Spatial and Temporal Variation of Faecal Indicator Bacteria in Three Reservoirs of Ivory Coast (Taabo, Kossou and Fae)

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1. Introduction

Hydropower reservoirs offer multiple purposes and provide services beyond electricity generation. The Dam waters are used as water supply, drought management, irrigation, fisheries, environmental services, and recreational activities [1]. These hydropower reservoirs also recreate a specific ecosystem with particular food-web structure. The Dam water ecosystems are often impacted by the hydraulic condition, the climatic conditions, the operation of the hydropower system and the cumulative effects of industries and activities around or upstream the hydroelectric system [2,3]. The main activities developed around and on reservoirs are: irrigation, fisheries and recreational activities. These reservoirs, connected to the rivers or their tributaries, receive industrial, agricultural and domestic wastewaters containing pathogenic microorganisms, organic matter, nitrogen, phosphorus and other heavy metals. These pollutants discharged by sewage waters contribute to disturb the reservoirs ecosystem and also alter waters quality. The physico-chemical and biological pollution from point and non-point sources may cause eutrophication and aquatic animals depletion [4,5].

Dams of Taabo, Kossou and Fae are three hydroelectric reservoirs in Ivory Coast, which are highly impacted by domestic and agricultural wastewaters, causing mortality of fish and diseases for fishers and other users of water bodies [6-8]. Indeed, household waste, aquaculture, cattle farming and agriculture developed around these hydroelectric dams, brought nutrients and other pathogenic microorganisms into these reservoirs [6-8]. The microbiological water quality of these reservoirs is unknown while the waters of these hydroelectric reservoirs are often used for domestic purposes, aquaculture and agricultural activities. Thus, it is appearing very important to perform monitoring studies in order to evaluate the microbiological quality of reservoir waters and then prevent sanitary risk associated to the waters uses.

Assessment of microbiological water quality is based on the quantification of faecal indicator bacteria. Nowadays, Escherichia coli (E. coli) and Intestinal Enterococci (IE) are the most important faecal indicator bacteria used for assessing faecal pollution in surface waters [9]. They are abundant in the faeces of warm-blooded animals, including humans, and their presence indicates whether faecal contamination is present and whether potential risks from these and other pathogenic bacteria or viral agents may exist [10]. These bacteria have been used in many research studies for assessing microbial quality of water [11-15]. The study aims to i) evaluate the microbiological water quality of these Dam waters and ii) determine the spatial distribution and the temporal variation E. coli and IE abundances in these reservoirs.

2. Experimental Methods

2.1 Study Area

The study area is composed by three man-lakes located in Ivory Coast: Kossou, Taabo and Fae (Fig. 1). The Kossou reservoir covers an area of 1700 km² in the center part of the country. The Taabo reservoir, located 120 km downstream of the Kossou reservoir, covers an area of 62 km² [6,16]. The Fae hydroelectric dam covers an area of 16.28 km² located in South-western region of Ivory Coast [17]. Watershed of Taabo, Kossou and Fae hydroelectric reservoirs covers, an area of 58700 km²; 32400 km² and 2424 km² respectively. These watersheds are mostly composed by rural area and agriculture [67]. Invasive aquatic plants are present and occupy a large part of the surface of the different water bodies.

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Sampling was conducted over a period of 1 year, from November 2017 to October 2018 inclusive. A total of 128 samples were collected in the whole lakes. Briefly, sterile bottles of 1 L were filled out with water sampled from the surface of all reservoirs along a transect for comparing the littoral and depth area. 5 sampling points for Taabo and Kossou lakes and 6 sampling points for Faé lake (Fig. 1). The bottles have been labeled and transported to the laboratory on ice in coolers box (4 °C) and processed within a maximum of 8 h after sampling for microbiological analysis. Land use patterns in the areas near sampling points are described in Table 1.

Table 1 Coordinates and characteristics of the sampling sites in each man-made lake

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Location</th>
<th>Description of land use types</th>
<th>Coordinates</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taabo</td>
<td>Urban zone near of lake, cattle farming on the shore, agriculture (hevea, cassava crops)</td>
<td>06°15'46.6&quot; - 05°04'57.4&quot;</td>
<td>T1</td>
<td>06°15'42.2&quot; - 05°04'59.3&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing into the lake, fishing area</td>
<td>T2</td>
<td>06°15'42.2&quot; - 05°04'59.3&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing into the lake, fishing area</td>
<td>T3</td>
<td>06°13'53.0&quot; - 05°04'55.2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area</td>
<td>T4</td>
<td>06°13'00.8&quot; - 05°06'13.7&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Big village close to the lake, fishing area, agriculture</td>
<td>T5</td>
<td>06°12'59.2&quot; - 05°06'14.6&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kossou</td>
<td>Small village near of the lake, cattle farming, mining activities in the shore</td>
<td>K1</td>
<td>07°03'12.5&quot; - 05°30'25.1&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area, mining activities in the shore</td>
<td>K2</td>
<td>07°03'12.2&quot; - 05°30'25.7&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area</td>
<td>K3</td>
<td>07°03'53.3&quot; - 05°29'30.1&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area</td>
<td>K4</td>
<td>07°04'16.6&quot; - 05°28'37.2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faé</td>
<td>Fishing area</td>
<td>K5</td>
<td>07°04'24.6&quot; - 05°28'30.2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area</td>
<td>Fae</td>
<td>04°59'24.2&quot; - 06°39'01.3&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area</td>
<td>F2</td>
<td>04°59'27.2&quot; - 06°38'40.2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area, watercourse pathway, agriculture on the shore (cocoa, hevea)</td>
<td>F3</td>
<td>04°59'26.3&quot; - 06°39'00.8&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area, agriculture on shore (cocoa, hevea crops)</td>
<td>F4</td>
<td>04°59'15.9&quot; - 06°39'30.2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area, agriculture on shore (cocoa, hevea crops)</td>
<td>F5</td>
<td>04°59'21.5&quot; - 06°39'40.7&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fishing area, agriculture on the shore (cocoa, hevea crops)</td>
<td>F6</td>
<td>04°59'24.5&quot; - 06°39'55.7&quot;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.3 Analysis of Physico-Chemical Parameters

Temperature and dissolved oxygen were measured in situ by the Oxygen Meter (HANNA HI 9146) and the pH using the pH meter (HANNA HI 91491001) with specific probes. The transparency was measured using a Secchi disk. The analytical method used to determine these parameters were described by Pereira et al. [23] as acceptable for good aquatic and, between 6.9 and 8.7 in Faé lake. The median pH values were 7.39, 7.49 and 7.6 in Taabo, Kossou and Faé respectively. These pH median values are acceptable for good aquatic living and diversity (6.5 and 8.5) [21].

However, according to WHO [22], these pH and temperatures ranges are favourable to the growth of bacteria. This may explain the high correlation recorded between faecal indicator bacteria concentrations and pH values at all sites (Table 2). Pereira et al. [23] also found the highest correlation between faecal bacteria abundance and pH values. In lakes Taabo and Kossou, the dissolved oxygen values ranged from 4.6 mg/L to 7.7 mg/L with respective values median of 5.74 and 5.69, those of Faé lake varied from 2.3 mg/L to 5.6 mg/L with median values of 4.23. These median values are inferior to WHO standard of ≤ 2 mg/L (acceptable values for good aquatic diversity). The low levels of dissolved oxygen could be related to the bacteria increase after breaking down organic matter in aerobic conditions. In contrast to other environmental variables, transparency values were lower in sampling sites near the shore area, especially in the deepest sites. Transparency values highly varied in Taabo lake (22 cm - 120 cm) and in Kossou lake (60 cm - 130 cm). In the Faé lake, these values varied between 27 and 80 cm. The low transparency values were recorded in sampling sites near the shore areas and this could be explained by human activities [24,25] as indicated in the Table 1. The transparency parameter was weakly correlated to the faecal contamination in these lakes (Table 2). Significant differences were reported between the physico-chemical parameters obtained over months in all dam waters (Kruskal-Wallis; p ≤ 0.05).

Table 2 Spearman's rank correlations describing the relationship between environmental variables and faecal indicator bacteria concentrations in each reservoir

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Temperature</th>
<th>pH</th>
<th>Dissolved oxygen</th>
<th>Transpiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taabo</td>
<td>E. coli</td>
<td>-0.16</td>
<td>0.28**</td>
<td>-0.21 **</td>
</tr>
<tr>
<td></td>
<td>IE</td>
<td>-0.12</td>
<td>0.25*</td>
<td>0.02 -0.39*</td>
</tr>
<tr>
<td></td>
<td>Kossou</td>
<td>-0.16</td>
<td>-0.24**</td>
<td>-0.15 0.03</td>
</tr>
<tr>
<td></td>
<td>IE</td>
<td>-0.26*</td>
<td>-0.64***</td>
<td>-0.07 0.04</td>
</tr>
<tr>
<td>Faé</td>
<td>E. coli</td>
<td>-0.16</td>
<td>0.28*</td>
<td>-0.27** -0.44**</td>
</tr>
<tr>
<td></td>
<td>IE</td>
<td>-0.12</td>
<td>0.25*</td>
<td>0.02 -0.21</td>
</tr>
</tbody>
</table>

*Significative correlation à p < 0.05; **Significative correlation à p < 0.01; ***Significative correlation à p < 0.001

3.2 Spatial Variation of Faecal Indicator Bacteria in Reservoir

The spatial variation of faecal indicator bacteria abundance in reservoirs is illustrated in Fig. 2. In Taabo lake, the highest median concentrations of faecal indicator bacteria were observed at T1 (2.17 × 10^2 CFU.100 mL^-1 for E. coli and 4.6 × 10^2 CFU.100 mL^-1 for IE) and the lowest concentrations at T4 (10 CFU.100 mL^-1 for E. coli) and T5 (inferior to 10 CFU.100 mL^-1 for IE) (littoral area) (Fig. 2A). In the Kossou reservoir, the lowest faecal indicator bacteria median concentrations were recorded at station K4 (inferior to 10 CFU.100 mL^-1 for E. coli) and K3 (2.1 × 10^3 CFU.100 mL^-1 for IE) situated in depth area, while the highest concentrations (1.11 × 10^4 CFU.100 mL^-1 for E. coli and 3.4 × 10^4 CFU.100 mL^-1 for IE) were recorded at stations K1 and K5 located in littoral area (Fig. 2B). In the Faé lake, the lowest abundances of faecal indicator bacteria were observed at station F5 (3.3 × 10^1 CFU.100 mL^-1 for E. coli and inferior to 10 CFU.100 mL^-1 for IE), while the highest concentrations were recorded at F1 (1.13 × 10^4 CFU.100 mL^-1 for E. coli and 1.32 × 10^4 CFU.100 mL^-1 for IE) (littoral zone) (Fig. 2C). Significant differences were reported between low and high bacteria concentrations in all dam (Kruskal-Wallis: p < 0.05). The high concentrations of faecal indicator bacteria observed in the littoral area could be attributed to livestock manure, domestic wastewater and livestock farming that characterize these sampling stations of Taabo, Kossou and Faé dam waters. The contribution of domestic wastewater and livestock on the faecal pollution of surface waters are reported by Forman [26] and Nguyen et al. [27].

The 5 percentile values of E. coli in the reservoir of Taabo, Kossou and Faé were calculated in order to compare the FIB abundances to EU guideline for bathing or other recreational activities.

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With regards to EU Directives for bathing ($9.0 \times 10^3$ CFU/100 mL for $E. \ coli$ and $3.3 \times 10^2$ CFU/100 mL for IE), the 90th percentile of $E. \ coli$ and IE obtained in Taabo and Kossou lakes were below acceptable limits. Therefore, Taabo and Kossou water quality were sufficient for bathing based on the two criteria ($E. \ coli$ and IE) [9]. The 90th percentile of $E. \ coli$ was about the EU guideline for bathing in water unlike that of IE. EU guideline for bathing did not indicate if it necessary to consider that the microbiological quality of the water is acceptable for recreational activities when one of the two criteria is respected.

Accordingly, Fae water exceeded the admissible level required for bathing. The $E. \ coli$ and IE abundances recorded in all dam waters were also compared to WHO standard for irrigation ($10^{20}$ CFU/100 mL for $E. \ coli$). Globally, the average concentration of $E. \ coli$ and IE exceed the standard value required for the use of these waters for irrigation. Consequently, the use of the water from these reservoirs for irrigation is not appropriate and presents a health risks particularly during the months of June and September.

### 3.3 Temporal Variation of Faecal Indicator Bacteria

The faecal indicator bacteria (FIB) abundance temporal variation in Taabo, Kossou and Fae lakes showed two trends (Fig. 3). The first trend was characterized by a low abundance from November to February in the Taabo lake, from November to July in the Kossou lake and in the Fae lake, from November to April. The second trend was characterized by high faecal bacteria abundances from April to October, September to October and from June to October, respectively in Taabo, Kossou and Fae reservoirs.

These trends of bacteria abundance reported to the studied waters could be related to rainy events. In fact, the months showing the low bacteria concentrations were characterized by low rainy events, while the whole of the months showing the high faecal indicator bacteria concentrations were characterized by the high rainy events. During the rainy season, many organic materials and bacteria could be dumped into water reservoirs due to run-off water way out from the watershed, sewer overflows and defective septic systems located near water bodies [28]. The increase in FIB abundances after rainfall has been widely recognized in scientific literature [29].

In all studied waters, the lowest faecal indicator bacteria median abundances recorded were inferior to 10 CFU/100 mL, while the highest concentrations reported were from $3.8 \times 10^3$ to $10^4$ CFU/100 mL for $E. \ coli$ and $2.4 \times 10^4$ to $10^5$ CFU/100 mL for IE in Taabo dam water (Fig. 3A), $2.53 \times 10^5$ to $10^6$ CFU/100 mL for $E. \ coli$ and $3.5 \times 10^4$ to $10^5$ CFU/100 mL for IE in Kossou dam water (Fig. 3B) and $4.85 \times 10^4$ to $10^5$ CFU/100 mL for $E. \ coli$ and $5.7 \times 10^4$ to $10^5$ CFU/100 mL for IE in Fae dam water (Fig. 3C). Significant differences were noted between the low and high bacteria concentrations.

Levels of faecal contamination observed in lakes Taabo, Kossou and Fae were close to those found in other surface waters of Côte d’Ivoire. Kouamé et al. [14] showed that concentrations in the Comoé River ranged from $1.09 \times 10^3$ to $8.88 \times 10^3$ CFU/100 mL for $E. \ coli$ then $5.33 \times 10^2$ and $4.49 \times 10^2$ CFU/100 mL for IE. Ouattara et al. [15] also found an abundance of faecal indicators ranging from $1.72 \times 10^4$ CFU/100 mL and $1.48 \times 10^2$ CFU/100 mL for $E. \ coli$ and between $2.26 \times 10^2$ CFU/100 mL and $7.72 \times 10^4$ CFU/100 mL for IE in the waters of the Aghien lagoon. The variation observed between the abundance of faecal bacteria in the studies reported above may be related to the size and type of hydrosystem, anthropogenic pressures, and climatic seasons. In Ghana water dams, Kipti and Laari [30] found that faecal pollution was between $10^1$ to $65 \times 10^4$ CFU/100 mL for faecal coliform group.

### 3.4 Relationship Between $E. \ coli$ and IE Abundances

Globally, $E. \ coli$ abundances were higher than those of IE in the water samples of these three lakes. This may indicate that these reservoirs received continuously faecal pollution from domestic sewage [11]. According to literature, the $E. \ coli$ abundance obtained in surface waters is more often higher than that of IE. The Spearman test showed that $E. \ coli$ and IE abundances (in log units) were positively correlated (Taabo: $r^2 = 0.27; \ p < 0.001$; Kossou: $0.50 < r^2 < 0.79; \ p = 0.048$), whereas these two FIBs were significantly correlated (Taabo: $r^2 = 0.53, p < 0.001$; Kossou: $r^2 = 0.77, p < 0.001$; Fae: $r^2 = 0.62, p = 0.001$) (Fig. 4). Chalierre et al. [31] and Simmons et al. [32] showed that, due to their same origin, $E. \ coli$ and IE abundances were strongly linked. This could explain why these two FIBs were significantly correlated on the three sites. Significant correlations between these two FIBs were already reported in research studies [11,20].

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**Fig. 2** Spatial variability box plots of faecal indicator bacteria abundance in dams’ waters (A: Taabo; B: Kossou; C: Fae). Median (horizontal line in the box), lower and upper quartiles (bottom and top box lines), and the 90th percentiles (bottom and top whiskers) and the outliers (circles) are shown; Values on the same line having different letters in exponent differ significantly (Kruskal-Wallis; p < 0.05).

**Fig. 3** Temporal variation box plots of faecal indicator bacteria abundance in dams’ waters (A: Taabo; B: Kossou; C: Fae). Median (horizontal line in the box), lower and upper quartiles (bottom and top box lines), 90th percentiles (bottom and top whiskers) and the outliers (circles) are shown; Values on the same line having different letters in exponent differ significantly (Kruskal-Wallis; p < 0.05).

**Fig. 4** Log-log linear regression between IE and $E. \ coli$ abundances in reservoir dam of Taabo (A), Kossou (B) and Fae (C). A: $\log(IE/100 \, mL) = 0.30 \log(E. \ coli/100 \, mL) + 0.54$ ($r^2 = 0.72; n = 40; p = 0.001$); B: $\log(IE/100 \, mL) = 0.69 \log(E. \ coli/100 \, mL) + 0.23$ ($r^2 = 0.77; n = 40; p < 0.001$); C: $\log(IE/100 \, mL) = 0.41 \log(E. \ coli/100 \, mL) + 0.58$ ($r^2 = 0.62; n = 48; p < 0.001$).
4. Conclusion

Natural conditions, as well as human activities, in catchment areas of surface reservoirs of Taabo, Kossou and Fae significantly affect the quality and safety of stored water. This study showed that for every reservoir, the shore indicated evidence of pollution more than those far from the shore. The levels of faecal indicator bacteria found are most of the times higher than those of the standard values required for water quality related to public health risk. It is important to sensitize decision makers and different stakeholders on a sustainable management of lakes.

Acknowledgement

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