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ORIGINALE ARTICLE

# QUALITY CONTROL OF THE AQUATIC ECOSYSTEM, IN RELATION WITH FISHING ACTIVITIES OF *Solen guineensis*: CASE OF SEDIMENTS OF THE COASTAL CAP ESTERIAS AREA, LIBREVILLE GABON

CONTROLE DE LA QUALITE DE L'ECOSYSTEME AQUATIQUE EN RELATION AVEC LES ACTIVITES DE PECHE DE Solen guineensis : CAS DES SÉDIMENTS DE LA ZONE CÔTIÈRE DU CAP ESTERIAS, LIBREVILLE GABON

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## ABSTRACT

**Background:** The Gabonese coastal waters are subject to several activities, that most of the time, degrade this ecosystem. **Objectives:** It is in this context that sediments from the coastal of Cap Estérias were studied, in order to assess its state of pollution in relation with the *Solen guineensis* (sea knife) species fishing activities. **Methods:** Sediment samples were collected during the dry season in three sites (Bobanya, Évanidja Ndoumba and Idolo) in the Akanda Estérias Cap area. In these different sites, the physical parameters (Temperature, pH, Electrical conductivity, Salinity and Turbidity) of water are measured in situ, using the AQUAREAD multi-parameter. Chemical pollutants contained in these sediments (Pb, $F^-$, $SO_4^{2-}$ and $NO_3^-$ ions) are recorded using activated strips. Finally, the identification of fecal germs is conducted by counting the number of colonies in Petri dishes, on Mac Conkey agar. **Results:** Parameters such as temperature (30 °C) and pH (basic) are within the limits of good water quality and therefore favorable for the coastal aquatic fauna. This is not the case for the other parameters (EC, Salinity and Turbidity) measured. The measured chemical elements reveal that sediments of this water body are highly polluted by two of the four targeted chemicals, in proportion ranging from 300 to 600 times more (for Lead) than the required environmental threshold, and between 3 to 6 times more (of the same threshold) for fluoride ions. On the contrary, no pollution (with neither sulphate, nor nitrogen) is detected. Bacteriological analysis reveals that sediments of the studied soils harbor pathogenic fecal coliform germs, with a high bacterial density. In addition, it is found that this microbial contamination is related to aquatic turbidity. **Conclusions:** Chemical pollution and density of coliform germs found in these sediments could be transferred from water to the fished aquatic organisms, including *Solen guineensis* species. In the long term, this contamination chain could cause major health issues to consumers. **Perspectives:** Finally, an analysis of the biological quality of aquatic organisms in target environments, in relation to the observed pollution, could be interesting to complete this study.

***Keywords***: *Cap Estérias coastal*, *Water and sediment quality*, *Prevention environmental pollution risks*, *Solen guineensis*, *Artisanal fishing activities*.

## 1. INTRODUCTION

Bivalve mollusks and crustaceans are extensively consumed by coastal populations due to their tender flesh, providing a diet rich in unsaturated proteins and lipids [1,2]. The consumption of bivalves, such as *Solen guineensis*, is associated with a cardioprotective effect attributed to the nature of the fatty acids present in their edible tissues [3,4]. In the Akanda district of Cap Estérias, local fishermen capture *Solen guineensis*, which is subsequently sold in Gabonese supermarkets and exported to other countries, often at premium prices.

Despite the economic significance of this seafood, various environmental factors pose threats to its quality. Chemical pollutants and pathogenic organisms present in the aquatic environment, including breeding and survival sites of major fish species, as well as sediments, are frequently responsible for aquatic pollution [5,6,7]. The accumulation of these chemical species and pathogenic germs in marine environments serves as the primary cause of water and sediment quality deterioration. The disturbance of the environment undoubtedly has adverse effects on the health of aquatic organisms, eventually impacting human beings at the end of the food chain.

Preserving the health of coastal water bodies is crucial to ensuring the well-being of edible fish species, such as *Solen guineensis*. While existing research has addre ssed sediment pollution in coastal areas, particularly concerning heavy metals and industrial pressure [8,9,10,11], there is a noticeable gap in our understanding of the degeneration of the



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aquatic environment in the specific context of Akanda (Cap Estérias), where *Solen guineensis* resides and reproduces. This study aims to assess the "health" of the brackish waters and soils in the coastal area of *Cap Estérias* in relation to the intensive fishing activities targeting Solen guineensis, commonly known as sea knife.

## 2. MATERIALS AND METHODS

### 2.1 Study site

The study area, Cap Estérias is located in the commune of Akanda, about 30 kilometers North of Libreville (the capital city of Gabon). Precisely, Akanda city is located near the Komo Estuary and the Mondah bay, at the following geographic coordinates: (longitudes 9°18′50″ and 9°28′20″ east and latitudes 0°40′20″ and 0°34′10″ north) (Figure 1).

The study is conducted on sediment samples from this coastal resource. This study zone is chosen based on the following reasons: it is notable for small-scale fishing activities, to meet with the growing demand for fish. These invertebrates (seafood) play a key role in the functioning of the marine aquatic ecosystem and are good biological indicators of water quality [1], and because the site is currently witnessing increased urbanization. According to data collected from the National Census Commission (NCC), the population of Akanda increased from 4407 in 2013 to about 5857 in 2015. That corresponds of an annual growth rate of about 2.9% [12]. This demographic pressure could contribute to the increase in the pollution of water bodies, in particular by the discharge of household waste into the aquatic ecosystem.

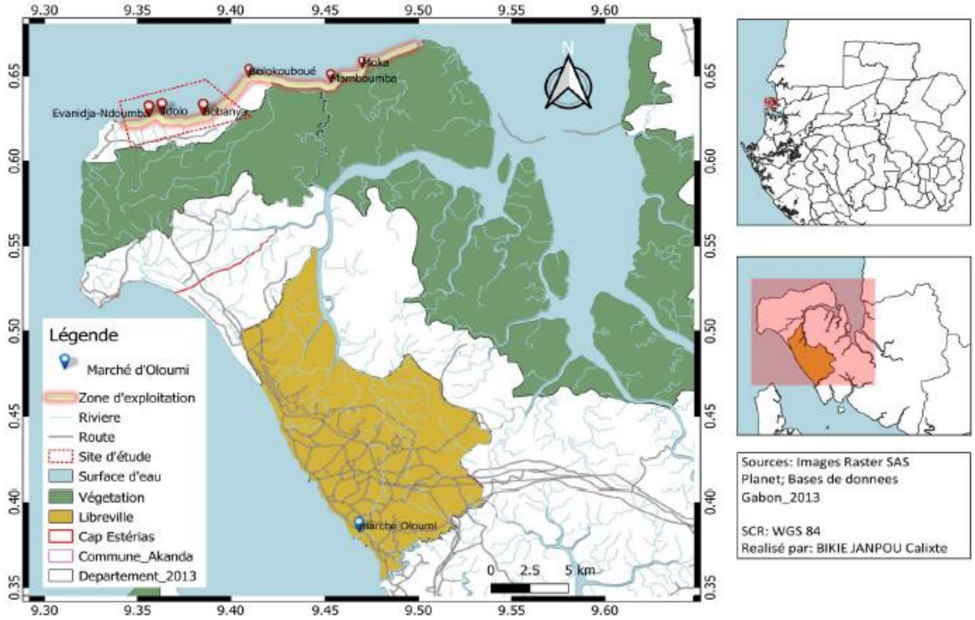


**Figure 1:** Location of the study zone Cap Esterias in the Akanda commune (BIKIE JANPOU Calixte).

### 2.2 Collection of sediment samples

Sediment samples were systematically obtained from three designated sites within the Cap Estérias region, specifically Bobanya, Évanidja Ndoumba, and Idolo. These sites were strategically chosen as they constitute primary fishing grounds for the Solen guineensis species. The sampling period spanned from August 10 to September 22 of the year 2021, coinciding with low water levels characteristic of the dry season. Sampling occurred monthly, with each session including two replicated sampling events, resulting in a total of two samplings (each with replicate samples) over the entire observational period.

To extract sediment samples, a polystyrene pipe measuring approximately 5 cm in diameter and 40 cm in length was employed. The pipe was carefully inserted into the soil, and sediment collection was achieved by applying hand pressure, reaching a depth of approximately 10 cm. Subsequently, the pipe, containing the trapped soil samples, was removed from the aquatic ecosystem. Sediments adhering to the pipe's length were then carefully extracted and preserved in plastic containers. Prior to storage, these containers underwent meticulous cleaning procedures, including washing and rinsing with soapy tap water, alcohol, and water from the specific aquatic ecosystem corresponding to each sampling site.

Maintaining the integrity of collected soil samples, they were stored at a constant temperature of 4 °C until subjected to subsequent chemical and bacteriological analyses [7-13]. These standardized procedures are imperative for assessing the 'health state' of the aquatic ecosystem, particularly relevant to the reproduction and survival of the Solen guineensis species.

## 2.3 Physical parameters

Physical parameters such as: Temperature [°C], pH [-], Electrical conductivity [µS/cm], Salinity [mg/L] and Turbidity [NTU] (Nephelolometric Turbidity Unit) are measured in situ (because they are sensitive to environmental conditions), using an AQUAREAD multi-parameters, combined with five probes. Each probe corresponds to the measurement of each tested parameter. These physical parameters give a first indication of the substrate quality to be analyzed. For example, salinity will give an idea of the concentration of dissolved salts in samples, while turbidity will indicate the disturbance of water. The measuring tool is calibrated before each sampling event and this is carried out by introducing the appropriate probe into liquid media, then waiting for the stabilization and display of measured value on the device screen.

The figure 2 shows some pictures ranging from physical parameters at one of the three tested sites (Figure 2a), the multi-parameter (Figure 2b), as well as the three soil samples coming from the three studied sites (Bobanya, Évanidja Ndoumba and Idolo) (Figure 2c).

| Measurement of physical parameters | AQUAREAD multi-parameters | Sediment samples |
|---|---|---|

| a | b | c |
|---|---|---|

**Figure 2:** Measurement of water and soil physical parameters and the presentation of the three sediment samples. (**a**): in situ measurement (T°, pH, EC, salinity and turbidity); (**b**): measurement tool; (**c**): soil samples

## 2.4 Chemical parameters

Chemical pollutants measured are: lead (Pb) and the following ionic elements: fluoride ($F^-$), sulphate ($SO_4^{2-}$) and nitrates ions ($NO_3^-$). These pollutants are chosen because of their impact on human/aquatic population health and water quality [14,15,16]. Each test is performed in duplicate and the results are averaged. This allow estimation of the standard error. Quantification of chemical pollutants content in the studied sediments is carried out by colorimetric method using strip tests (Figure 3).

The sampling method consists first of making dilutions ($10^{-1}$, $10^{-2}$ and $10^{-3}$) of the stock solution (1 g of soil) from the three study sites with demineralized water. The soil mass is weighed (1 g), using a balance (Balance BP 100-précision 0.01 g, Sartorius, Germany). The final volume of each hemolysis tube (Falcon tube) containing the diluted solution is adjusted to V= 10 mL of solution and then vortexed. Whoontrading Commercial trip (Figure 3a) is introduced during 10 seconds under manual stirring into the Falcon tube containing the diluted sample to be tested (Figure 3b). The activated trip is then removed from the hemolysis tube, and dried for 30 seconds. After drying, the colored strip is compared to the color given by the color chart, in order to read the value [in ppm] of the chemical pollutant measured (Figure 3c).

| Strips test for the determination of chemical parameters | Activation of the strip by inserting it into the diluted soil solution | Reading of the strip activated kit [mg/L] |
|---|---|---|


| a | b | c |
|---|---|---|

**Figure 3:** Colorimetric test (in strips) for determination of ion content in sediment. *(**a**) : Strip test kit; (**b**) : Insertion of trip in sample to be analysed; (**c**) : Ion content of tested pollutant [mg/L].*

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Table 1 presents the WHO limits of the targeted chemical pollutants, the potential sources of contamination, as well as the negative health effects, following prolonged exposure by those pollutants.

**Table 1:** Maximum tolerable rate of pollutants (Pb, $F^-$, $SO_4^{2-}$ et $NO_3^-$), sources of contamination and health effects [6-17,18,19].

| Chemical pollutant [-] | Lead (Pb) | Floride ($F^-$) | Sulphates ($SO_4^{2-}$) | Nitrates ($NO_3^-$) |
|---|---|---|---|---|
| **WHO limits [mg/L]** | 0.01 | 1.5 | 250 | 50 |
| **Sources of contamination [-]** | Human activities, pipes line composition connected to drinking water network. Pb is not eliminated by body. | Natural presence and used in the phosphate fertilizer industries. | Human activities (cosmetics, food, and sanitary products). | Coming from agricultural runoff, septic tanks leaks and sewage network. |
| **Health effects [-]** | Excess causes lead poisoning = neurological disorder and mental retardation in children. | At low dose (0.5 à 1.0 mg/L) = protection against dental caries. At C>1.0 mg/L, stain and dental fluorosis. Bone deformation | Laxative effect, digestive disorders, nausea, abdominal pain and harmful to the skin. | $NO_3^-$ are reduced to $NO_2^-$ which attach to hemoglobin instead of $O_2$. What causes respiratory disorders = metha emoglobinaemia (blue baby syndrome). |

## 2.5 Microbiological parameters

Another series of dilutions ($10^{-1}$, $10^{-2}$ and $10^{-3}$) of the previously prepared soil stock solution (1 g), is used for the determination of microbiological parameters. This analysis is focused on the quantification of fecal pollution indicator germs: fecal coliforms (*E. coli*), by the method known as indirect counting in Petri dishes.
Figure 4 shows the main steps of this experimental test.

| Preparation of culture media for the E. coli determination | Raw soil samples (1 g of soil + V= 9 mL demineralized $H_2O$ ➔ $V_{solution}$= 10 mL | Decimal dilutions at $10^{-1}$,$10^{-2}$ and $10^{-3}$ of the stock solution (coming from b) | Seeding culture in Petri dishes |
|---|---|---|---|
|  |  |  |  |
| a | b | c | d |

**Figure 4:** Enumeration of fecal pollution indictor germs by spreading (V=0.1 mL) on nutrient agar. *(**a**): Autoclaved and ready-to-use culture media; (**b**): Raw soil samples from the 3 studies sites; (**c**) : dilutions performed on the raw soil samples; (**d**): spreading the inoculum on the Mac Conkey agar media.*

### 2.5.1. Culture medium preparation

The culture media (Mac Conkey Agar (HIMEDIA, M083)) used for growing the desired bacteria is prepared at 50 g/L of commercial product (Figure 4a). This conditioning is one of those recommended by the French manufacturer. Specifically, it involes suspension of 50 g of deshydrated powder, dissolves in 1 L of demineralized water. Culture media is then brought to boil under constant stirring (Fisherbrand scientific 2006 magnetic hot plate) until complete product dissolution. Culture media is then sterilized in autoclave (Autoclave SN 310 Yamato brand) at 121 °C for 15 mins. Finally, the liquid agar prepared is distributed in 90 mm Petri dishes, with volume of about 15 mL in each. After solidification, the agar media is ready for use.

### 2.5.2. Culture and isolation of bacterial colonies on nutrient agar cooked in 2.5.1.

Fecal coliforms (FC) isolation is performed by surface seeding of V=0.1 mL of the test portion of each dilution (Figure 4c) of the stock solution (Figure 4b) onto a culture media (nutrient agar). The culture media used is Mac Conkey agar (HIMEDIA, M083) selective for the isolation of Enterobacteria (*E. coli*, Salmonella, and Shigella) [20]. The 'Z' streak spreading method (using a plastic loop), allows for good distribution of bacteria on the nutrient agar (Figure 4d).
Fecal coliforms counts (thermotolerant coliforms) are performed after 24 hours of incubation (Memmert GmbH Models 30-750 brand oven) at 44 °C (optimal growing conditions. For each dilution, two Petri dishes cultures are seeded.

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### 2.5.3. Equations

Finally, colony counts are carried out on Petri dishes where between 15 and 300 colonies have developed. The mean of the colonies counted is determined, by considering the corresponding dilution factor ($F_d$) Eq. (1) or the lowest dilution factor ($F_{dLowest}$), in case of several dilutions giving exploitable results Eq. (2). The result is then expressed in Colony Forming Unit per mL (CFU/mL) [20]. If the agar culture media contains less than 15 colonies, the obtained result is not exploitable. In this case, the concerned Petri dish is discarded.

$$C_{N(\text{suspension cells})[\text{CFU/mL}]} = \frac{\text{Number CFU}_{\text{counted}}}{V_{\text{inoculum pipetted}}} \times F_d \quad (1)$$

$$C_{N(\text{suspension cells})[\text{CFU/mL}]} = \frac{\sum \text{of CFU}_{\text{counted}}}{1.1 \times V_{\text{inoculum pipetted}}} \times F_{d_{\text{Lowest}}} \quad (2)$$

Where: $CFU_{Counted}$ is the number of colonies developed in the Petri dish, $V_{inoculum}$ is volume equal to 0.1 mL and $F_d$ is the dilution factor.

## 3. RESULTS

Table 2 presents results of the physical parameters measured. These parameters are directly measured at the sampling site and will give first information on the quality of the ecosystem studied.

**Table 2 :** Physical parameters (T°, pH, EC, Turbidity and Salinity) of ecosystem hosting the fishing sites $S_i$ (Bobanya, Évanidja Ndoumba and Idolo) of *Solen guineensis* (sea knife), according to the sampled month $M_i$.

| Sampling month $M_i$ | T [°C] | | pH [-] | | EC [µS/cm] | | Turbidity [NTU] | | Salinity [mg/L] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_1$ | $M_2$ | $M_1$ | $M_2$ | $M_1$ | $M_2$ | $M_1$ | $M_2$ |
| **Bobanya, $S_1$** | 31.2±0.02 | 28.1±0.03 | 8.72±0.01 | 8.87±0.02 | 18.47±0.21 | 52.0±0.01 | 7.1±0.05 | 6.40±0.04 | 12.00±0.03 | 38.35±0.01 |
| $\overline{S_1}$ | **29.65±2.19** | | **8.80±0.10** | | **35.25±23.72** | | **7.15±0.07** | | **25,18±18.63** | |
| **Évanidja Ndoumb, $S_2$** | 31.3±0.01 | 29.8±0.02 | 8.77±0.12 | 8.63±0.01 | 41.63±0.04 | 19.36±0.06 | 17.30±0.01 | 16.40±0.03 | 29.86±0.02 | 12.82±0.01 |
| $\overline{S_2}$ | **30.55±1.06** | | **8.70±0.10** | | **30.50±15.75** | | **16.85±0.64** | | **21,34±12.05** | |
| **Idolo, $S_3$** | 31.3±0.01 | 31.6±0.01 | 8.78±0.01 | 8.92±0.03 | 42.18±0.28 | 43.26±0.03 | 7.18±0.04 | 7.52±0.06 | 30.29±0.05 | 12.14±0.07 |
| $\overline{S_3}$ | **31.45±0.21** | | **8.85±0.10** | | **42.72±0.76** | | **7.35±0.24** | | **21,22±18.83** | |
| **WHO limits** | - | | Good: 6≤pH≤9 Worst: 4.5≤pH≤5.5 and pH≥9.5 | | Good: 180≤EC≤2500 Worst: 0≤EC≤60 and EC≥4000 | | Good: Turbidy ≤5 Worst: Turbidity ≥5 | | Good: C≤300 Medium: C=300 Worst: C ≥ 500 | |

All values are the average of two measurements (mean ± SD, n=2). For each parameter, average measurements in the sampling area $\overline{S_i}$ it rated $S_i$. Minus sign (-) indicates that temperature value depends on the country climate (equatorial area). ***(M₁** = in August, **M₂** = in September).*

### 3.1 Physical parameters

- **Temperature**

Water temperature at the Bobanya site, ranges from 31.2±0.02 to 28.1±0.03 °C in August and September, respectively. For both sampling periods, the calculated mean value is about $T_{(Bob\_mean)}$= 29.65±2.19 °C. For Évanidja Ndoumba, this indicator ranges from 31.3±0.01 °C (in August) to 29.8±0.02 °C (In September). The mean temperature is $T_{(Éva\_mean)}$= 30.55±1.06 °C. Finally, for the Idolo site, the calculated values are very close to each other (T=31.3±0.01 and 31.6±0.01 °C), with an average of about $T_{(Ido\_mean)}$= 31.45±0.21 °C. Overall, water temperature at the three sites studied is around T= 30 °C. This corresponds with the country's seasonal average temperature, in the dry season.

- **pH**

For the Bobanya site, pH of the water oscillates between 8.72±0.01 and 8.87±0.02, in August and September respectively, a difference of 1.7% was found, which is not significant. For these two periods, average pH is $pH_{(Bob\_mean)}$= 8.49±0.10. The Bobanya waters are rather basic. In the case of Évanidja Ndoumba, pH is egal to pH= 8.77±0.12 (in August) and pH= 8.63±0.01 (in September), with a decrease value about 1.6%. Mean pH value is egal to $pH_{(Éva\_mean)}$= 8.39±0.10. The aquatic ecosystem is also alkaline in sampling area of Évanidja Ndoumba. Finally, for Idolo, values of this parameter are also close to each other (pH= 8.78±0.01 and pH= 8.92±0.03) during the two months considered, with variation of about 1.6%. The mean value is around $pH_{(Ido\_mean)}$= 8.54±0.10 (basic water). Finally, for the three sites studies, results show that aquatic environment tends to be basic. This indicates good water quality in this region, in accordance with the WHO limits regulation, which sets pH threshold value at: 6≤pH≤9 (**Table 2**). This pH range is favorable for the protection and survival of aquatic fauna.

- **Electrical conductivity**

For the water samples from Bobanya, electrical conductivity increases sharply from August (EC= 18.47 ±0.21 µS/cm) to September (EC= 52.02±0.01 µS/cm). Variation rate between the two values is rather high, by a factor of 181.65%. The mean value between the two measurements gives an electrical conductivity of about $EC_{(Bob\_mean)}$= 35.25±23.72 µS/cm. The mean EC of the water samples from Évanidja Ndoumba is 41.63±0.04 µS/cm during August and EC=19.36±0.06 µS/cm during the month of September. The calculated mean EC of Évanidja Ndoumba is 30.50±15.75 µS/cm.
At the Idolo site, the highest value (EC= 42.18±0.28 µS/cm) is obtained in August and the lowest (EC=43.26 ±0.03 µS/cm) in September, with variation of about 2.6%. The mean conductivity between August and September is $EC_{(Ido\_mean)}$= 42.72±0.76 µS/cm. Electrical conductivity values from different sites are below the WHO threshold (EC≤ 60 µS/cm) (**Table 2**). Results show a very poor water electrical conductivity and therefore a low mineralization of the aquatic system studied.

- **Turbidity**

On the Bobanya site, water turbidity varies between 7.1±0.05 and 6.40±0.04 NTU, respectively in August and September, with 11% of variation (**Table 2**). For these two sampling periods, the calculated mean turbidity is of order of 7.15±0.07 NTU= $turbidity_{(Bob\_mean)}$. In Évanidja Ndoumba site, this parameter ranges between 17.30±0.01 NTU (in August) and 16.40 ±0.03 NTU (in September). This leads to 5.5% decrease of initial turbidity. The avarage value of Évanidja Ndoumba water turbidity is about $turbidity_{(Éva\_mean)}$= 16.85±0.64 NTU. For Idolo, the turbidity values are quite close with 7.18±0.04 NTU recorded in August and 7.52±0.06 NTU in September, with an average of about $Turbidity_{(Ido\_mean)}$= 7.35±0.24 NTU.
The observed turbidity at the Bobanya aquatic site is rather close to that found at the Idolo site (7.15±0. 07 NTU Vs 7.35±0.24 NTU). Water disturbance on Évanidja Ndoumba appears to be about 2.4 times more (2.4*7 NTU ≈16.85 NTU) than that observed in the other two sampling sites. In all cases, pollution related to water disturbance appears to occur at the three targeted sites of Cap Estérias. The calculated values (7.15±0.07, 16.85±0.64 and 7.35±0.24 NTU, respectively) are above threshold turbidity (Turbidité≤ 5 NTU, see Table 2). In the three aquatic systems studied, Évanidja Ndoumba appears to be the most turbid.

- **Salinity**

The Bobanya water salinity is equal to C= 12.00 ±0.03 mg/L in August and C= 38.35±0.01 mg/L in September. The difference in values is quite significant between the two test periods with mean value of $C_{Bob\_mean}$= 25.18±18.63 mg/L.
For the Évanidja Ndoumba site, the trend seems to be reversed: the highest value is C= 29.86±0.02 mg/L (reached in August) and the lowest ($C_{Éva}$= 12.82±0.01 mg/L) in September. Mean salinity is equal to $C_{Éva\_mean}$= 21.34±12.05 mg/L.
For Idolo, Salinity seems to be the same as that already observed in Évanidja Ndoumba area: the highest level of salts (C= 30.29±0.05 mg/L) is obtained in August and the lowest (C= 12.14 ±0.07 mg/L) in September, with an average of about $C_{Ido\_mean}$= 21.22±18.83 mg/L, between the two test periods. To summarize, dissolved average salt for all sites is below the WHO guideline value (Salinity≤ 300 mg/L) (Table 2).

## 3.2 Chemical parameters

**Figure 5** shows results of the concentration of tested and dissolved chemical pollutants (Pb, $F^-$, $SO_4^{2-}$ and $NO_3^-$) in the sediments of the Cap Estérias fishing sites.

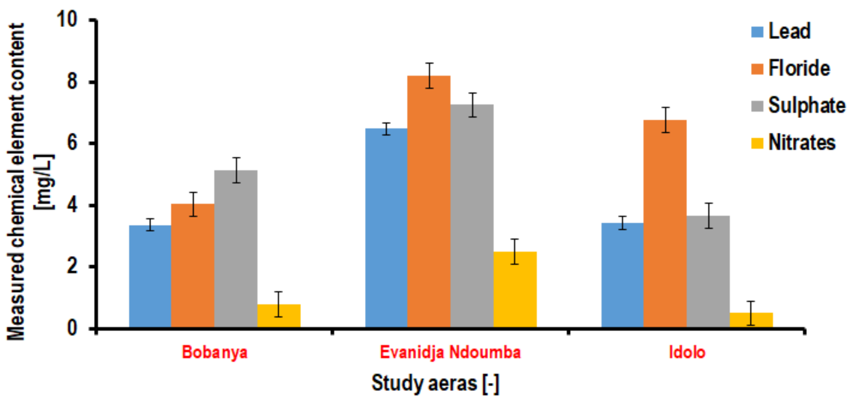


**Figure 5**: Chemical pollutants (Pb, $F^-$, $SO_4^{2-}$ and $NO_3^-$) dissolved in soils sampled at the fishing sites $S_i$ (Bobanya, Évanidja Ndoumba and Idolo).

Lead (Pb) dosage in Bobanya sediments, reached the mean peak of $C_{P(Bob\_mean)}$= 3.37 ±0.64 mg/L during both sampling periods (August and September). The WHO tolerance limit is $C_{P(WHO)}$= $10^{-2}$ mg/L (Cf. Table 1). That is represent a content of element Pb about 337 times more than the WHO's guideline.

For the sediments of Évanidja Ndoumba site, the titration trials gives an average value of $C_{P(Éva\_mean)}$= 6.49±0.07 mg/L. that is 649 times the content allowed by the directive of the World Health Organization. For Idolo, results show a mean peak estimated at $C_{P(Ido\_mean)}$= 6.43±0.24 mg/L, thus close to the lead content observed at the Évanidja Ndoumba site. Approximately 643 times the allowable WHO value. Finally, in the three study sites, an indescribable disturbance of the aquatic ecosystem, related to lead contamination is shown.

For the titration of fluoride ions ($F^-$) in Bobanya sediments, the calculated mean value is equal to $C_{F^-(Bob\_mean)}$= 4.04 ±0.02 mg/L. This value is 2.7 times the WHO limit value $C_{F^-(WHO)}$= 1.5 mg/L (Cf. **Table 1**).
In Évanidja Ndoumba sediments, $F^-$ is $C_{F^-(Éva\_mean)}$= 8.21±0.27 mg/L. This is 5.5 times the WHO normalized value. For the Idolo site, fluoride content is $C_{F^-(Ido\_mean)}$= 6.76±0.66 mg/L (2.5 times the WHO guideline). Finally, in the three sites, pollution related to fluoride ion content is observed.

The concentration of sulphate ions ($SO_4^{2-}$) in the Bobanya, Évanidja Ndoumba and Idolo sediments, is of the order of: $C_{SO4^{2-}(Bob\_mean)}$= 5.14 ±0.01, $C_{SO4^{2-}(Éva\_mean)}$= 7.26±0.05 and $C_{SO4^{2-}(Ido\_mean)}$= 3.7±0.10 mg/L, respectively. The calculated values are negligible compared to the acceptability WHO limit ($C_{SO4^{2-}(WHO)}$= 250 mg/L) (**Table 1**). Finally, for the nitrogen ($NO_3^-$) contained in Bobanya sediments, results give : 0. 8 ±0.05 mg/L and is $1.6.10^{-2}$ times WHO limit value ($C_{NO3^-(WHO)}$= 50 mg/L) (Cf. **Table 1**). The Bobanya site is therefore not polluted by nitrogen ions ($C_{NO3^- calculated}$<<< $C_{NO3^-(WHO)}$). For the sediments of the two other studied sites (Évanidja Ndoumba and Idolo), $NO_3^-$ content is $C_{NO3^-(Éva\_mean)}$= 2.5±0.08 and $C_{NO3^-(Ido\_mean)}$= 0.5±0.04 mg/L, respectively. ($C_{NO3^- calculated}$<<< $C_{NO3^-(WHO)}$). Definitively, it can be concluded that the three studied sites are not affected by nitrogen pollution.

### 3.3 Microbiological parameters

Results of pathogenic microorganism's content, found and quantified in the sediments of Cap Estérias fishing area, are presented in **Table 3**. Of all Petri dishes containing seeded culture media, only the $10^{-1}$ and $10^{-2}$ dilutions of the initial suspension stock are exploitable (the mean of the counted colonies is between 15 and 300 CFU). Based on the data reported by this table, the mean of counted pathogen is $\overline{S}_{1(Bob\_mean)}$= 50.50±2.12 and $\overline{S}_{2(Ido\_mean)}$= 58±2.83 CFU, respectively for Bobanya and Idolo sampling. For the sediments provided by Évanidja Ndoumba area, the mean of pathogen counted is $\overline{S}_{3(Éva\_mean1)}$= 167±5.66 CFU for the $10^{-1}$ dilution and $\overline{S}_{3(Éva\_mean2)}$= 16.5±0.71 CFU for that at $10^{-2}$ dilution of the stock solution. Finally, for all sampling sites, the concentration of cell numbers in the sediment suspension is calculated and expressed in Colony Forming Unit [CFU/mL], as shown in equations on the Material and Methods section. Results show that the highest level of microrganisms ($C_{N(Éva)}$= $16.7*10^3$ CFU/mL) is obtained from the sediments of the Évanidja Ndoumba site and the lowest ($C_{N(Bob)}$= $5.05*10^3$ CFU/mL) is noted at Bobanya sampling site. For Idolo, the mean value of *E. coli* concentration is $C_{N(Ido)}$= $5.80*10^3$ CFU/mL.
Finally, bacteriological pollution caused by coliform pathogens is therefore present in the coastal zone of Cap Estérias.

**Table 3:** Pathogenic germs contained in soils of fishing areas $S_i$ (Bobanya, Évanidja Ndoumba and Idolo) of *Solen guineensis* (sea knife), with respect to the sampled month $M_i$ ($M_1$= in August, $M_2$= in September), $V_{inoculum}$= 0.1 mL.

| | Dilution, d [-] | **$10^0$** | | **$10^{-1}$** | | **$10^{-2}$** | | **$10^{-3}$** | |
|---|---|---|---|---|---|---|---|---|---|
| | Dilution factor, $F_d$ [-] | **$10^0$** | | **$10^1$** | | **$10^2$** | | **$10^3$** | |
| | Période $M_i$ [month] | **$M_1$** | **$M_2$** | **$M_1$** | **$M_2$** | **$M_1$** | **$M_2$** | **$M_1$** | **$M_2$** |
| **Bobanya, $S_1$** | Number of [CFU] | > 300 | | 49 | 52 | <15 | | <15 | |
| | $\overline{S}_1$ [CFU] | - | | 50.50±2.12 | | - | | - | |
| | $C_{N(suspension\ cells)}$ [CFU/mL] | - | | **$5.05*10^3$** | | - | | - | |
| **Evanidja Ndoumba, $S_2$** | Number of [CFU] | > 300 | | 163 | 171 | 17 | 16 | <15 | |
| | $\overline{S}_2$ [CFU] | - | | 167±5.66 | | 16.5±0.71 | | <15 | |
| | $C_{N(suspension\ cells)}$ [CFU/mL] | - | | **$16.7*10^3$** | | | | - | |
| **Idolo, $S_3$** | Number of [CFU] | > 300 | | 56 | 60 | <15 | | <15 | |
| | $\overline{S}_3$ [CFU] | - | | 58±2.83 | | - | | - | |
| | $C_{N(suspension\ cells)}$ [CFU/mL] | - | | **$5.80*10^3$** | | - | | - | |

All values are the average of two measurements (mean ± SD, n=2). For each Petri dish, the mean counted colonies on the sampling site $S_i$ is rated $\overline{S}_i$. Unusable Petri dishes are formed with counted colonies< 15 CFU and >300 CFU. In this case, sum $\overline{S}_i$ and the estimated cells concentration $C_N$ is not calculable. This is indicated by minus sign (-). Concentration of cell numbers in the stock solution ($C_{N(suspension\ cells)}$) is calculated and expressed in [CFU/mL]; see in yellow highlighted on the table.

A correlation is established between the pathogenic germs contained in the soils of the three different fishing sites and the turbidity of the aquatic ecosystem (Figure 6).

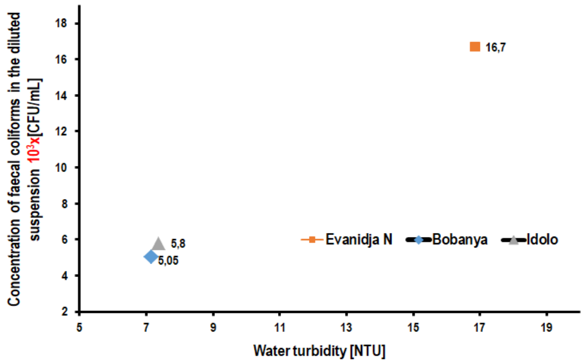


**Figure 6:** Pathogenic germs in soils of fishing areas $S_i$ (Bobanya, Évanidja Ndoumba and Idolo) of *Solen guineensis* (sea knife) and water turbidity of the aquatic ecosystem $S_i$.

The concentration of pathogenic bacteria is strongly correlated with turbidity. Indeed, for Bobanya and Idolo sites, when turbidity is 7 NTU, the pathogenic *E. coli* content is $C_N$= 6.10$^3$ CFU/mL. For Évanidja Ndoumba site, the concentration of these microorganisms is $C_{N(Éva)}$= 16.7*10$^3$ CFU/mL when turbidity turns to 17 NTU, about twice that observed in the first two cases. There is a positive linear relationship between these two environmental variables.

## 4. DISCUSSION

Temperature reflects the conditions of aquatic ecosystem. Any variation in temperature has an effect on biochemical balances of water, for example suspended solids content. On the coastal sites of Bobanya, Évanidja Ndoumba and Idolo, average temperatures are $T_{Bob}$= 29.65±2.19, $T_{Éva}$= 30.55±1.06 and $T_{Ido}$=31.45±0.21 °C (See Table 2). The calculated values are close to each other (around 30 °C) for all sampling sites. These temperature values correspond to the seasonal values usually found in dry season in wet equatorial regions [21].

Hydrogen potential measures concentration of hydronium ion contains in water. Its values indicate the degree of acidity (0≤pH≤7) or alkalinity (7≤pH≤14), on logarithmic scale ranging from 0 to 14 [17]. In aquatic ecosystems, pH influences metal solubility that can have negative effects on aquatic organisms [17]. Considering the three study sites: Bobanya, Évanidja Ndoumba and Idolo, the mean pH values are: $pH_{Bob}$= 8.49±0.10, $pH_{Éva}$= 8.39±0.10 and $pH_{Ido}$= 8.54±0.10, respectively. The entire aquatic system is alkaline (Table 2). Good water quality is shown, based on the recorded pH values. This is even consistent with pH values usually found in brackish water (pH=8) [22].

In addition, for the three sites, average pH ($pH_{Éva}$= 8.39, $pH_{Bob}$= 8.49 and $pH_{Ido}$= 8.54) is favorable to aquatic fauna survival and reproduction, that has already been reported to fall within the interval of 6≤pH≤9.
pH levels observed in this study are quite close to those related by a study on the assessment of mineral nitrogen pollution, in surface water of the Ramsar wetland of Fetzara lake in northeastern Algeria [16]. Authors obtained during the same season (summer) pH values close to pH= 8.

Usually, acidic pH water is found in granitic areas; while alkaline water is found in calcareous areas, because of high calcium salt content of hard water [23,24]. Basic waters usually present a more diversified fauna than their acid counterparts which, weakly mineralized, allow only limited development of aquatic plants. These statements by authors of the two aforementioned articles suggest that the geology of the coastal Cap Estérias area is of calcareous type.

Electrical conductivity of a water system gives an idea of dissolved ions content (EC is therefore closely related to water salinity). It also provides an indication of water origin. Mean water conductivity at each study site gives the following results: $EC_{Bob}$= 35.25±23.72 µS/cm (Bobanya), $EC_{Éva}$= 30.50±15.75 µS/cm, (Évanidja Ndoumba) and $EC_{Ido}$= 42.72±0.76 µS/cm (Idolo) (Cf. Table 2). The low values observed for EC index reflect a very poor water conductivity and low mineralization of the aquatic systems studied. This is related to the low water salinity (Table 2). This means that aquatic system of Cap Estérias area lacked mineral salts. The physicochemical analysis conducted on samples from the Coastal area of Ondo State in Nigeria, Bamidele, et al. (2016) [25], resulted in almost a double outcome. Water conductivity ranges from EC= 80.8±1.56 to EC= 93.6±1.35 µS/cm, during the two sampling periods, respectively in (December and July 2016).

Salinity measures the concentration of water in dissolved salts (sodium chloride, magnesium chloride, magnesium sulfate). It reflects the degree of global mineralization of water. Results show mean values of EC as follows: $C_{Bob}$= 25.18±18.63, $C_{Éva}$=21.34±12.05 and $C_{Ido}$=21.22±18.83 mg/L, respectively for Bobanya, Évanidja Ndoumba and Idolo (See Table 2). The highest salt content was found in the Bobanya waters ($C_{Bob}$= 25.18±18.63 mg/L). The waters of the Cap Estérias coastal zone responded to the criteria of class of waters known as low mineralized water, as already specified above, in the paragraph discussing on electrical conductivity. Salinity levels observed in this work are slightly below those already obtained by Yusuf et al. (2021) [26], by studying the distribution of turbidity values, total suspended solids and heavy metals such as Pb and Cu in Tanah Merah Beach waters and Semujur Island Waters, Bangka Tengah Regency. These authors found dissolved salt content, ranging from 28 to 32 ppm.

Turbidity is responsible for water disturbance. It is due to the presence of colloidal particles, suspended solids and organic matter contain in water [27]. This pollution index often reduces water transparency. Results presented in Table 2, indicate that the mean turbidity of Bobanya, Évanidja Ndoumba and Idolo sites are 7.15±0.07, 16.85±0.64 and 7.35±0.24 NTU respectively. According to current data, study sites waters are mosty turbid. The deterioration of the ecosystem quality (by this parameter), seems to be more pronounced in the aquatic system of the Évanidja Ndoumba site. Turbidity water deterioration can be explained by materials resuspension contained in soil samples (clay, sand, colloïdal perticles). A high level (turbidity=15.3 NTU) is also reported by Macdonald et al. (2013) [28], in an environmental water turbidity monitoring study in the open coastal waters of the Great Barrier Reef. According to authors, waves resuspension within Cleveland Bay, with subsequent advection to Horseshoe Bay by tidal currents, could be responsible for this increase in turbidity values.

For the analyzed ions, results reveal that the aquatic systems studied are very polluted by lead (between 300 to 600 times the permissible WHO values). The mean calculated values are: Bobanya $C_{P(Bob)}$= 3.37 ±0.64 mg/L, and twice as much on the Évanidja Ndoumba and Idolo samples, with values of $C_{P(Éva)}$= 6.49±0.07 and $C_{P(Ido)}$= 6.43±0.24 mg/L) respectively (Cf. Figure 5). For a good ecologically ecosystem, toxicity threshold related to lead should not exceed C=0.01 mg/L of Pb as reported already in Table. 1. This worrying pollution could be attributed to many activities practiced around and inside coastal areas such as industrialization, fuels and oils used for the operation of engines of fishing boats. Finally, anthropogenic action on environmental degradation is strongly suspected.

The high lead content is quite critical compared to those already reported by Manda et al. (2010) [29], where authors evaluated the contamination of the food chain by trace elements (Cu, Co, Zn, Pb, Cd, U, V and As), in the basin of the upper Lufira of Katanga of the democratic republic of Congo. Authors obtained water Pb content, ranging from $2.10^{-3}$ to $8.10^{-3}$ mg/L. This corresponds to the ratio k, ranging from 1685 to 800 ($k_1$= 3.37/0.002= 1685 to $k_2$= 6.4/0.008= 800). For the disturbance caused by fluoride ions (F-) that varied with sediments from the different sites as such: Bobanya, $C_{F-(Bob)}$= 4.04 ±0.02 mg/L; Évanidja Ndoumba, $C_{F-(Éva)}$= 8.21±0.27 mg/L; and Idolo, $C_{F-(Ido)}$= 6.76±0.66 mg/L. This represents about 3 times WHO limits for Bobanya and Idolo, whereas is 6 times more in Évanidja Ndoumba site (Cfs. Table 1 and Figure 5). The observed values are just as critical as those reported by Currell et al. (2011) [30], when the authors assessed the fluoride and arsenic concentrations in groundwater from the Yuncheng Basin. They found that in water sediments of the basin, pollution by element F- was dangerous, with obtained values of 1.5 to 6.6 mg/L of fluorides. The authors speculated that the high level of this element was due to anthropogenic activities.

Finally, the presence of metallic trace elements (Pb, F-, etc.) in aquatic environments could have devastating effects on the ecological balance of aquatic environments [29]. In the long term, environmental toxicity, due to the high fluorides and lead content causes diseases already listed in Table 1, but also others, related to the transfer of metallic trace elements through the food chain [18]. On the contrary, the mean concentration of sulphates ($SO_4^{2-}$) and nitrogen ($NO_3^-$) ions from Bobanya, Évanidja Ndoumba and Idolo sediments, are: $C_{SO4^{2-}(Bob)}$= 5.14 ±0.01, $C_{SO4^{2-}(Éva)}$= 7.26±0.05 and $C_{SO4^{2-}(Ido)}$= 3.7±0.10 mg/L for sulphates ions, and $C_{NO3^-(Bob)}$= 0.8 ±0.05, $C_{NO3^-(Éva)}$= 2.5±0.08 and $C_{NO3^-(Ido)}$= 0.5±0.04 mg/L, respectively (Cf. Figure 5). Finally, the detection of these anions in Cap Estérias sediments showed no pollution, neither sulphated, nor nitrogened, is detected. The calculated concentrations of this current study are negligible compared to the WHO toxicity limits (Cf. Table 1).

Bacteriological analysis carried out in the present study reveal pathogenic microorganisms pollution in all studied sites. Bacterial content in the sediments from the different study sites is as follows: Bobanya and Idolo sediments values are $C_{N(Bob)}$= 5.05*$10^3$ and $C_{N(Ido)}$= 5.80*$10^3$ CFU/mL respectively, while it is almost three times for samples from Évanidja Ndoumba site ($C_{N(Éva)}$= 16.7*103 CFU/mL) (Cf. Table 3). This increase in the degree of pathogenic pollution on Évanidja Ndoumba can be attributed to the release of additional substances from industrial effluents, while in the other two sites, the more pronounced sunshine effect reduces microbial load. This finding aligns with the results obtained by some authors like Saab et al. (2008) [23], where they revealed that sunshine is inversely proportional to the amount of pathogens present in the environment. Radiations emitted by light rays could exert a germicidal effect on the bacteria found in the aquatic system.

Finally, a correlation between microorganism content in different sediments and the coastal pollution is established. Results show that turbidity increases with increase in bacterial concentration of the biotope (Figure 6). Similar observations have already been noted in river water, coastal areas and even drinking troughs on cattle farms [31,32,33]. As already reported by Whitman et al.?, (2004) [34], higher turbidity results in increased concentration of sediment particles, which facilitates the attachment of *E. coli* pathogen and can thus increase their suspension in water. In addition, stream discharge may contribute to increased turbidity and may transport urban runoff to beach areas [35].

## 5. CONCLUSION

To meet with the food needs of populations, several types of activities (agriculture, hunting, etc.) are often practiced, including fishing for aquatic vertebrate and invertebrate organisms. However, the increase in human activities in marine coastal sites is often accompanied by increased pollution which results in risks of disturbance of aquatic ecosystem, where these animal resources live. This pollution (chemical and bacteriological) can be transferred from the water environment to these microorganisms. This could lead to the accumulation of these dangerous chemicals in animal muscles and flesh, especially when the content of ingested pollutants becomes high. Preserving the quality of water resources is therefore a major environmental problem. Chemical and bacteriological study conducted on the sediments of the three sites (Bobanya, Évanidja Ndoumba and Idolo) constituting coastal resource of Cap Estérias, made it possible to know and quantify the degree of pollution affecting this aquatic ecosystem. The obtained results show that pH value of analyzed water areas is basic with an almost constant temperature, while the other parameters such as: electrical conductivity, salinity and water disturbance are above quality thresholds set by the World Health Organization. In addition, the entire aquatic ecosystem, through the analysis of its sediments, is polluted, to almost worrying proportion, by lead and on a secondary scale, by fluoridated pollution one. On the contrary, for sulphate and nitrates ions, the calculated values are lower than the WHO limits. The studied sites could be described as non-sulphato-nitrate polluted. In addition, bacteriological analysis carried out on these same hydro-sediments reveal the existence of fecal coliforms pollution, which moreover, increases with increase in biotope turbidity.

This bacteriological and chemical disturbance of the coastal Cap Estérias could be transferred to aquatic bivalve species, including *Solen guineensis* species, and even to other fishes. Finally, the contamination of the biotope could result in bioaccumulation of these dangerous exogenous substances in humans who remain the ultimate consumer. Finally, it would be interesting to extend this study to other coastal ecosystems of Gabon, and add aquatic quality bio-assays, based on the calculation of biotic indices, which undoubtedly could help to determine the impact of the pollution observed on aquatic organisms. More ever, chemical and microbiological assay on flesh, muscles and intestinal organs of bivalve molluscs is necessary to determine whether the pollutants identified in water and sediments of Cap Estérias, are necessarily found in the body of these benthic macroinvertebrates. Indeed, these species are good indicators of the quality of marine and continental ecosystems. Finally, the triad physicochemistry/microbiology/and biology of aquatic organisms, would better characterize not only water environment, but also its fauna diversity, in relation with natural zoonotic diseases.

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