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Distribution and Contamination of Arsenic in Fish, Gastropods and Bivalves in the Aby and Tendo Lagoons in East of Ivory Coast

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Abstract

Lagoons are ecosystems for biodiversity and the livelihoods of coastal communities. The main objective of the study was to analyze the variability of arsenic concentrations in gastropods and bivalves in the Aby and Tendo lagoons, taking into account spatial, seasonal and hydrological variations. The study was carried out in four stages spread over two successive hydroclimatic cycles, including two seasons during the rainy season and two more during the dry season. The samples were taken in two areas of the Aby and Tendo lagoons. Arsenic levels were measured by ICP-MS. The results showed that mean arsenic concentrations in the muscles of organisms in Aby Lagoon ranged from 0.01 to 1.26 µg As/g, with a mean and median of 0.17 and 0.06 µg As/g, respectively. Fish had the highest levels of arsenic, followed by crustaceans, while molluscs and plants had lower and comparable concentrations of As. Arsenic concentrations in tilapia and jawbones varied significantly between sites and seasons, with higher concentrations at Tendo and during the rainy season. Arsenic concentrations in gastropods and bivalves were significantly higher than those of other species, with averages of 0.74 and 1.03 mg As/kg, respectively.

Keywords

Arsenic, Pollution, Fish, Gastropods, Lagoons, Health Effect

1. Introduction

Lagoon ecosystems are critically important aquatic environments because of their multifunctional role in maintaining biodiversity and supporting the livelihoods of coastal communities [1] [2]. These dynamic ecosystems, where the fresh waters of rivers meet the salty waters of the ocean, are characterized by a unique eologic diversity [3] [4]. The Aby North and Tendo lagoons are two of the four lagoons that make up the Aby lagoon complex, located in the southeast of Côte d'Ivoire. They form a natural border with Ghana. Aby Lagoon is the northernmost of the four lagoons [5]. It is fed by the Bia River and is known for its strong winds and waves. The lagoon is a popular spot for fishing and boating. Tendo Lagoon is the largest of the four lagoons. It is located in the central part of the Aby lagoon complex and is fed by the Tanoé River [6]. The lagoon is home to a variety of fish and wildlife, including hippos, crocodiles, and birds [7]. Both Aby and Tendo lagoons are important ecosystems that are home to a variety of plants and animals. They are also popular tourist destinations and offer visitors the opportunity to experience the beauty and diversity of the Ivorian coast [8] [9] [10]. The Aby-North (AbyN) and Tendo lagoons, in particular, located in a specific region, stand out for their rich biological heritage [11] [12]. Within these lagoons, considerable biodiversity flourishes, including a variety of marine species, among which gastropods and bivalves occupy a prominent place [12]. These molluscs, as essential components of the local food chain, play a crucial role in the livelihoods of human communities dependent on fishing and seafood collection [13]. They are important sources of protein and nutrients for local populations, contributing to the food security of the region's inhabitants [14]. However, the health and viability of these marine species face environmental challenges, including toxic metal contamination [6], such as arsenic, which is of particular importance [15] [16]. Environmental variations, whether natural or human-related, can influence the concentration of arsenic in lagoons, directly affecting the living organisms that reside there [17]. As a result, gastropods and bivalves, as filter organisms, are likely to accumulate varying levels of arsenic depending on the geography, hydrographic features, and water quality of the lagoons [18] [19]. This variability in arsenic concentrations within gastropods and bivalves in the Aby and Tendo lagoons is of major concern due to its potential implications for human health, biodiversity and ecological balance [20]. Thus, the study of this variability becomes imperative to assess environmental risks, develop effective conservation strategies, and ensure the long-term sustainability of these crucial lagoon ecosystems. The main objective of this study is to analyze the variability of arsenic concentrations in gastropods and bivalves in the Aby and Tendo lagoons.

2. Materials and Methods

2.1. Study Area

Aby lagoon (5˚05' - 5˚22'N and 3˚16' - 2˚55'W) is located in West Africa, on the coast of the Gulf of Guinea between Côte d'Ivoire and Ghana. Aby lagoon covers

24.5 km and 56 km, respectively, from east to west with an estimated area of 420 km^2, while the Tendo lagoon is formed by the band from west to east and has a width of about 20 km. Aby and Tendo lagoons are located in an equatorial climate region with a climate composed of 4 successive seasons: 2 rainy seasons from May to July and from October to November and 2 dry seasons from August to September and from December to March/April. We indicated successively from north to south for Aby north and south lagoons, and from west to east for Tendo (**Figure 1**). The north and south Aby lagoons will simply be called Aby throughout this study. Several towns, villages, and seasonal fishing camps exist around the Aby and Tendo lagoons. The population estimated to 30,000 are living around Aby and Tendo lagoons that constitute and provide a real source of food and living for these populations through fishing activities. Aby and Tendo lagoons are under the influence, respectively, of the Bia river whose watershed is estimated at about 10,000 km^2 with an average flow estimated at 300 m^3/s during rainy floods and the Tanoe river whose watershed is at about 16,074 km^2 with an average flow estimated at 142 m^3/s. These rivers are home to numerous gold deposits that have gradually developed over the years. Thus, artisanal and industrial gold mining around the Bia and Tanoe rivers fears that these rivers will serve as a pollution vector for heavy metals, especially mercury from gold-mining areas to its outlets in Aby and Tendo lagoons. Assessment of Aby and Tendo lagoon sediments' exposure to pollutants resulting directly or indirectly from gold-mining activities, namely, mercury, is a relevant indicator of this pollution. In addition to spatial, bathymetric, and hydrological variations, Aby and Tendo lagoons were influenced by the Bia and Tanoe rivers, respectively. Aby and Tendo lagoons are the estuaries of the Bia and Tanoe rivers, respectively.

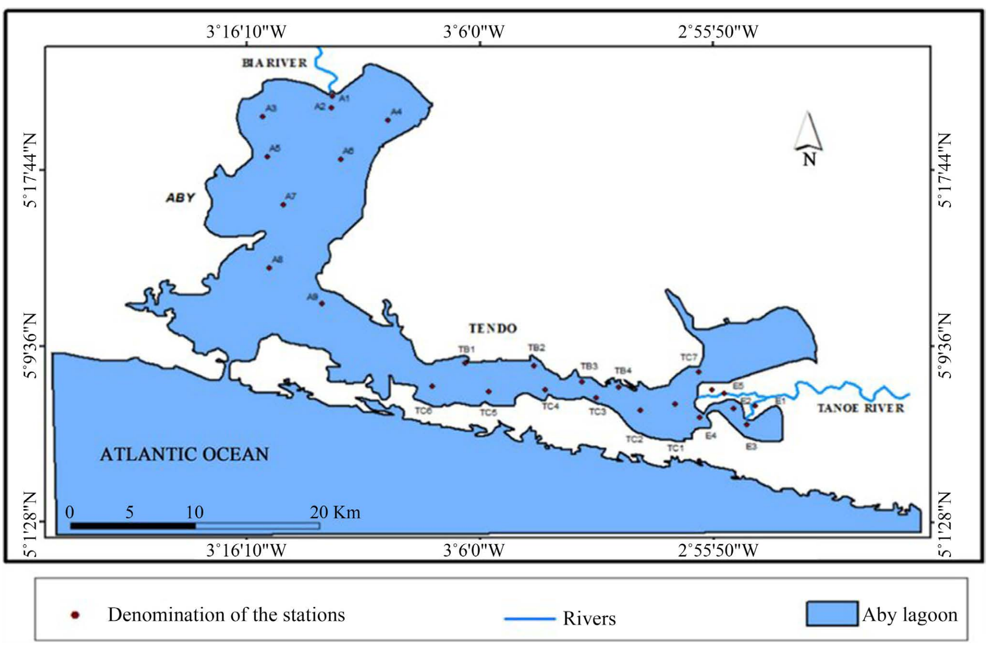

Figure 1. Locations of sampling sites.

2.2. Target Species

The species analysed are gastropods and bivalves. These two groups of shell molluscs live in the Aby and Tendo lagoons in Côte d'Ivoire. They have been studied for arsenic contamination. These species could be used as bioindicators for monitoring lagoon contamination. The species sampled include gastropods, bivalves and fish. Indeed, gastropods and bivalves are molluscs that live in the Aby and Tendo lagoons. Among the fish that inhabit the Aby and Tendo lagoons are the tilapia (*Tilapia guineensis*), the jawbone (*Chrysichthys maurus*), the mademoiselle (*Trachinotus teraia*), the elops (*Elops lacerta*) and the barracuda (*Sphyraena)*. These species are varied and adapted to their environment, but they are also threatened by arsenic pollution. The Aby and Tendo lagoons are home to a great diversity of molluscs and fish, which are important for the ecosystem and for the local economy.

2.3. Sampling

Samples of animal species were taken in the Aby Lagoon, taking into account spatial, bathymetric and hydrological variations for the selection of sampling stations. 139 samples of lagoon organisms were collected. The influences of the rivers were taken into account to define two zones: Tendo for the Tanoe River and Aby North (AbyN) for the Bia River. The stations were then divided into four sub-zones based on spatial variability, bathymetry and hydrodynamic data. These sub-zones correspond to Aby, the channel, the bays of the Tendo Lagoon.

2.4. Sample Preparation

In the Aby and Tendo lagoons, gastropods and bivalves are indicators of water quality because they accumulate arsenic from their environment. Fish, on the other hand, are food sources for local populations, but their consumption poses risks to human health, depending on the species and levels of contamination. The fish and molluscs were purchased from the fishermen at the landing stage of the various lagoons. The large specimens were placed in a polyethylene bag, taking care not to pierce the fins or spurs, and then the bag was tightly closed after squeezing out the air. Small fish samples were grouped into lots of 5 animals. The fish and shellfish samples were then placed in a cooler and frozen with dry ice until they reached the laboratory.

2.5. Digestion of Fish and Molluscs

For the digestion of fish and molluscs, the weight weighed for mineralization is about 0.4 g fresh weight weighed with an accuracy of 0.005. The protocol has three main steps. The first step is to mineralize the samples with 10 ml of nitric acid (HNO_3) at a power of 60 W for 20 minutes. This step dissolves the organic compounds and releases the arsenic in the form of ions. Then, the second step is to cool the samples to room temperature for 5 minutes. This step stabilizes the temperature and reduces the risk of sample degradation. Finally, the third step is to re-mineralize the samples with 5 ml of hydrogen peroxide (H_2O_2) at a power of 80 W for 15 minutes. This step oxidizes the arsenic and makes it more easily detectable by induced plasma mass spectrometry (ICP-MS). After these three steps, the samples are ready to be analyzed by ICP-MS to determine the concentration of arsenic in the muscles of the lagoon organisms.

2.6. Arsenic Determination

The analyses were conducted on a Perkin Elmer® Elan 6000 ICP-MS. The methodology used to optimize the instrument and perform the analysis was described in EPA Method 6020, published in 1998 for arsenic. Measurements were made in triplicate, with limits of quantification between 0.01 and 0.1 µg/L. The limits may be higher in the presence of interfering substances or memory effects, as is the case with arsenic.

2.7. Expression of Results

The formula for calculating arsenic levels in the samples was expressed as follows:

Arsenic content (µg/g):

$$\frac{\text{Arsenic content}}{\text{Sample weight}} \times 1000 \tag{1}$$

Arsenic content in milligrams per kilogram (µg As/g);
Amount of arsenic measured during analysis (micrograms);
Fresh weight test sample mass (grams).

2.8. Processing of Statistics

Data were analyzed using SPSS statistical software, which provides statistical tools to perform a one-factor ANOVA. Specifically, the main objective was to compare arsenic concentrations between the different sampling sites, *i.e.*, to determine if there were significant differences in the amount of arsenic found in the sediments collected at the different sites. One-way ANOVA is a commonly used statistical method for comparing means between multiple groups. By testing the null hypothesis that these means are equal, the analysis determines whether the differences between sampling sites are statistically significant.

3. Results and Discussion

3.1. Arsenic Levels in Fish and Molluscs

Figure 2 shows the means and standard errors of arsenic concentrations in organisms in Aby Lagoon. The organisms were classified into three groups: fish, crustaceans and molluscs. The mean arsenic concentrations in the muscles of the 139 samples of lagoon organisms ranged from 0.01 to 1.26 µg As/g. The mean and median were 0.17 and 0.06 µg/g, respectively. Fish showed the highest levels of arsenic, followed by crustaceans. Molluscs had lower levels of arsenic. It was also found that standard errors were greater in fish and crustaceans than in

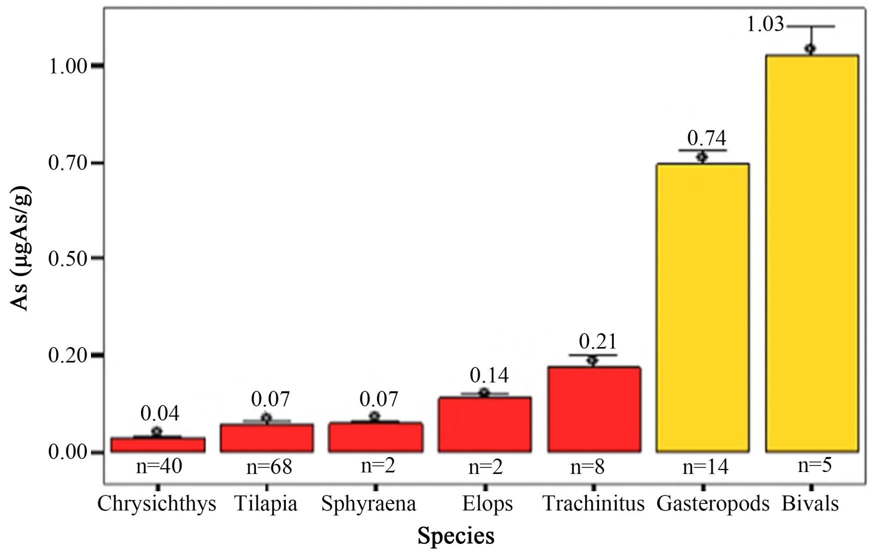

Figure 2. Means and standard errors of arsenic concentrations in organisms in Aby Lagoon.

molluscs. This may reflect greater variability in arsenic levels within fish and crustacean groups. These results were similar to those obtained by [21] with 5 species of freshwater fish. The authors also observed significant bioaccumulation with levels up to 8.2 µg As/g. In addition, the arsenic content in crustaceans that is higher than that obtained in molluscs in this study was consistent with Almela's work [22] carried out in a coastal environment. Their analyses showed a concentration ratio of about 1.5 between these two groups of species. Nevertheless, the differences in within-group concentrations appear to be more pronounced in this study, particularly for fish and crustaceans. One possible explanation lies in the fact that this study area encompasses a greater diversity of aquatic ecosystems, generating heterogeneity of exposures. In addition, the maximum value found in molluscs exceeds the thresholds reported by Ferrante [23] in a bay with similar environmental conditions. In addition, illegal gold panning is also responsible for the pollution of lagoons by arsenic, a chemical element naturally present in some soils. Arsenic is released when rocks are crushed or chemicals are used to dissolve gold. Arsenic contaminates surface and groundwater, as well as soils [24] [25].

3.2. Spatial Variations of Arsenic in Tilapia

Table 1 presents descriptive statistics of arsenic concentrations in T. *guineensis*, for two different lagoon sites, Aby North (AbyN) and Tendo, as well as the overall average. Mean arsenic concentrations differed between sites with 0.06 µgAs/g at Aby North, 0.08 mgAs/g at Tendo. These results would reflect significant geographic variability. The overall mean (0.07 µg As/g) provided an overview of the data. The variability of arsenic concentrations in *T. guineensis* between the two lagoon sites observed in our study was also found in three lagoons in Côte d'Ivoire [26]. The authors measured deviations of up to 0.14 µgAs/kg between

Table 1. Descriptive statistics of arsenic concentrations in *T. guineensis*.

Statistics (µg As/g)	Aby-North	Tendo	Total
Number of Samples	35	33	68
Average	0.06	0.08	0.07
95% CI of Mean	0.03 - 0.08	0.05 - 0.10	0.05 - 0.08
Average Truncated to 5%	0.05	0.07	0.06
Median	0.03	0.06	0.05
Standard Deviation	0.07	0.07	0.07
90th percentile	0.19	0.20	0.19
Min - Max.	0.01 - 0.24	0.03 - 0.31	0.01 - 0.31
Interval	0.23	0.28	0.30
Interquartile Ranges	0.06	0.03	0.05

the means per site. They attributed this to differences in the sources of arsenic inputs, potentially anthropogenic around certain water bodies. However, the concentrations found in this study are still lower than the arsenic levels of 0.12 to 0.15 µg As/g in Brazil in *T. guineensis* from estuarine environments [27] [28]. This significant difference may be due to their growing conditions in brackish water and muddy sediments that are more concentrated in inorganic arsenic. Thus, the results of this study showed that *T. guineensis* seems to be a fairly good bioindicator of arsenic impregnation levels. Its distribution in various lagoons would even make it an interesting sentinel organism for monitoring the contamination of these coastal ecosystems [29]. In addition, the 95% confidence intervals provided an indication of the accuracy of the means. Means truncated to 5% are also presented to mitigate the influence of outliers. The medians, which are lower than the averages, indicate a possible positive asymmetry of the distributions. The narrow interquartile ranges indicate a relative stability of concentrations in half of the central samples. Similar standard deviations between sites indicate close dispersion within each site, highlighting the consistency of measurements. These results show variability in arsenic levels in *T. guineensis* between the AbyN and Tendo lagoons, with possible implications for their ecological health. Finally, Student's test ($t = -3.870$; ddl = 43.24; $p < 0.01$) showed significantly higher concentrations at Tendo (0.08 µg As/g) compared to North Aby (0.06 µg As/g).

3.3. Seasonal Variations in Arsenic in Tilapia

Mean arsenic concentrations in tilapia fish varied across seasons and sites, as shown in **Figure 3**. In the North Aby Lagoon, arsenic concentrations measured in tilapia are higher during the rainy season (0.27 µg As/g) than during the dry season (0.08 µg As/g). This difference is statistically significant, as indicated by Student's t-test ($t = 4.61$, degrees of freedom = 33, $p < 0.01$). Seasonal variability in arsenic levels in tilapia was consistent with MK's work [30], which also observed

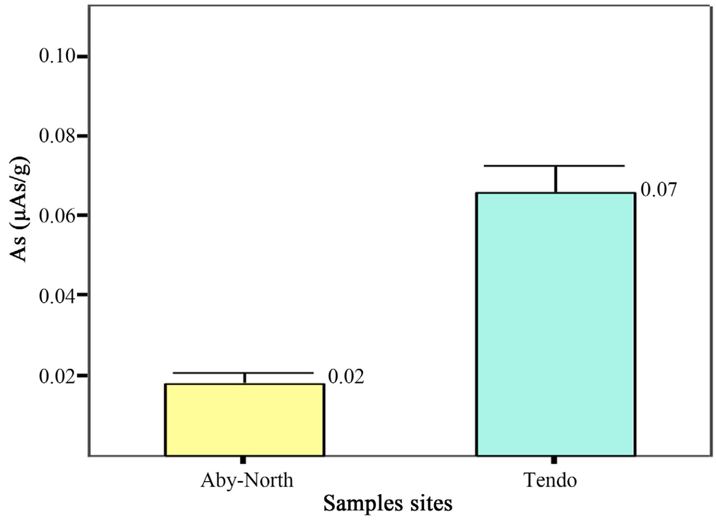

Figure 3. Mean and mean errors in arsenic concentrations in the muscles of *Tilapia guineensis* in the Aby North and Tendo Lagoons.

greater bioaccumulation during the wet season in aquaculture tilapia. The authors attributed this to a greater bioavailability of inorganic arsenic related to physicochemical disturbances of floodwaters. However, unlike Lee and his collaborators, we didn't find this marked seasonal effect at Tendo's second site. This could be explained by a more chronic contamination of the waters of this lagoon, masking the temporal dynamics, as described by Monteiro [31] in environments polluted by industrial activities. Thus, the seasonal pattern of arsenic impregnation in tilapia seems to depend on the environmental context, with a possible influence of diffuse sources that can be temporarily remobilized in certain aquatic ecosystems [32]. The inter-site comparison therefore reveals a heterogeneity of contamination situations that deserves to be studied in greater detail.

3.4. Seasonal Variations of Arsenic in *T. guineensis*

Figure 4 shows the mean arsenic concentrations in T. guineensis samples from the North Aby and Tendo lagoons, according to the rainy (SP) and dry (SS) seasons. These data revealed both seasonal and geographic differences in arsenic levels. In Aby-Nord Lagoon, mean concentrations of As were higher during the rainy season, at 0.07 µg As/g, than compared to the dry season when the average was 0.001 µg/g. At the Tendo site, the means measured were 0.09 µg As/g in the rainy season compared to 0.08 µg As/g in the dry season. This seasonal variability in arsenic concentrations in *T. guineensis* confirms the observations of Ju [18] in other filter-feeding bivalves (oysters, clams) exposed to temperate estuarine environments. The authors associated these differences with changes in the flow of adjacent streams, resulting in increased re-mobilization of sediments and trace metals during rainy months. However, this seasonal influence does not seem to be as marked in our tropical study area, with less pronounced differences in averages, for example, for the Tendo site. This result is consistent with Krikech's

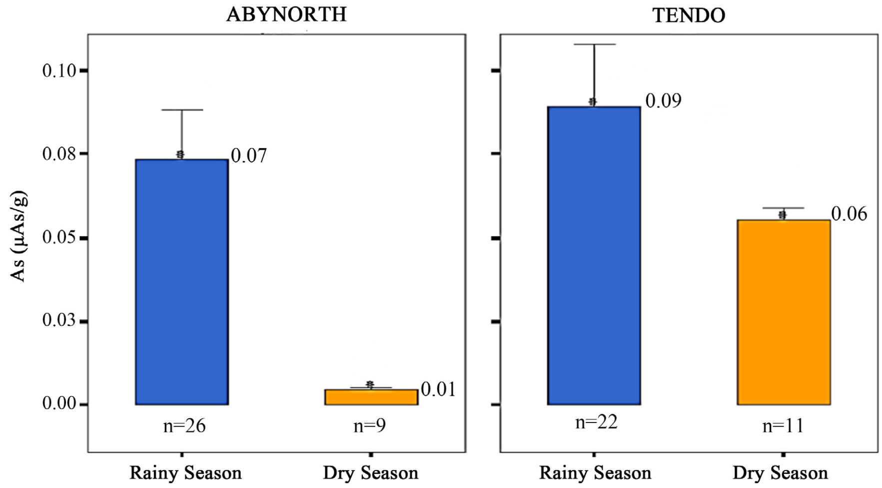

Figure 4. Averages and errors on the mean of Arsenic in *T. guineensis* in the AbyN and Tendo lagoons as a function of the seasons.

work [33] on tropical bivalves. This work showed that arsenic bioaccumulation fluctuated less throughout the year due to less rainfall variability. Thus, the seasonal effect on arsenic impregnation of *T. guineensis* appears to be conditioned by the climatic regime and seems to be attenuated in tropical latitudes. Understanding these dynamics is essential for the use of this organism as a local bioindicator of lagoon water contamination [23].

3.5. Seasonal Variations of Arsenic in *C. maurus*

Figure 5 shows the mean arsenic concentrations measured in *C. maurus* muscle from the North Aby and Tendo lagoons, as a function of the rainy (SP) and dry (SS) seasons. As can be seen from the graph, in the North Aby Lagoon, the mean As content was 0.02 µg As/g during the rainy season, while it was 0.01 µg/g during the dry season. Similarly, at the Tendo site, mean concentrations were 0.08 µg As/g and 0.06 µg As/g between the wet and dry seasons, respectively. These data indicate that overall arsenic levels are higher in *C. maurus* during the rainy seasons compared to the dry seasons, for the two lagoons studied. In addition, arsenic concentrations in Tendo Lagoon are higher than those in North Aby Lagoon for both seasons. The error bars on the graph indicated the variability of the data. Indeed, this greater bioaccumulation of arsenic in *C. maurus* during the rainy season is consistent with the work carried out by Fichez [34] on several species of tropical fish. The authors also observed increased impregnation during monsoon or flood months, which they would explain by mobilization of contaminated sediments and dissolution of sedimentary arsenic. However, unlike Fichez [34], there is no significant difference in arsenic concentrations between the data from this study of the two lagoon sites, despite their contrasting hydrological profiles and anthropogenic activities. This result converges with Feng's observations [35] which have shown relatively stable bioaccumulation in fish between different estuaries subject to historical contamination.

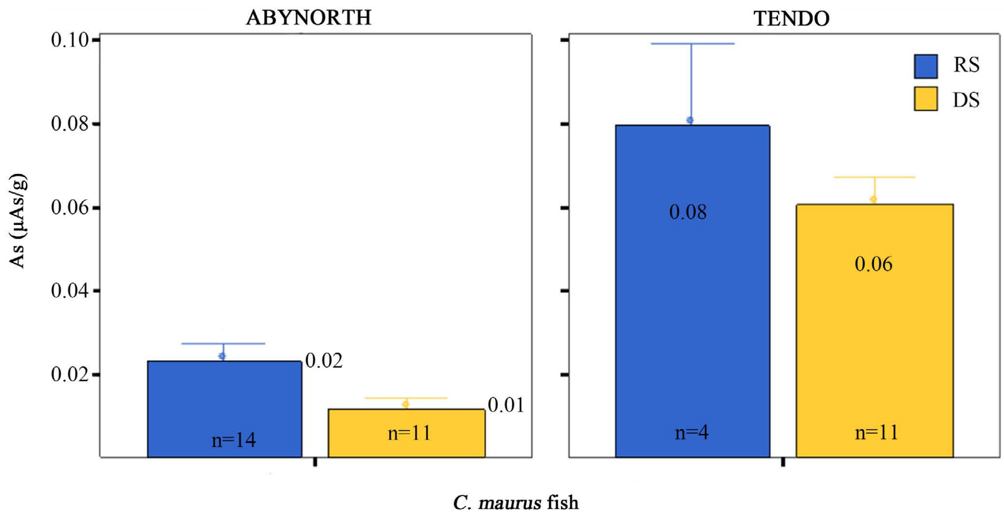

Figure 5. Averages and errors on the average of arsenic concentrations in the muscles of *C. maurus* as a function of the seasons and the AbyN and Tendo lagoons (*RS*: *Rainy Season*, *Dry Season*).

3.6. Spatial Variations of Arsenic in Jaws

Table 2 shows the concentrations of arsenic in the muscle tissue of *C. maurus* collected from the North Aby and Tendo lagoons. Based on this table, the averages of these concentrations revealed a significant disparity between the two sites, with concentrations of 0.02 µg As/g at Aby North and 0.07 µg As/g at Tendo, respectively. Indeed, this difference indicates significant variations in arsenic exposure between study sites. These results are in agreement with those of Togbe [36]. These authors also observed differences in the bioaccumulation of heavy metals in fish living in Ebrié lagoon. To enhance the reliability of the means, the 95% confidence intervals are presented, as well as the truncated mean to 5% which is introduced to mitigate the potential influence of outliers, following standard recommendations in environmental statistics. Despite the fact that the median was below the mean at both sites, this result showed positive data asymmetry and relatively small standard deviations, indicating consistency in measurements within each site. As a result, arsenic concentrations measured in *C. maurus* muscles showed a significant disparity between the North Aby and Tendo lagoons. The higher grade was found at Tendo. This could be explained by increased exposure to arsenic in this lagoon's part. In addition, this observation also suggests a possible bioaccumulation of this contaminant in this species at the Tendo site, as recently shown by Usese [16] as well as Adetutu [27] in Nigeria in estuarine fish. These authors reported a mean total arsenic concentration of 0.35 mg/kg in muscle, in a predominantly organic form (63.4%). Based on their ecological and health risk indices, the potential for arsenic to cause toxicity to sediment and fish is moderate to high [37].

3.7. Seasonal Variations of Arsenic in Jaws

Figure 6 has illustrated the means and standard errors of arsenic (As) concentrations in various species of fish and molluscs, including *Trachinotus*, Elops,

Table 2. Concentrations of As in the muscles of *C. maurus* in the North Aby and Tendo lagoons.

Statistics (µg As/g)	Aby-North	Tendo	Total
Number of Samples	25	15	40
Average	0.02	0.07	0.04
95% CI of Mean	0.01 - 0.02	0.05 - 0.08	0.03 - 0.05
Average Truncated to 5%	0.02	0.07	0.03
Median	0.01	0.06	0.03
Standard Deviation	0.01	0.03	0.03
90th Percentile	0.04	0.11	0.09
Min. – Max.	0.01 - 0.05	0.02 - 0.11	0.01 - 0.11
Interval	0.05	0.05	0.10

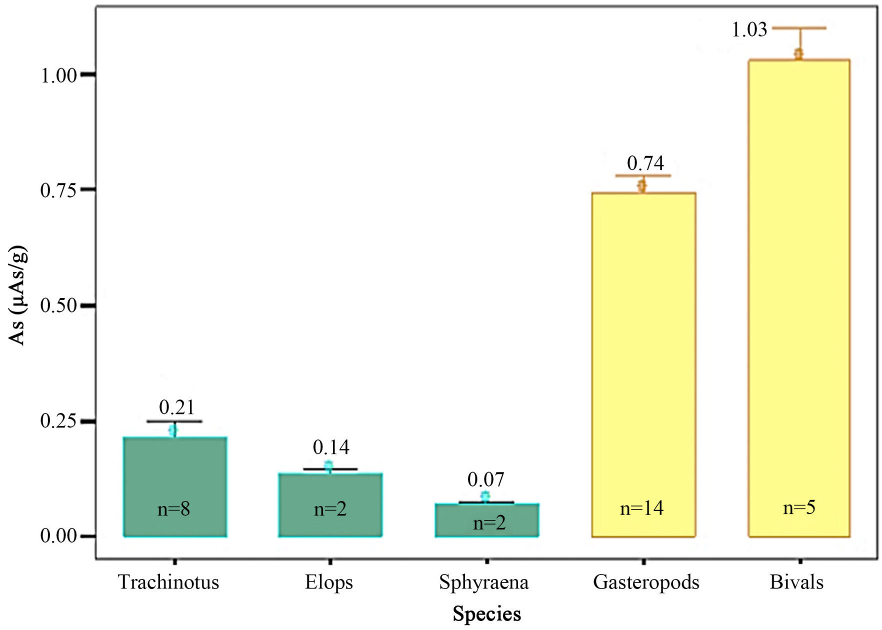

Figure 6. Means and standard errors of arsenic concentrations in fish and molluscs.

Barracuda, gastropods, and bivalves. Gastropods and bivalves had significantly higher arsenic concentrations, with averages of 0.74 µg As/g and 1.03 µg As/g, respectively. Conversely, *Trachinotus*, Elops and Barracuda had significantly lower concentrations. These values reflect the variability or uncertainty associated with the means of arsenic concentrations for each species, as shown by standard errors. In addition, the higher levels of arsenic found in molluscs compared to fish corroborated the results obtained by El-Sorogy [38] in several tropical species. The authors also observed a 1.5 to 2 times greater factor of impregnation in bivalves and gastropods studied in coastal bays. They explained this differential by the filtering properties of mussels and oysters, which are more concentrated in benthic and planktonic contaminants. However, the arsenic concentrations obtained in this study exceeded the maximum averages reported by this team for reference organisms. This finding suggested potentially worrying levels of pollution in this tropical lagoon area. Wang and Mulligan [39] have also shown that in these sedentary species there is a significant biomagnification of concentrations over the long term. As a result, the lagoon molluscs studied seemed to be good indicators for local environmental monitoring and the screening of risk situations for adjacent ecosystems and populations, thanks to their capacity to accumulate toxics.

3.8. Arsenic Levels in Other Fish

The analysis of **Table 3** presented descriptive statistics of arsenic concentrations in *Trachinotus teraia*, *Elops lacerta*, and *Sphyraena sp* fish. These results indicated significant evidence regarding the presence of arsenic in these species. Indeed, the mean values revealed disparities in arsenic concentrations between the different species studied, with an average of 0.21 µg As/g for *Trachinotus teraia*, 0.14 µg As/g for *Elops lacerta*, and 0.07 µg As/g for *Sphyraena sp*. These figures show that the Mademoiselle fish had the highest concentration of arsenic, followed by Elops and then *Sphyraena sp*. In addition, the low standard deviation observed for *Elops lacerta* and *Sphyraena sp* indicates a limited dispersion of individual concentrations around their respective means. To assess the accuracy of the estimated means, 95 % confidence intervals were calculated for each species. However, longer intervals found in *Trachinotus teraia* and *Elops lacerta* fish could reflect greater variability in arsenic levels within the samples analyzed for each group. The medians were 0.19 µg As/g for *Trachinotus teraia* 0.14 µg As/g for *Elops lacerta*, and 0.07 µg As/g for *Sphyraena sp*. The ranges from minimum to maximum values for these medians highlighted the intrinsic variability of arsenic concentrations within each species. It was noted that *Trachinotus teraia* showed a more significant amplitude, ranging from 0.13 to 0.46 µg As/g. This analysis revealed differences in arsenic levels between the fish examined, highlighting the predominance of *Trachinotus teraia* in terms of concentrations. This interspecies variability in arsenic impregnation levels in lagoon fishes was consistent with Krikech's observations [33] in tropical environments. Their work also revealed a more marked bioaccumulation in some benthic and demersal

Table 3. Descriptive statistics of arsenic concentrations in other fish.

Statistics (µg As/g)	Fish species		
	Trachinotus teraia	*Elops lacerta*	*Sphyraena sp*
Number of Samples	8	2	2
Average	0.21	0.14	0.07
Mean 95% CI	0.13 - 0.30	0.02 - 0.26	0.03 - 0.12
Median	0.19	0.14	0.07
Standard Deviation	0.10	0.01	0.00
Min - Max	0.13 - 0.46	0.13 - 0.15	0.07 - 0.08

species compared to pelagics, in relation to differential trophic and sediment exposures. However, unlike Krikech [33], the median concentrations reached in *Trachinotus teraia* in our study exceeded the values generally accepted for human consumption [40]. This highlights the possible health risks associated with this fish that is frequently caught locally, and would require further investigation of the causes of this singular biomagnification. Thus, the interspecific comparison appeared relevant to identify atypical impregnation situations and to highlight possible factors of vulnerability of certain species to contaminants according to their ecology [41] [42].

3.9. Levels of Arsenic in Molluscs

The analysis of **Table 4** presented descriptive statistics on the variability of arsenic concentrations in different species. It is observed that in the AbyN Lagoon gastropod group, the average arsenic concentrations in these molluscs is 0.75 µg As/g, with a median almost equivalent 0.76 µg As/g. This means that the standard deviation of 0.14 showed a relatively limited dispersion of data around this mean. In addition, arsenic concentrations in this group of gastropods show observable variability in the range of 0.56 to 1.00 µg As/g.

In contrast, in the Tendo Lagoon gastropod group, the mean arsenic concentrations in these molluscs were 0.70 µg As/g, while the median was slightly higher at 0.71 gAs/g. This implies that the standard deviation of 0.21 indicated a greater dispersion of data around the mean, highlighting greater variability in this group. On the other hand, arsenic concentrations had a wide range from 0.48 to 0.91 µg As/g. Finally, in the AbyN Lagoon Bivalves group, the mean arsenic concentrations in these molluscs were 1.03 µg As/g, with a near-equivalent median of 1.03 µg As/g.

It can be seen that the standard deviation of 0.17 indicated a moderate dispersion of data around the mean; This could show a relatively balanced variability within this group. Similarly, arsenic concentrations in AbyN bivalves showed observable variability in the range of 0.80 to 1.27 µg As/g. These results show a significant variation in arsenic concentrations between the groups of molluscs studied. They highlighted the need to regularly monitor arsenic levels in aquatic ecosystems [43]. This analysis may contribute to a better understanding of the bioaccumulation of arsenic in gastropods and bivalves and to a better assessment of the public health risk associated with the consumption of these contaminated shellfish [44]. Finally, these results highlighted the need for further research on the bioaccumulation of arsenic in gastropods and bivalves in order to better understand the factors underlying these variations and to assess the impact of bioaccumulation on human health and the ecosystem [45] [46].

Health Risks of Arsenic

Table 5 provided a comparison of arsenic levels in different edible species with the maximum acceptable limits for human consumption. According to FAO standards, the maximum acceptable levels of arsenic for human consumption

Table 4. Descriptive statistics of arsenic concentrations in molluscs as a function of lagoons.

Parameters	AbyN gastropods (µg As/g)	Gasteropods Tendo (µg As/g)	Bivalves AbyN (µg As/g)
Number of Samples	11	3	5
Average	0.75	0.70	1.03
Median	0.76	0.71	1.03
Standard Deviation	0.14	0.21	0.17
Min - Max	0.56 - 1.00	0.48 - 0.91	0.80 - 1.27

Table 5. Comparison of arsenic concentrations to FAO maximum acceptable limits.

Species	Average (µg As/g)	Min - Max (µg As/g)	Maximum Acceptable Limits (µg As/g)
Fishes	0.17	0.01 - 1.26	
Crustaceans	0.07	0.03 - 0.31	0.01
Molluscs	0.89	0.48 - 1.27	

are 10 µg/L for drinking water and 0.1 µg/g for food. These values are based on the toxic effects of arsenic on human health, including the risk of cancer and cardiovascular disease [47]. However, when these values are compared to the arsenic concentrations measured in fish and molluscs in the North Aby Lagoon, they were higher than the limit of 0.1 µg/g for food products. Average arsenic concentrations in the muscles of lagoon organisms range from 0.01 to 1.27 µg As/g, or 10 to 1270 times higher than the acceptable standard. These results suggest that the consumption of these fishery products poses a high risk to the health of local populations [48].

4. Conclusion

Lagoon ecosystems are aquatic environments of great ecological and socio-economic importance, but they are threatened by contamination by toxic metals, such as arsenic. This study analysed the variability of arsenic concentrations in gastropods and bivalves in the AbyN and Tendo lagoons, Côte d'Ivoire, taking into account spatial, seasonal and interspecific variations. Mean arsenic concentrations in the muscles of lagoon organisms ranged from 0.01 to 1.26 µg As/g, with a mean and median of 0.17 and 0.06 µgAs/g. In gastropods and bivalves, results showed significantly higher arsenic concentrations than those found in fish, showing greater exposure or an increased ability to bioaccumulate arsenic. Arsenic concentrations varied significantly between sampling sites, with higher values in the Tendo Lagoon than in the North Aby lagoon. Arsenic concentrations reflect spatial distribution in lagoons. Likewise, Arsenic concentrations also vary seasonally, with higher values during the rainy season than during the dry season, reflecting a hydroclimatic influence of river inputs and sediments. Arsenic concentrations are negatively correlated with the size and mass of fish, indicating a biological influence on the morphological and physiological characteristics of organisms. Finally, further studies are needed to assess the health risks associated with the consumption of these contaminated molluscs and to develop effective environmental protection strategies.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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