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Level and Origin of Faecal Contamination of the Waters of a Tropical Urban Lagoon: The Case of the Ebrié Lagoon

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Abstract The increasing enrichment of the estuarine waters of the Ebrié Lagoon with faecal bacteria represents a potential risk of faecal contamination of this ecosystem. In order to combat this phenomenon, the aim of this study is to determine the extent to which these waters are enriched with faecal bacteria. Fifteen lagoon water sampling campaigns were carried out from 2014 to 2016 at eleven (11) stations. The samples were subjected to physico-chemical and bacteriological analyses based on French standards. The results show that bacterial counts give values between 9000 and 2330000 CFU/100mL for faecal coliforms, between 390 and 320000 CFU/100mL for faecal streptococci and in the range 233 and 4600 CFU/100mL for *Clostridium perfringens*. Water contamination by faecal bacteria is therefore high, and is mainly of human origin. The level of contamination is very high in the bays of Marcory, Cocody and Yopougon because of the strong anthropic pressures exerted there and their state of confinement. However, the level is low in bays less influenced by human activity, such as Anna and M'Badon. According to WHO/UNEP standards, the waters analysed are unhealthy and unsuitable for all seaside activities.

Keywords: *Ebrié Lagoon, Faecal bacteria, Faecal contamination, Water quality*

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1. Introduction

Today, the deterioration of the water quality of the Ebrié lagoon is a complex problem, both in terms of ecological conditions and the socio-economic development of the city of Abidjan [1]. The lagoon is subject to a great deal of pollution, of which microbial pollution is one of the most worrying, given the associated health risks [2]. The first assessments of microbial pollution of faecal origin in the Ébrié lagoon were carried out by Pagès [3] and Pagès and Citeau [4]. The results of these assessments showed that the state of health of the waters near Abidjan is a cause for concern, especially in the bays where the rate of water renewal is very low. In addition, Lanusse [5], Lanusse and Guiral [6] and Kouassi *et al.* [7] have highlighted the unsanitary nature of these waters, even indicating that they are unsuitable for any seaside activity. More recently, a study of three bays in the Ebrié lagoon (Banco, Cocody and M'Badon) by Akpo *et al.* [8] revealed that concentrations of faecal coliforms and streptococci had exceeded the threshold value of 1000 CFU/100 mL set by the WHO for water intended for bathing activities. Furthermore, the faecal bacteria contained in the waters of lagoon bays represent major health risks for local populations, in particular diarrhoeal syndromes following the consumption of water and fish products from these bays and skin problems following the bathing activities that take place there [8]. Diarrheal diseases are essentially caused by faecal pollution, the main indicator agents of which are bacteria identified as faecal Coliforms, faecal Streptococci and *Clostridium perfringens* [9]. The contamination of the Ebrié lagoon by faecal matter has been an omnipresent theme in studies for several decades. However, to our knowledge, the last two assessments of the state of its faecal pollution were carried out between 1993 and 1998 [8,10]. A new assessment of the level of faecal contamination in this lagoon is therefore necessary three decades later, especially as the most recent one [8] only covered three bays. The aim of this study is therefore to determine the level and origin of faecal contamination of the water in the urban area of the Ebrié Lagoon, with a view to maintaining health monitoring of the water.

2. Materials and Methods

2.1. Study Area

With a surface area of 71 km^2 and an average depth of 4.5 m, our study area is the part of the Ebrié Lagoon in which the district of Abidjan bathes, with its population estimated at over six million inhabitants [11,12,13]. This area, which is subject to oceanic influence via the Vridi Canal, serves as a dumping ground for household waste, waste from businesses, wastewater and septic tank dumps [14,15,16].

2.2. Sampling Sites

Fourteen (14) sites have been selected for this study, which are all part of the Ebrié Lagoon in the Abidjan district. They are the Vridi canal, the East channel, the Azito channel and the bays of Anna, Banco, Biétry (with two sites), Cocody, Koumassi (with three sites), M'Badon, Marcory and Yopougon. These were selected from all the stations in the National Observation Network (RNO) on the quality of lagoon environments run by the Ivorian Anti-Pollution Centre (CIAPOL). These stations were chosen in order to analyse the impact of human activities in the city of Abidjan on the lagoon environment. Figure 1 shows the location of the sampling sites for lagoon water in the Abidjan agglomeration.

2.3. Sampling Campaigns

Sampling campaigns were carried out every two months from April 2014 to October 2016 at fourteen (14) sampling sites spread over eleven (11) stations. A total of fifteen measurement campaigns were carried out, resulting in two hundred and ten (210) samples being taken. These samples were packaged in sterilised transparent glasses and stored in a cooler containing ice in accordance with current standards [17] for bacteriological analysis in the laboratory.

2.4. Analysis of Ecological Variables

Dissolved oxygen was measured *in situ* using a YSI 6920 V2 multi-parameter probe. For each measurement, the pre-calibrated probe was immersed in the water and, after stabilisation, the reading was taken on the instrument's digital display screen. The nutrients (nitrate, nitrite, ammonium and orthophosphate) were analysed at the Central Environmental Laboratory of the Ivorian Anti-Pollution Centre within 48 hours, in accordance with Afnor [18], Hach [19] and Rodier *et al.* [17].

2.5. Enumeration of Faecal Bacteria

Faecal bacterial counts were also carried out at the Central Environmental Laboratory (LCE) of the Ivorian Anti-Pollution Centre (CIAPOL). They were carried out within 48 h in accordance with Afnor [18] and Rodier *et al. [17]*. Coliforms were analysed using the membrane filtration enumeration method. After filtration of the water to be studied, the membrane was deposited on a lactose agar medium containing TTC and Tergitol. After incubation for 24 hours at 44°C, the presence of coliforms was indicated by a purplish-red coloration of the colonies. Faecal streptococci were also counted using the membrane filter method (0.45 µm) on BEA (Bile with Esculin and Sodium Azide) medium. After incubation at 37°C for 24 and 48 hours, faecal streptococci showed up as black coloured colonies surrounded by a black halo. *Clostridium perfringens were* counted using the Trypticase Sulfite Neomycin (TSN) agar incorporation method at 45°C for 18 and 24 hours. Their presence was indicated by black coloration of the colonies.

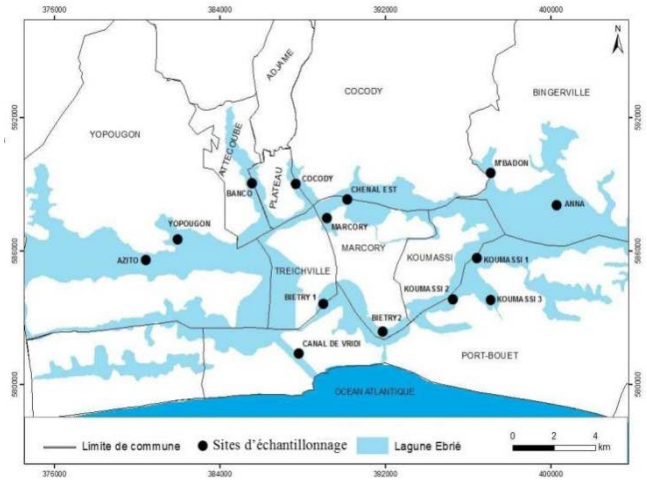

Figure 1. Location of sampling sites

2.6. Determination of Bacterial Densities D50 and D90

The bacterial densities D50 and D90 represent the concentrations of bacteria that correspond to 50% and 90% respectively of the counts carried out for the waters of the stations sampled according to Rodier *et al.* [5,8,20]. Bacterial densities D50 and D90 were determined using the rank method [7,8]. This method consists of ranking the different bacterial concentrations in ascending order and identifying the concentration that corresponds to 50% (D50) and 90% (D90) of the total number of samples respectively. The healthiness of lagoon waters was assessed [5] according to the WHO/UNEP criteria [21] developed during the MED. POL.VII programme (WHO/UNEP programme for monitoring the quality of Mediterranean waters). These criteria indicate that if the density D50 < 100 faecal coliforms or faecal streptococci per 100 mL of water and the density D90 < 1000 faecal coliforms or faecal streptococci per 100 mL of water, then the bathing water is considered to be bacteriologically satisfactory. In this study, *C. perfringens was* also included in these criteria.

2.7. Determining the Degree of Faecal Contamination

On the basis of the WHO/UNEP criteria set out above, the degree of contamination or faecal pollution (D.P.) is defined as the number of times a bacterial concentration exceeds the limit recommended by the WHO/UNEP [8]. Thus, the degree of faecal pollution is obtained by dividing D90 by the threshold concentration of 1000

bacteria per 100 mL.

2.8. Determining the Source of Faecal Contamination

The origin of faecal contamination is related to the quantitative ratio of faecal coliforms to faecal streptococci (R = CF/SF). According to the criteria defined by Borrego and Romero [22] if:

- R < 0.7: the origin is mainly or entirely animal ;
- 0.7 < R < 1: the origin is mixed, predominantly animal ;
- 1 < R < 2: the origin is uncertain;
- 2 < R < 4: mixed origin, predominantly human;
- R > 4: the cause is exclusively human.

The CF/SF ratio was calculated for all measurements taken over the study period.

2.9. Analysis of the Correlation Between Faecal Bacteria and Ecological Variables

Correlations between ecological variables (dissolved oxygen and nutrients) and faecal bacteria (faecal coliforms, faecal strptococci and *Clostridium perfringens*) were studied using a correlation matrix. This matrix groups together the values calculated for the linear correlation coefficients between the variables taken in pairs. The correlation coefficients (r) between the different parameters were determined using the Pearson test performed with STATISTICA version 7.1 software.

3. Results

3.1. Bacterial Densities

Table 1 and Table 2 show the 50% (D50) and 90% (D90) bacterial concentrations in surface water samples from the Abidjan area of the Ebrié Lagoon. The D50 concentrations in Yopougon Bay are the highest for faecal coliforms (290000 CFU/100 mL) and faecal streptococci (7200 CFU/100 mL). However, it was in Cocody bay that *C. perfringens* had the highest D50 concentration (1500 CFU/100 mL). Anna Bay, on the other hand, recorded the lowest D50 bacterial concentrations (500 CFU/100 mL for faecal coliforms, 80 CFU/100 mL for faecal streptococci and 30 CFU/100 mL for *Clostridium perfringens*). D90 concentrations (Table 2) are highest in Marcory Bay for faecal coliforms (2330000 CFU/100 mL) and in Yopougon Bay for faecal streptococci (320000 CFU/100 mL) and *C. perfringens* (4600 CFU/100 mL). On the other hand, Anna Bay recorded the lowest D90 concentrations (9000 CFU/100 mL for faecal coliforms, 390 CFU/100 mL for faecal streptococci and 233 CFU/100 mL for *Clostridium perfringens*). It can also be seen that the D90 concentrations of the various bacteria are much higher than their D50 concentrations.

In comparison with the WHO/UNEP criteria developed during the MED.POL.VII programme (WHO/UNEP programme for monitoring the quality of Mediterranean waters), the D50 concentrations are above the threshold of 100 CFU/100 mL for all the stations with the exception of Anna Bay (80 CFU/100 mL) for faecal streptococci and M'badon Bay (70 CFU/100 mL) and Anna Bay (30 CFU/100 mL) for *C. perfringens*. The D90 concentrations for faecal coliforms are all above 1000 CFU/100 mL; the same is true for faecal streptococci except in Anna Bay (390 CFU/100 mL) where the D90 is below this threshold value. For *C. perfringens*, the D90 correspond to values above 1000 CFU/100 mL for the bays of Banco (1320 CFU/100 mL), Cocody (3740 CFU/100 mL), Marcory (2200 CFU/100 mL), Yopougon (4600 CFU/100 mL) and Koumassi (1583 CFU/100 mL). For the other sampling stations, the values were below 1000 CFU/100 mL.

Table 1. 50% bacterial concentration (D50) of coliform samples (CF), faecal streptococci (SF) and *Clostridium perfringens* (CP) lagoon waters

Stations	CF	SF	CP
Anna bay (An)	500	80	30
Azito channel (Az)	8000	650	120
Banco bay (Ba)	19500	633	500
Biétry bay (Bi)	5000	900	195
Vridi canal (CV)	4800	1200	200
East channel (CE)	6360	1000	120
Cocody bay (Co)	170000	5363	1500
Koumassi bay (Ko)	8000	260	240
M'badon bay (Mb)	1800	270	70
Marcory bay (Ma)	34500	4100	290
Yopougon bay (Yo)	290000	7200	1167
WHO/UNEP limit value: 100 CFU/100 mL			

Table 2. 90% bacterial concentration (D90) of coliform samples (CF), faecal streptococci (SF) and *Clostridium perfringens* (CP) lagoon waters

Stations	CF	SF	CP
Anna bay (An)	9000	390	233
Azito channel (Az)	23000	2170	405
Banco bay (Ba)	119000	15000	1320
Biétry bay (Bi)	109000	6400	500
Vridi canal (CV)	30272	4200	300
East channel (CE)	104545	1733	383
Cocody bay (Co)	1315000	87000	3740
Koumassi bay (Ko)	103000	3600	1583
M'badon bay (Mb)	9000	1200	367
Marcory bay (Ma)	2330000	27000	2200
Yopougon bay (Yo)	910000	320000	4600
WHO/UNEP limit value: 1000 CFU/100 mL			

3.2. Degree of Faecal Contamination

The results of the degrees of pollution (DP) grouped together in Table 3 show that for faecal coliforms, Marcory bay (DP = 2330) is the most polluted and M'badon and Anna bays (DP = 9) the least polluted. For faecal streptococci, the most contaminated station was Yopougon bay (DP = 320), while Anna bay (DP = 0.39) was the least contaminated. *Clostridium perfringens* contamination is highest in Yopougon Bay (DP = 4.6) and lowest in Anna Bay (DP = 0.23). The degrees of pollution also make it possible to establish a classification from the most contaminated to the least contaminated stations. This gives a series of degrees of contamination for each parameter.

For faecal coliforms: Ma > Co > Yo > Ba > Bi > CE > Ko > CV > Az > Mb > An.

For faecal streptococci: Yo > Co > Ma > Ba > Bi > CV > Ko > Az > CE > Mb > An.

For *Clostridium perfringens:* Yo > Co > Ma > Ko > Ba > Bi > Az > CE > Mb > CV > An.

Table 3. Degree of faecal coliform (FC) contamination (DP), faecal streptococci (FS) and *Clostridium perfringens* (CP) in water of Ebrié lagoon

Stations	CF	SF	CP
Anna bay (An)	9	0.39	0.23
Azito channel (Az)	23	2.17	0.41
Banco bay (Ba)	119	15	1.32
Biétry bay (Bi)	109	6.4	0.5
Vridi canal (CV)	30.27	4.2	0.3
East channel (CE)	104.55	1.73	0.38
Cocody bay (Co)	1315	87	3.74
Koumassi bay (Ko)	103	3.6	1.58
M'badon bay (Mb)	9	1.2	0.37
Marcory bay (Ma)	2330	27	2.2
Yopougon bay (Yo)	910	320	4.6

3.3. Origin of faecal Contamination

Table 4 shows that for each of the stations sampled, the origin of the faecal contamination is animal or predominantly animal for percentages of samples ranging from 0% in the Cocody bay to 27% in the Vridi canal. The origin was uncertain or undetermined for percentages of samples ranging from 0% (Cocody, Yopougon and Azito) to 18% (Vridi canal). Finally, the origin of the contamination is human or predominantly human for percentages of samples ranging from 55% in the Vridi canal to 100% in the Cocody bay. It should also be noted that just half of the samples from the Vridi canal (55%) showed human or predominantly human faecal contamination. However, at the other stations, at least three quarters of the samples (75% in Biétry Bay) or even all of them (100% in Cocody Bay) were contaminated.

Table 4. Spatial distribution of CF/SF ratio values in water calculated for each station

Stations	Animal or predominantly animal origin	Uncertain or undetermined origin	Human or predominantly human origin
An	8 %	8 %	84 %
Az	9 %	0 %	91 %
Ba	8 %	8 %	84 %
Bi	17 %	8 %	75 %
CV	27 %	18 %	55 %
CE	8 %	17 %	75 %
Co	0 %	0 %	100 %
Ko	5 %	2 %	93 %
Mb	8 %	8 %	84 %
Ma	15 %	8 %	77 %
Yo	15 %	0 %	85 %

3.4. Correlation Between Faecal Bacteria and Ecological Variables

Table 5 gives the Pearson correlation values between faecal bacteria and the ecological variables (dissolved oxygen and nutrient salts). Analysis of the table reveals a negative correlation between bacteria and dissolved oxygen (- 0.53 < r < - 0.67) and a positive correlation between bacteria and ammonium (0.50 < r < 0.81). The table also shows that faecal bacteria are positively correlated with each other (0.53 < r < 0.93).

Table 5. Correlation coefficients between faecal bacteria and ecological variables

	Total Coliforms	**Faecal Coliforms**	**Faecal Streptococci**	**Clostridium Perfringens**
Dissolved oxygen	**- 0.67**	**- 0.68**	- 0.42	**- 0.53**
Nitrate	0.11	0.31	0.06	0.26
Nitrite	- 0.23	- 0.20	- 0.11	- 0.09
Ammonium	**0.62**	**0.76**	**0.50**	**0.81**
Orthophosphate	0.15	0.35	0.04	0.30
Total coliforms		**0.93**	**0.74**	**0.83**
Faecal coliforms			**0.53**	**0.76**
Faecal Streptococci				**0.88**

In bold: significant correlations

4. Discussion

The lagoon waters of the estuarine zone of the Ebrié lagoon are heavily contaminated with bacteria indicative of faecal contamination. Bacterial counts give values between 9000 and 2330000 CFU/100mL for faecal coliforms, between 390 and 320000 CFU/100mL for faecal streptococci and in the range 233 and 4600 CFU/100mL for *Clostridium perfringens*. These results are in line with those obtained by other authors such as Konan *et al.* [23] in the Grand-Lahou lagoon and by Kambiré *et al.* [24] in the Aby lagoon. According to Leclerc [25], faecal coliforms are abundant in faeces and represent the predominant environmental indicators.

The assessment of bacterial densities in lagoon waters highlighted the unsanitary nature of these waters. Determination of bacterial concentrations (D50 and D90) revealed that the highest densities were recorded in the bays of Yopougon, Marcory and Cocody. This indicates that these three bays are particularly exposed to faecal contamination, as shown by the faecal pollution levels calculated for each station over the entire study period (Table 1 and Table 2). On the basis of these levels, the stations were ranked from the most contaminated to the least contaminated. The results are similar to those obtained by Kouassi *et al.* [10] for the period 1993 to 1998. These authors reported that Yopougon Bay receives all the urban and industrial effluent from the commune of Yopougon. At the bottom of Cocody Bay, an outfall from the stormwater network carries highly contaminated water. The bay also receives wastewater from several neighbouring districts. The Marcory bay, which is landlocked, receives the commune's wastewater due to frequent breakdowns at the lifting stations. In addition, the low turnover of water in these bays may be responsible for the high levels of contamination [26]. Indeed, as Pagès and Citeau [4] point out, the degree of contamination is a function of both the size of the discharges and the confinement of the water. On the other hand, the fact that

Anna Bay is located outside the urban area may explain the low bacterial densities D50 and D90 obtained in this bay. As a result, there is little contamination of the water. The healthiness of the lagoon waters was assessed according to the WHO/UNEP [21] criteria drawn up during the Mediterranean water quality monitoring programme. All of the water was found to be unhealthy and unsuitable for any kind of seaside activity. Effluent discharges contribute to a very significant increase in faecal contamination of the water in the urban area. In addition, the densities of bacteria indicative of faecal contamination indicate a high level of pollution of the lagoon banks compared with the open waters of the Ebrié Lagoon [27]. This enrichment is due to the proximity of the stations sampled to the discharge sites. Hydrodynamics in these confined sites are less active and bacterial pollution tends to concentrate there [20]. Faecal coliforms are generally more abundant in human faeces than faecal streptococci. The latter are thought to be more numerous than faecal coliforms in animals [28]. Thus, the importance of the CF/SF ratio calculated during the spatial and temporal monitoring in this work shows that faecal contamination of lagoon waters was mainly of human origin or of mixed origin with a predominance of humans. This is directly related to domestic pollutant inputs. Indeed, various studies have shown an increase in faecal pollution of this lagoon due to illicit discharges of septic tank effluent [8].

Negative correlations were observed between bacteria and dissolved oxygen (Table 5). This shows that the increase in bacterial levels leads to a decrease in dissolved oxygen in the water, certainly due to the use of oxygen by bacteria for the biodegradation of organic pollutants contained in the water. Positive correlations were also observed between faecal bacteria and ammonium, and between the bacteria themselves. The former reflects the omnipresence of bacteria in domestic effluent, while the latter shows that the detection of one bacterium indicates a high probability of the presence of others.

5. Conclusion

This study consisted in determining not only the level of contamination of the waters of the Ebrié Lagoon in Abidjan by faecal bacteria, but also the origin of this contamination. The study was essentially based on microbiological parameters indicative of faecal pollution (faecal coliforms, faecal streptococci and *Clostridium perfringens*). Standardised methods were used to count these bacteria in water samples taken from fourteen (14) sites. The results obtained show that contamination of water by faecal bacteria is high and is mainly of human origin or mixed with a predominance of human origin. The level of contamination is very high in bays such as Marcory, Cocody and Yopougon because of the strong anthropic pressures exerted there and their state of confinement. However, the level is low in bays that are less affected by human activity, such as Anna and M'Badon. According to WHO/UNEP standards, the waters analysed are unhealthy and unfit for any kind of seaside activity. Awareness-raising campaigns are needed among the general public, and the authorities must take steps to minimise damage to this vital environment.

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