH) to 0.0509 ppm in the middle course of the Pinaret River (PIN2) near a large uncontrolled waste dump. The mean copper concentration was 0.037 ± 0.010 ppm.

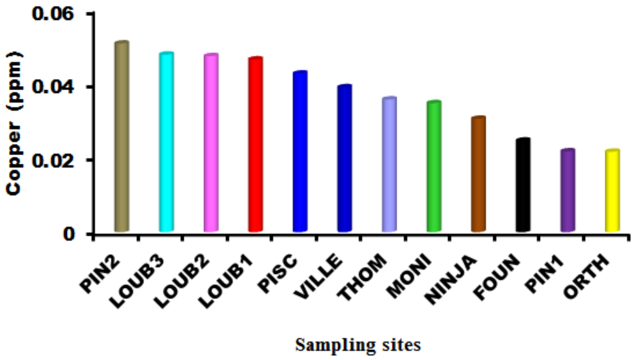


Figure 9. Copper concentration variation.

Zinc (Zn)

Figure 10 shows zinc concentrations obtained in the laboratory, ranging from 0.0004 ppm in the Tahiti fish ponds (PISC) to 0.00311 ppm upstream of the Loubomo River (LOUB1). The overall mean zinc concentration for all sampling points was 0.004 ± 0.008 ppm.

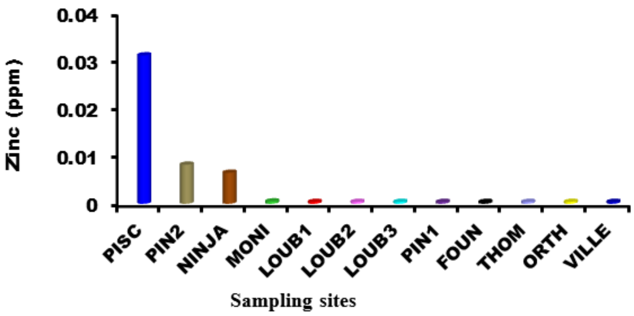


Figure 10. Zinc concentration variation.

4.1.3. Microbiological Parameters

a. Total Mesophilic Aerobic Flora (TMAF)

Analysis of the histogram (Figure 11) shows that all water samples were contaminated with TMAF. Microbial concentrations ranged from 1,000 CFU/100mL in the Tahiti fish ponds (PISC) to 6,000 CFU/100mL downstream of the Founou-Founou River (FOUN), with a mean of 3,333 ± 1,670 CFU/100mL.

b. Total Coliforms (TC)

Figure 12 presents the distribution of total coliforms across all sampling points. Counts ranged from 69 CFU/100mL in the middle course of the Pinaret River (PIN1) to 193 CFU/100mL in Ninja Lake (NINJA), with a mean of 133 ± 43 CFU/100mL.

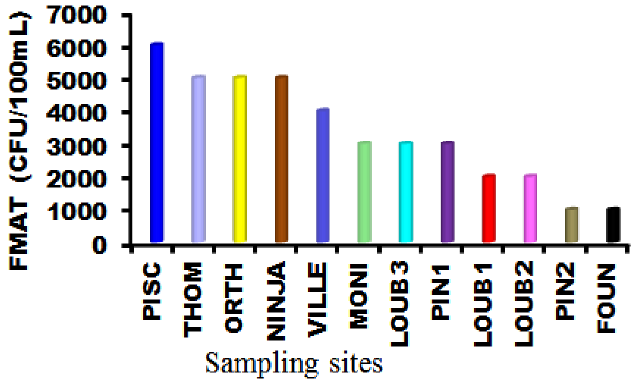


Figure 11. Variation of Total Mesophilic Aerobic Flora (TMAF).

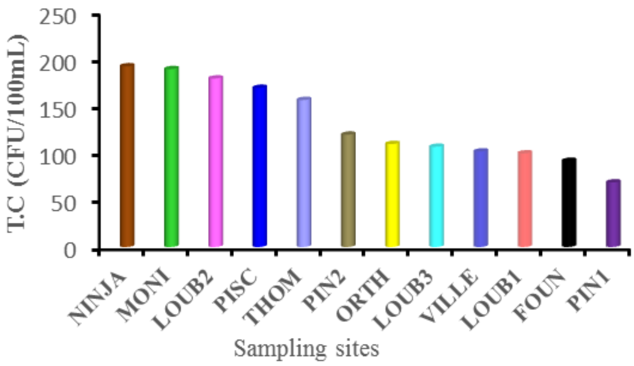


Figure 12. Variation of Total Coliform.

c. Fecal Coliforms (FC)

Microbiological analysis (Figure 13) shows that river, pond, and market garden water samples contained fecal coliforms ranging from 32 CFU/100mL upstream of the Loubomo River (LOUB1) to 102 CFU/100mL in the Ma Monique fish pond (MONI), with a mean of 64 ± 21 CFU/100mL.

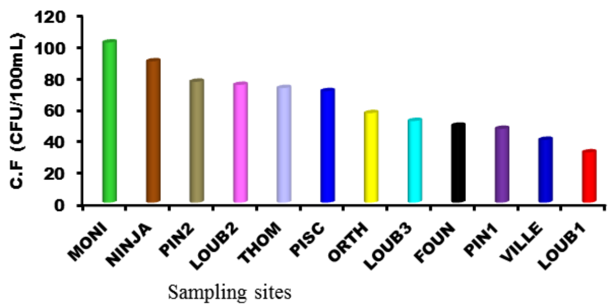


Figure 13. Variation of Fecal Coliforms.

d. Fecal Streptococci (FS)

Figure 14 shows fecal streptococci counts across all sampled water points. Values ranged from 30 CFU/100mL in the middle course of the Pinaret River (PIN2) to 72 CFU/100mL in the mid-course of the Loubomo River (LOUB2), a popular bathing site. The mean value was 55.5 ± 13.20 CFU/100mL.

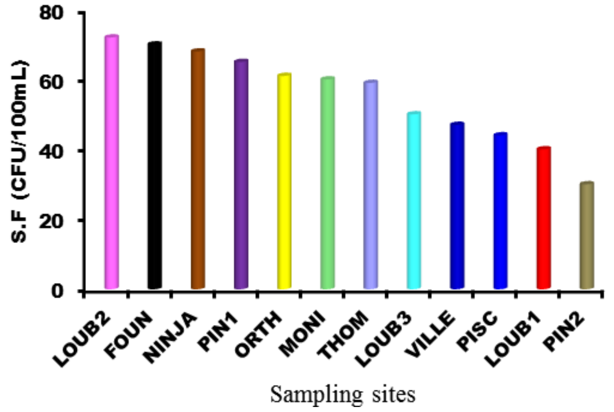


Figure 14. *Variation of Fecal Streptococci.*

e. *Staphylococcus* spp

According to Figure 15, *Staphylococcus* counts at the sampling sites ranged from 14 CFU/100mL in the marsh located in the city center (VILLE) to 97 CFU/100mL in Ninja Turtle Lake (NINJA), with a mean of 63.75 ± 27.77 CFU/100mL.

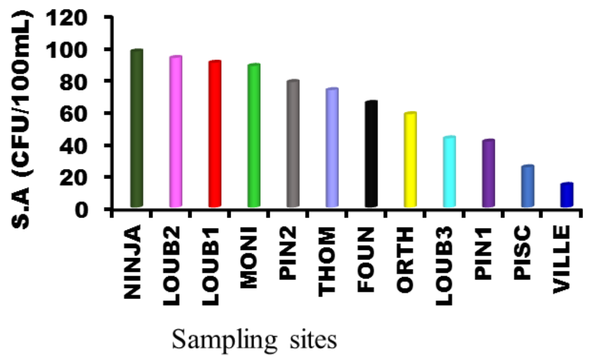


Figure 15. *Variation of Staphylococcus spp.*

f. *Salmonella*

Figure 16 shows that *Salmonella* concentrations varied from 40 CFU/100mL in the marsh at the city center (VILLE) to 110 CFU/100mL in the mid-course of the Loubomo River (LOUB2), with a mean of 68.08 ± 21 CFU/100mL.

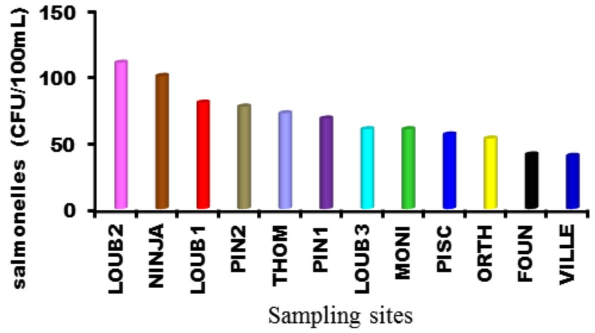


Figure 16. *Variation of Salmonella.*

g. *Shigella*

Microbiological analysis (Figure 17) indicates that *Shigella* counts ranged from 19 CFU/100mL downstream of the Loubomo River (LOUB3) to 77 CFU/100mL in Ninja Lake (NINJA), with a mean of 45 ± 22 CFU/100mL.

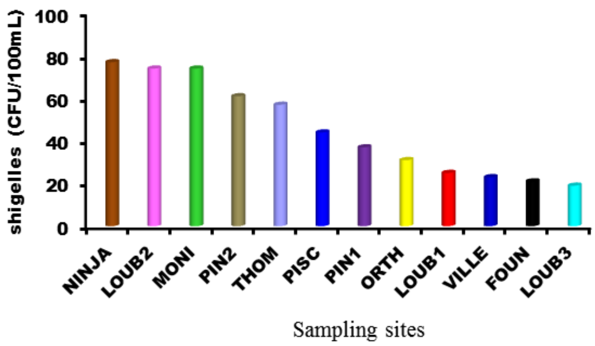


Figure 17. *Variation of Shigella.*

h. *Pseudomonas aeruginosa*

In the water samples of this study (Figure 18), *Pseudomonas aeruginosa* counts ranged from 15 CFU/100mL upstream of the Loubomo River (LOUB1) to 62 CFU/100mL in Ninja Turtle Lake (NINJA), with an overall mean of 37 ± 16 CFU/100mL.

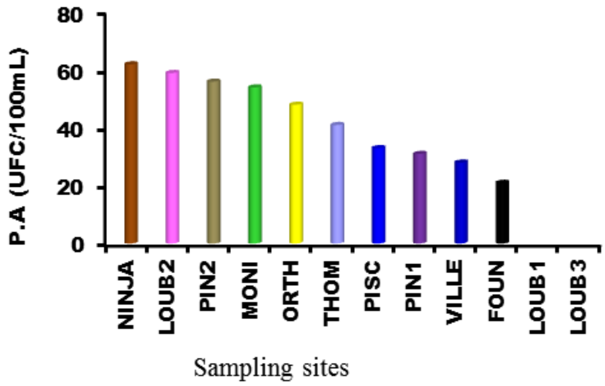


Figure 18. *Variation of Pseudomonas aeruginosa.*

4.1.4. Correlation Between Bacteriological and Physico-chemical Parameters

Correlations between the physico-chemical and bacteriological parameters of the sampled water points were investigated using a correlation matrix and principal component analysis (PCA). The correlation matrix for all parameters is presented in the following table:

Table 1. Correlation Matrix between Physico-Chemical and Bacteriological Parameters.

	T °C	pH	CE	TDS	CT	CF	SF	SA	Salm	Shyg	PA
T °C	1										
pH	0,25	1									
CE	0,05	0,46	1								
TDS	-0,06	0,32	0,91	1							
CT	0,69	-0,19	-0,19	-0,19	1						
CF	0,63	-0,14	0,11	0,17	0,86	1					
SF	0,26	0,16	0,02	-0,25	0,22	0,21	1				
SA	0,01	0,04	0,01	0,07	0,46	0,49	0,25	1			
Salm	0,40	-0,21	-0,09	0,02	0,83	0,90	0,24	0,63	1		
Shyg	-0,07	-0,13	-0,23	-0,12	0,51	0,40	0,19	0,71	0,69	1	
PA	0,39	0,05	0,00	0,13	0,64	0,76	0,26	0,51	0,87	0,52	1

Analysis of the correlation matrix shows the presence of moderate to strong positive relationships among several parameters:

Temperature is fairly well correlated with total coliforms (TC) ($r = 0.69$) and fecal coliforms (FC) ($r = 0.63$).

Electrical conductivity (EC) is strongly correlated with total dissolved solids (TDS), with a very high value of 0.91.

Total coliforms (TC) are strongly associated with fecal coliforms (FC) ($r = 0.86$), *Salmonella* (0.83), *Shigella* (0.51), and *Pseudomonas aeruginosa* (PA) (0.64).

Staphylococcus spp. is well correlated with *Salmonella* (0.63), *Shigella* (0.71), and PA (0.51).

Salmonella is also strongly correlated with *Shigella* (0.69) and PA (0.87).

Finally, *Shigella* is moderately correlated with PA (0.52).

According to the principal component analysis (PCA) diagram of microbiological and physico-chemical parameters, the first axis (F1) represents 42.24% of the total variance (Figure 19). This axis is associated with the following variables: total coliforms (TC), fecal coliforms (FC), fecal streptococci (FS), *Pseudomonas aeruginosa* (PA), *Staphylococcus* spp., and the bacteria *Shigella* and *Salmonella*. The second axis (F2) represents 20.7% of the total variance and is primarily associated with electrical conductivity (EC), total dissolved solids (TDS), and pH.

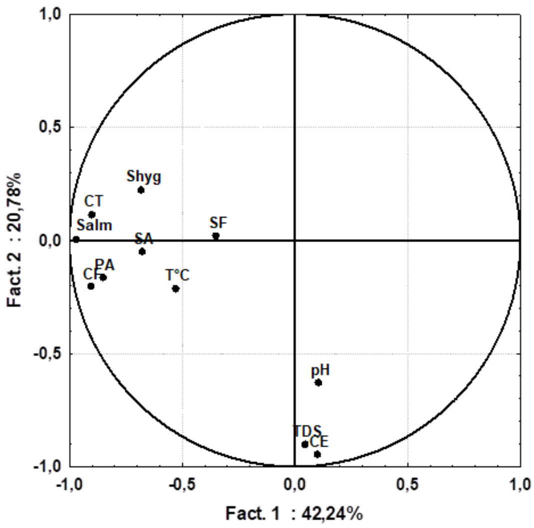


Figure 19. Correlation circle between physicochemical and bacteriological parameters.

4.2. Discussion

The temperatures recorded in all water samples range from 25.36°C to 28.5°C. These temperatures are consistent with the meteorological data for the city of Dolisie. The pH values obtained are mostly acidic, being less than or equal to 6. Three groups can be distinguished: pH around 10 (marsh near the Orthodox Church), pH around 7 (Lake Thomas, midstream and downstream of the Loubomo River), and pH around 6 (the remaining eight sampling sites). The basic nature of the water from the Orthodox Church marsh could be attributed, on one hand, to the strong degradation of organic matter and, on the other hand, to numerous anthropogenic activities (market gardening, civil engineering works, etc.) visible in the area.

The neutral pH observed in the waters of the Loubomo River and Lake Thomas can be explained by the fact that these waters are used by local populations for bathing, laundry, and dishwashing. The acidity observed in most of the waters studied may be due to the ferralitic soils they flow through [11].

The electrical conductivity (EC) values measured in Dolisie surface waters range between 116 and 315 µS/cm. These results, which are below the European Union standard (maximum limit of 500 µS/cm), indicate a low mineralization of these waters, which could be due to the nature of the rocky substrate and surrounding ecosystems [12]. Similar results were reported by Makhoukh et al. [13] during a physicochemical study of the surface waters of Oued Moulouya in northeastern Morocco. This could also be explained by a low mineralization of salts present in these waters.

The total dissolved solids (TDS) and salinity levels measured in this study range from 57 to 210.50 mg/L. These values remain below the thresholds set by UNEP (TDS/Salinity < 600 mg/L). The parallel evolution of TDS, salinity, and electrical conductivity confirms the low mineralization of the analyzed waters. Indeed, high rainfall or a significant input of non-mineralized runoff water (recent rain, rooftop or road runoff) dilutes the dissolved solids. These waters have not had enough time to become enriched in minerals or dissolved pollutants [11]. The swampy areas where water was collected are rich in aquatic vegetation, which can capture or filter certain ions (phosphates, nitrates, metals), thus reducing TDS. Biological processes, such as nutrient uptake by plants, may also lower dissolved solid concentrations. These results are consistent with those of Bendjammaa et al. [14], who studied the impact of wastewater on the Oued Ghourzi in Algeria.

Regarding heavy metal characterization, six (6) elements were analyzed in the laboratory: cadmium (Cd), copper (Cu), zinc (Zn), lead (Pb), chromium (Cr), and nickel (Ni). Among these, cadmium, copper, and zinc were detected in all water samples. Copper and zinc concentrations were below the European Union limit values for surface waters. In contrast, cadmium concentrations exceeded the EU maximum permissible limit (0.045 mg/L) in all samples analyzed.

The presence of these elements in water could have both natural and anthropogenic origins. On one hand, they may come from regional rocks or soils, gradually released into rivers, ponds, and marshes through natural degradation and erosion processes. On the other hand, they may also originate from domestic or agricultural discharges, whether direct or diffuse. Indeed, the study by Ntari [15] on the characterization of waste and soils under illegal dumpsites in Dolisie revealed notable concentrations of Cu, Zn, Cd, Pb, Cr, and Ni in the soils and wastes of the studied dumps. Rainwater runoff could therefore transport these elements into the city's rivers, lakes, marshes, and ponds.

The analysis of the water samples revealed the presence of the following microorganisms: FMAT (total mesophilic aerobic flora), total coliforms (CT), fecal coliforms (CF), fecal streptococci (SF), *Staphylococcus* sp., P*seudomonas aeruginosa* (PA), *Salmonella*, and *Shigella*.

The FMAT concentrations ranged from 1,000 to 6,000 CFU/100mL. These aerobic bacteria, generally non-pathogenic, include molds and yeasts naturally present in the environment. Their presence in water is an indicator of possible microbiological contamination [16].

The total coliform counts in this study ranged from 69 to 193 CFU/100mL, which is well above the European Community Council Directive, ECCD [17] standard of 50 CFU/100mL for bathing and domestic water sources. Fecal coliforms ranged from 32 to 102 CFU/100mL, exceeding the ECCD [17] limit of 20 CFU/100mL for surface waters intended for drinking water production.

As for fecal streptococci (SF), values ranged from 30 to 72 CFU/100mL, also above European standards. The high presence of CT, CF, and SF in water suggests contamination mainly from domestic wastewater, particularly from toilets. Several sampling sites are located near dwellings or areas with intense poultry or pig farming. Rainwater runoff easily carries fecal matter and other waste to water bodies. These findings are consistent with those of Tchoumou et al. [18] and Mulungulungu et al. [16], who found bacterial pollution in river and well water in Brazzaville and Lubumbashi, respectively.

Furthermore, microbiological analysis revealed the presence of pathogenic bacteria such as *Pseudomonas aeruginosa*, *Staphylococcus*, *Salmonella*, and *Shigella* in all samples. Their concentrations far exceed the standards set by ECCD [17]. The presence of these microorganisms indicates persistent contamination, linked to human and animal excreta, which are the main sources of these pathogens. These bacteria can be excreted not only during illness but also by asymptomatic carriers [11]. Thus, their presence in Dolisie's waters is likely due to untreated human and animal waste entering rivers, ponds, and swamps. The highest bacterial loads were found in sites with intense human activity, such as Lake Tortue Ninja (NINJA), the midstream Loubomo River (LOUB2), and fish ponds in the Tahiti (PISC) and Ma Monique (MONI) districts.

These results are consistent with those of Hounsounou et al. [19] in their study on the contamination of wells by *Salmonella* and *Vibrio* species in the precarious neighborhoods of the 6th district of Cotonou (Benin). The contamination of these wells also resulted from human (excreta, used clothing, sweat, mucus, etc.) and animal (droppings, mucus, direct contact with water) wastes, transported by rainwater—a typical runoff and infiltration pollution phenomenon. Similar observations were reported by Louzayadio et al. [20] in a study on the vulnerability of tap water and groundwater to microbiological contamination in southern Brazzaville. These authors particularly highlight the lack of hygiene and sanitation in households, making water sources highly vulnerable to contamination.

The relationship between physico-chemical and bacteriological parameters, expressed through Principal Component Analysis (PCA), shows that variables such as CT, PA, CF, SA, SF, *Salmonella*, *Shigella*, and temperature (T°C) are positively correlated on axis 1. This indicates that temperature plays a role in the proliferation of bacteria in water, as demonstrated by the studies of Josse et al. [21] and Ndeko-Mubembe et al. [1]. Moreover, the positive correlations among these variables can be explained by their common sources, namely human and animal waste carried by rainwater into the city's rivers, ponds, and lakes. This observation is similar to that reported by Benkaddour [22].

5. Conclusion

The study reveals a significant deterioration in the quality of surface waters in Dolisie, mainly due to domestic discharges and various human activities. The waters show low mineralization, generally acidic pH, and cadmium concentrations exceeding recommended limits. Microbiological analysis indicates widespread fecal and pathogenic contamination, with the presence of total and fecal coliforms, fecal streptococci, *Pseudomonas aeruginosa*, *Salmonella*, *Shigella*, and *Staphylococcus* spp. Statistical analysis shows strong correlations between physicochemical and bacteriological parameters, particularly between temperature and bacterial proliferation. This situation poses a major public health risk and calls for urgent measures, including wastewater treatment, improved sanitation, public awareness, and regular monitoring of water quality.

Abbreviations

T °C	Temperature in Degrees Celsius
pH	The Potential of Hydrogen
EC	Electrical Conductivity
TDS	Total Dissolved Solids
TC	Total Coliforms
CF	Fecal Coliforms
SF	Fecal Streptococci
SA	*Staphylococcus Aureus*
PA	*Pseudomonas Aeruginosa*
TMAF	Total Mesophilic Aerobic Flora
PCA	Principal Component Analysis Used for Statistical Correlations Between Physico-Chemical and Bacteriological

Conflicts of Interest

The authors declare no conflicts of interest.

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