

Distribution, Ecological and Health Risks of Arsenic in Sediment from the Mixing Zone of the Comoé River and the Ebrie Lagoon, Côte d'Ivoire, West Africa

Mamadou Coulibaly¹, N'guessan Louis Berenger Kouassi^{2, *}, Koffi Pierre Dit Adama N'goran², Donourou Diabate³, Albert Trokourey³

¹Department of Geoscience, University of Peleforo Gon Coulibaly, Korhogo, Ivory Coast

²Department of Mathematics, Physics and Chemistry, University of Peleforo Gon Coulibaly, Korhogo, Ivory Coast

³Laboratory of Constitution and Reaction of Matter, University of Felix Houphouët Boigny, Abidjan, Ivory Coast

Email address:

kberenger2015@gmail.com (N. L. B. Kouassi)

*Corresponding author

To cite this article:

Mamadou Coulibaly, N'guessan Louis Berenger Kouassi, Koffi Pierre Dit Adama N'goran, Donourou Diabate, Albert Trokourey.

Distribution, Ecological and Health Risks of Arsenic in Sediment from the Mixing Zone of the Comoé River and the Ebrie Lagoon, Côte d'Ivoire, West Africa. *American Journal of Applied Chemistry*. Vol. 10, No. 4, 2022, pp. 89-96. doi: 10.11648/j.ajac.20221004.13

Received: April 2, 2022; Accepted: June 1, 2022; Published: July 12, 2022

Abstract: The accumulation of metalloids in the food chain can pose a great risk to human health and aquatic biota. The aim of this study was to evaluate the repartition, ecological and health risks of arsenic in surface sediments from a fluvial-lagoon environment, between the Comoé River and Ebrié Lagoon in Côte d'Ivoire. Arsenic contamination levels in sediments were evaluated using the pollution indices. The ecological risk was investigated by potential ecological risk index. The non-carcinogenic and carcinogenic risks indices were used to assess human health risks. The results showed that total concentrations of arsenic (2.92 ± 0.27 - 5.42 ± 4.6 mg/kg) were higher than the Upper Continental Crusts value (2 mg/kg). The mouth of the Comoé River was also found to be one of the most contaminated fluvial-lagoon environments. The sediments were moderately contaminated by arsenic. The non-carcinogenic risk indices values were ranged from $1.49 \times 10^{-2} \pm 1.36 \times 10^{-3}$ to $3.48 \times 10^{-1} \pm 2.95 \times 10^{-1}$, indicating low adverse effects both for children and adults. The total carcinogenic risk showed low potential carcinogenic effects both for children and adults. However, the values of non-carcinogenic risk and the total carcinogenic risk indices for children were found to be higher than those for adults, suggesting that children are most exposed to deleterious effects than adults. The study also demonstrated the low mobility of arsenic. Further studies including the determination of arsenic total concentrations in fish, the assessment of the ability of fish to accumulate arsenic from the sediments, and the mobility assessment using in situ diffusive gradients in thin films (DGT) method will be investigated to better understand the fate of arsenic.

Keywords: Arsenic, Mouth of Comoé River, Sediment, Pollution Indices, Risks Assessment, Mobility

1. Introduction

Environmental contamination by metalloids is a worldwide problem due to their persistence and toxicity [1, 2]. Chronic exposure to arsenic can lead to diseases such as kidney and lungs cancers, and cause dysfunction of the reproductive organs [3]. Therefore, monitoring arsenic contamination levels in the environment is necessary.

In the aquatic system, sediments represent a sink for

chemical pollutants [4, 5]. Thus, they are considered as an appropriate aquatic pollution by arsenic indicator. Nonetheless, pollutants adsorbed into the sediments can be released into the water column under the variation of physicochemical conditions. This phenomenon can increase the concentrations of pollutants in the water column [5, 6]. Therefore, the assessment of pollutant mobility is necessary.

In Cote d'Ivoire, there is an important development of agricultural and mining activities in the Comoé River catchment. These activities were found to be potential sources of arsenic in the environment [8]. In addition, the Ebrié Lagoon which is the largest lagoon in west Africa receives industrial and domestic liquid effluents from the city of Abidjan which is the biggest town of Côte d'Ivoire [5]. These wastewaters may discharge arsenic into the Ebrié lagoon. In Cote d'Ivoire, studies on the contamination of the sediment by trace metals and metalloids were focused on the Ebrié Lagoon [5, 7] or on the rivers [9]. These studies showed that sediments from Ebrié Lagoon and Comoé Rivers were contaminated by Cd, Zn, Pb, Cu, and As. Therefore, studies on arsenic fate in sediments from the mouth of the Comoé river are limited. The mouth of Comoé River is a part of a fluvial-lagoon environment, between the Comoé River and Ebrié Lagoon. It represents the mixing zone of the Ebrié lagoon and the Comoé River.

The objectives of the present study were to: (i) determine the total concentrations of arsenic in surface sediments, (ii) assess the contamination level through the pollution indices, (iii) assess the ecological and human health risks, and (iv) assess the mobility of arsenic using the single extraction procedure. The relevance of this study is to establish for the first time data on arsenic concentrations in sediments from

the mouth of the Comoé River.

2. Material and Methods

2.1. Study Area and Samplings

The study area covers the Ebrié Lagoon, the Comoé River and the mouth of the Comoé Rivers (figure 1). The mouth of the Comoé River is located at the eastern end of the Ebrié Lagoon [10]. It is part of a fluvial-lagoon environment, between the Comoé River and Ebrié Lagoon. The mouth of the Comoé River is the outlet of the Comoé watershed with an average annual flow of 106 m³/s. Station E2 is located in a mixing zone of the Comoé River and the Ebrié Lagoon waters. Station E1 is located in the Ebrié Lagoon. It receives the industrial and domestic liquid effluents from the city of Abidjan, agricultural wastewater containing insecticides, and fungicides. Station E3 is located in the Comoé River.

The surface sediments were sampled in stations E1, E2, and E3 in October 2019 and November 2019. Sediments were collected according to USEPA (2001) using a Van Veen stainless steel grab. The samples were sealed in plastic bags, transported to the laboratory at 4°C, oven-dried at 60°C, homogenized, and stored at 4°C until analysis [7].

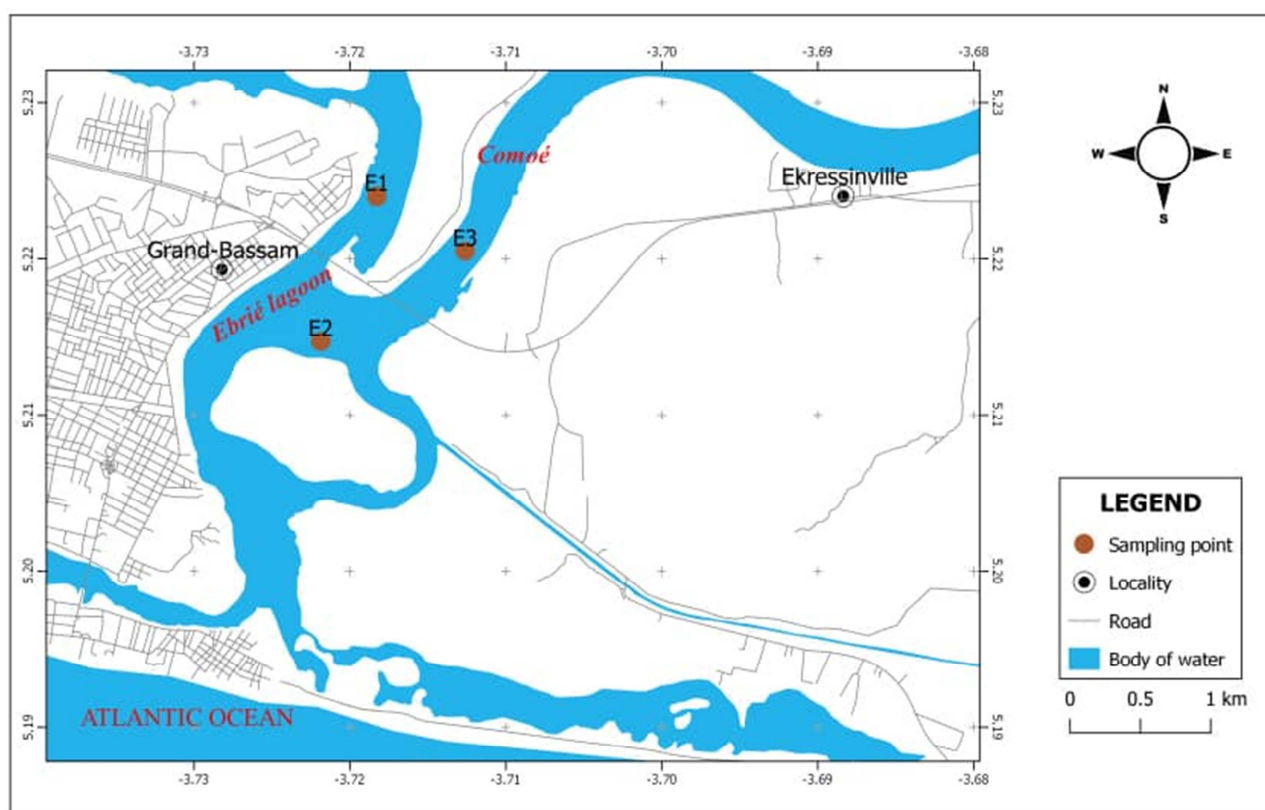


Figure 1. Sampling stations.

2.2. Chemical Analyses

2.2.1. Total Concentration of Arsenic in Sediments

Approximately 0.2 g of the homogenized sediment were

digested in Teflon containers with a mixture of 1 mL of aqua regia (HNO₃: HCl; 1:3, v/v) and 3 mL of HF on a hot plate, and then left for 15 min at room temperature. Next, 20 mL of H₃BO₃ (140 g/L) were added to each vessel to mask free fluoride ions in

the solution and re-dissolve fluoride precipitates. The final digestates were diluted to 50 mL with 2% ultrapure HNO₃. The liquid aliquots were filtered through 0.45 mm pore size membranes prior to analysis using an air-acetylene flame atomic absorption spectrometer (AAS, SpectrAA100: Varian, Tokyo, Japan) air-acetylene flame analyses [5].

2.2.2. Pollution Indices Assessment

The contamination factor (CF) and the enrichment factor (EF) were calculated to assess the level of arsenic contamination. The contamination factor was calculated as follow [11]:

$$CF = \frac{C_{\text{arsenic (sediment)}}}{C_{\text{arsenic (background)}}} \quad (1)$$

$C_{\text{arsenic (sediment)}}$ is the concentration of arsenic in the sediment sample and $C_{\text{arsenic (background)}}$ is arsenic background value given by Wedepohl [12].

Four class of CF have been distinguished by Hakanson [11]: class 1 (low contaminated) $CF < 1$; class 2 (moderately contaminated) $1 < CF < 3$; class 3 (considerably contaminated) $3 < CF < 6$; and, class 4 (very high contaminated) $CF > 6$.

The following equation was used to calculate the enrichment factor (EF):

$$EF = \frac{(C_{\text{sed}}/Fe_{\text{sed}})}{(C_{\text{back}}/Fe_{\text{back}})} \quad (2)$$

where C_{sed} and Fe_{sed} are total concentrations of arsenic and iron in the study sediment, respectively. C_{back} and Fe_{back} are background concentrations of arsenic and iron in the upper continental crust. According to Hakanson [11], when $EF > 50$, the sediment is extremely severe contaminated. EF values between $25 < EF < 50$ is associated to strongly to extremely contamination. $10 < EF < 25$ indicates moderately to strongly contamination. Sediment is modarely contaminated when $3 < EF < 5$. $1 < EF < 3$ indicates minor contamination, and $EF < 1$ is associated to no contamination.

2.2.3. Ecological Risk Assessment

The relation 3 was used to calculate the potential ecological risk (RI) (Hankason, 1980).

$$RI = T_i^r \left(\frac{C_{\text{sed}}}{C_{\text{back}}} \right) \quad (3)$$

where C_{sed} is total concentration of arsenic in the sediment. C_{back} is background concentrations of arsenic in the upper continental crust. T_i^r is the biological toxicity factor of arsenic ($T_i^r = 10$). RI values below 150 indicate low ecological risk. When $150 \leq RI < 300$ moderate ecological risks occur. $300 \leq RI < 600$ indicate considerable ecological risk, and $RI \geq 600$ show very high [11].

2.2.4. Human Health Risks Assessment

The human health risks were assessed using non-carcinogenic and carcinogenic risks indices. The total non-carcinogenic risk was assessed using the hazard index (HI). The hazard index is calculated as follows [13]:

$$HI = HQ_{\text{ing}} + HQ_{\text{der}} \quad (4)$$

Where HQ_{ing} and HQ_{der} are the hazard quotient through ingestion and dermal contact, respectively. $HI < 1$ indicates low adverse effects. $HI \geq 1$ indicates that adverse effects can occur on human health [13]. The the hazard quotients are expressed as follows:

$$HQ_{\text{ing}} = \frac{CDI_{\text{ing}}}{RfD_{\text{ing}}} \quad (5)$$

$$HQ_{\text{derm}} = \frac{CDI_{\text{der}}}{RfD_{\text{der}}} \quad (6)$$

In the equations 5 and 6, CDI_{ing} ($\mu\text{g/Kg.day}$) and CDI_{der} ($\mu\text{g/Kg.day}$) represent the chronic daily intake through ingestion and the chronic daily intake through dermal contact, respectively.

CDI_{ing} and CDI_{der} are calculated by the following equations [13 – 15].

$$CDI_{\text{ing}} = \frac{C_{\text{sed}} \times \text{IngR} \times CF \times EF \times ED}{BW \times AT_{\text{nc}}} \quad (7)$$

$$CDI_{\text{derm}} = \frac{C_{\text{sed}} \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT_{\text{nc}}} \quad (8)$$

The table 1 indicates the other exposure parameters.

Table 1. Exposure assessment parameters.

| Parameters | Meaning | Unit | Value | | Reference |
|--------------------|---|----------------------|--------------------|--------------------|------------|
| C_{sed} | Arsenic total concentration in sediment | mg/kg | Adults | Children | This study |
| IngR | Ingestion rate | mg/day | 100 | 1000 | [16] |
| ED | Exposure duration | years | 24 | 6 | [16] |
| EF | Exposure frequency | days/year | 350 | 104 | [16] |
| BW | Average body weight | kg | 70 | 15 | [16] |
| SA | Exposure skin area | cm ² | 5700 | 2800 | [16] |
| AF | Skin adherence factor | mg/cm ² h | 0.07 | 0.2 | [19] |
| AT_{nc} | Average time for non-carcinogenic | day | 24×365 | 6×365 | [20] |
| AT_{ca} | Average time for non-carcinogenic | day | $LE \times 365$ | $LE \times 365$ | [20] |
| CF | Conversion factor | kg mg ⁻¹ | 10^{-6} | 10^{-6} | [15] |
| RfD_{ing} | Reference dose of arsenic through ingestion | mg/Kg/day | 3×10^{-4} | 3×10^{-4} | [21] |
| SF_{ing} | Slop factor of arsenic through ingestion | mg/Kg/day | 1,5 | 1,5 | [15] |
| ABS_g | Gastrointestinal absorption factor | | 1 | | [15] |

According to Word bank [22] life expectancy in Ivory Coast is 58 years ($LE = 58$ years).

The total carcinogenic risk (TCR) index is calculated by the following equation [15 – 17]:

$$\text{TCR} = \text{CR}_{\text{ing}} + \text{CR}_{\text{der}} \quad (9)$$

Where CR_{ing} and CR_{der} are carcinogenic risk through ingestion and carcinogenic risk through dermal contact, respectively. TCR value $\leq 10^{-6}$ indicates no significant risk. When CR value $\geq 10^{-4}$, humans can develop a cancer. The range of acceptable carcinogenic risk is 10^{-6} to 10^{-4} [18].

The equations 10 and 11 were used to calculate CR_{ing} and CR_{der} .

$$\text{CR}_{\text{ing}} = \frac{C_{\text{sol}} \times \text{IR}_{\text{ing}} \times \text{EF} \times \text{ED} \times \text{CF} \times \text{SF}_{\text{ing}}}{\text{BW} \times \text{AT}_{\text{ca}}} \quad (10)$$

$$\text{CR}_{\text{derm}} = \frac{C_{\text{sol}} \times \text{SA} \times \text{AF} \times \text{EF} \times \text{ED} \times \text{CF} \times \text{ABS}_{\text{der}} \times \text{SF}_{\text{der}}}{\text{BW} \times \text{AT}_{\text{ca}}} \quad (11)$$

In equations 10 and 11, SF_{ing} and SF_{der} are slope factors.

$$\text{SF}_{\text{der}} = \frac{\text{SF}_{\text{ing}}}{\text{ABS}_g} \quad (12)$$

2.2.5. Single Extraction

The single extraction procedure was used to assess arsenic mobility in sediments. Three reagents such as H_2O , HCl , and EDTA were used. A mass of 3 g of sediment was mixed with 30 mL of H_2O or HCl 0.2 mol. L^{-1} [22] or 0.05 mol. L^{-1} EDTA [22] at room temperature and shaken for 1h. After shaking, the mixture was filtered at 0.45 mm pore size membranes analyses and the filtrate was analyzed using an air-acetylene flame atomic absorption spectrometer (AAS, SpectrAA100: Varian, Tokyo, Japan).

3. Results and Discussion

3.1. Assessment of Arsenic Contamination Levels in the Sediments

The average total arsenic concentrations are shown in figure 2. The average of As were 2.92 ± 0.27 mg/kg, 5.42 ± 4.6 mg/kg and 4.43 ± 2.08 mg/kg at station E1, E2 and E3, respectively. These values are relatively higher than the arsenic average value (2 mg/kg) in the Upper Continental Crusts [12]. The highest values were obtained in station E2.

The figure 3 showed the spatial variation of the contamination factor (CF) and the enrichment factor (EF). The average values of contamination factors were 1.46 ± 0.13 , 2.71 ± 2.30 , and 2.22 ± 1.04 at stations E1, E2, and E3, respectively. Arsenic enrichment factor mean values were found to be range from 6.23 ± 0.15 and 11.14 ± 10.02 . These values indicated that sediments were moderately contaminated by As. Among pollution indices, the enrichment factor (EF) is used to examine the possible sources of contamination. According to Zhang and Liu [24], the contamination sources are anthropogenic origin when EF values exceed 1.5. The EF values of arsenic were 4 to 10 times higher than 1.5, indicating an arsenic anthropogenic origin in the study area. The high total As concentration

obtained may infer anthropogenic activities such as agriculture practices, domestic waste, and mining activities. For example, several studies have reported that the use of fertilizers in agricultural practices is a potential source of arsenic in the environmental [8, 9]. Station E3 on the Comoé River is located in an agricultural area with the presence of industrial plantations of cocoa, coffee, rubber, and oil palm. In addition, during the last decade, there is an important increase in mining activities in the Comoé River catchment. It has been shown that mining activities can generate significant amounts of arsenic in the environment [8]. Therefore, elevated total arsenic concentrations obtained may be due to mining activities in the Comoé River catchment. The industrial and domestic liquid effluents from the city of Abidjan, agricultural wastewater containing insecticides, and fungicides discharged into the Ebrié Lagoon could explain the high concentration of arsenic obtained at station E1 [5]. Station E2 is located in a mixing zone of the Comoé River and the Ebrié Lagoon waters. The inputs from the Comoé River and the Ebrié Lagoon could explain in part the higher concentration of arsenic obtained in the sediments of station E2. In addition, this mixing zone also receives domestic and industrial effluents and municipal runoff from the city of Grand-Bassam which is a highly urbanized area. Furthermore, under the freshwater discharge (Comoé River), coagulation or precipitation processes of metal complexes can take place [25], resulting in an increased concentration of arsenic in sediments. Arsenic total concentrations in this study were compared to those from other studies. The data obtained by Even *et al.* [26] in the river Hokusetsu (11.2 - 55.2 mg/kg), Japon, by Devore *et al.* [27] in the river Cheyenne (7.40 - 2040 mg/kg), USA, and by Wang *et al.* [28] in the river Wuhan (8.16 - 14.94 mg/kg), China were higher than those from this study. However, our data were higher than those from the Lagos Lagoon (2.44 mg/kg) in Nigeria [29], the Brahmaputra River (1.36 mg/kg) in India [30], and the Piratininga Lagoon (2.1 mg/kg) in Brazil [31]. Therefore, the mouth of the Comoé River was also found to be one of the most contaminated fluvial-lagoon environment.

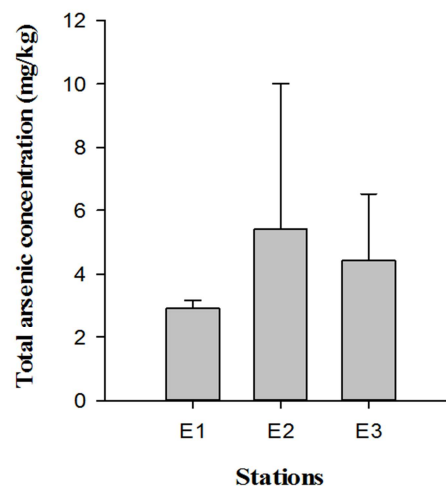


Figure 2. Total arsenic concentrations in sediments.

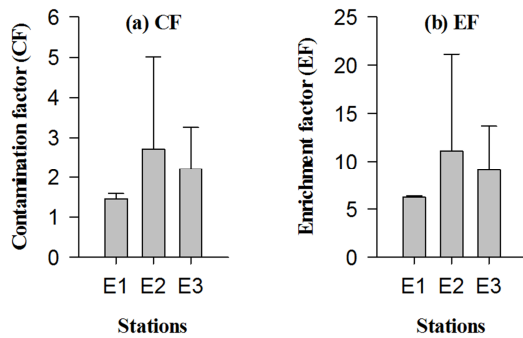


Figure 3. Contamination factor (a) and enrichment factor (b).

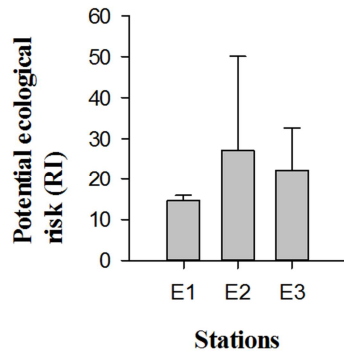


Figure 4. Potential ecological risk index (RI).

3.2. Potential Ecological Risk Assessment

The spatial variation of the potential ecological risk index for arsenic is shown in figure 4. The results of RI were lower than 150 suggesting low risks for organisms. The average values of RI varied between 14.61 ± 1.33 and 27.10 ± 22.98 . These values were lower than 150 suggesting low risks for organisms. The approach of sediment quality guidelines (SQGs) developed by MacDonald *et al.* [32] was also applied in this study to evaluate the sediment toxicity risk. According to MacDonal *et al.* [32], when the total concentration of As is below the Threshold effect concentration, TEC (10 mg/kg), no adverse effect is observed. While, the possible deleterious effect may occur when the concentration of As is above the probable effect concentration,

PEC (33 mg/kg). Total average concentrations of As (between 2.92 ± 0.27 and 5.42 ± 4.6 mg/kg) obtained in our study area were lower than 10 mg/kg. Therefore, sediments may not pose adverse effects to organisms.

3.3. Human Health Risk Assessment

The non-carcinogenic risk related to As in sediments through non-dietary ingestion and dermal contact was assessed. The results are given in table 2. The results showed that in all sampling stations, the HI values for adults varied between $1.49 \times 10^{-2} \pm 1.36 \times 10^{-3}$ and $2.77 \times 10^{-2} \pm 2.35 \times 10^{-2}$. Those for children ranging from $1.88 \times 10^{-1} \pm 1.71 \times 10^{-2}$ to $3.48 \times 10^{-1} \pm 2.95 \times 10^{-1}$. These values were lower than 1 indicating low adverse effects. The HI for children was found to be higher than HI value for adults. Therefore, children are most exposed to deleterious effects than adults. In addition, the highest values of HI were obtained in the sediments collected in station E2 which is the mixing zone. Therefore, sediments from the mixing zone may cause the most potential adverse effects. When we compare the HQing and HQder values both for adults and children, we can conclude that arsenic can cause potential adverse effects through ingestion due to HQing higher than HQder.

Arsenic is recognized as carcinogenic. The values of CRing, CRder and total risk (TCR) are reported in table 2. The TCR values were ranged between $2.78 \times 10^{-6} \pm 2.53 \times 10^{-7}$ and $5.16 \times 10^{-6} \pm 4.37 \times 10^{-6}$ for adults. For children, TCR varied between $6.28 \times 10^{-6} \pm 5.71 \times 10^{-7}$ and $1.11 \times 10^{-5} \pm 9.88 \times 10^{-6}$. The TCR values were in the acceptable carcinogenic risk value (10^{-6} - 10^{-4}). Therefore, adults and children cannot develop cancer. In this study, CRing averages were higher than those of CRder. Therefore, the ingestion may be the pathway of As exposure from sediments. In addition, the TCR values both for adults and children in sediments from the mixing zone (station E2) were found to be the highest. Therefore, the mixing zone sediments may cause the most carcinogenic effect.

Table 2. Values of non-carcinogenic risk and carcinogenic risk indices.

| | | | E1 | E2 | E3 |
|----------|-----------------------|-------|---|---|---|
| Adult | Non-carcinogenic risk | HQing | $1.33 \times 10^{-2} \pm 1.21 \times 10^{-3}$ | $2.47 \times 10^{-2} \pm 2.10 \times 10^{-2}$ | $2.02 \times 10^{-2} \pm 9.48 \times 10^{-3}$ |
| | | HQder | $1.59 \times 10^{-3} \pm 1.45 \times 10^{-4}$ | $2.96 \times 10^{-3} \pm 2.50 \times 10^{-3}$ | $2.42 \times 10^{-3} \pm 1.13 \times 10^{-3}$ |
| | | HI | $1.49 \times 10^{-2} \pm 1.36 \times 10^{-3}$ | $2.77 \times 10^{-2} \pm 2.35 \times 10^{-3}$ | $2.22 \times 10^{-2} \pm 1.06 \times 10^{-2}$ |
| | Carcinogenic risk | CRing | $2.48 \times 10^{-6} \pm 2.26 \times 10^{-7}$ | $4.61 \times 10^{-6} \pm 3.90 \times 10^{-6}$ | $3.77 \times 10^{-6} \pm 1.76 \times 10^{-6}$ |
| | | CRder | $2.97 \times 10^{-7} \pm 2.70 \times 10^{-8}$ | $5.51 \times 10^{-7} \pm 4.67 \times 10^{-7}$ | $4.51 \times 10^{-7} \pm 2.11 \times 10^{-7}$ |
| | | TCR | $2.78 \times 10^{-6} \pm 2.53 \times 10^{-7}$ | $5.16 \times 10^{-6} \pm 4.37 \times 10^{-6}$ | $4.22 \times 10^{-6} \pm 1.97 \times 10^{-6}$ |
| Children | Non-carcinogenic risk | HQing | $1.84 \times 10^{-1} \pm 1.68 \times 10^{-2}$ | $3.43 \times 10^{-1} \pm 2.91 \times 10^{-1}$ | $2.8 \times 10^{-1} \pm 1.31 \times 10^{-1}$ |
| | | HQder | $3.10 \times 10^{-3} \pm 2.83 \times 10^{-4}$ | $5.76 \times 10^{-3} \pm 4.88 \times 10^{-3}$ | $4.71 \times 10^{-3} \pm 2.2 \times 10^{-3}$ |
| | | HI | $1.88 \times 10^{-1} \pm 1.71 \times 10^{-2}$ | $3.48 \times 10^{-1} \pm 2.95 \times 10^{-1}$ | $2.85 \times 10^{-1} \pm 1.33 \times 10^{-1}$ |
| | Carcinogenic risk | CRing | $5.79 \times 10^{-6} \pm 5.27 \times 10^{-7}$ | $1.07 \times 10^{-5} \pm 9.11 \times 10^{-6}$ | $8.79 \times 10^{-6} \pm 4.11 \times 10^{-6}$ |
| | | CRder | $4.86 \times 10^{-7} \pm 4.43 \times 10^{-8}$ | $9.03 \times 10^{-7} \pm 7.65 \times 10^{-7}$ | $7.39 \times 10^{-7} \pm 3.45 \times 10^{-7}$ |
| | | TCR | $6.28 \times 10^{-6} \pm 5.71 \times 10^{-7}$ | $1.16 \times 10^{-5} \pm 9.88 \times 10^{-6}$ | $9.53 \times 10^{-6} \pm 4.46 \times 10^{-6}$ |

3.4. Arsenic Mobility Assessment

It has been reported that trace metals or metalloids' total

concentrations in sediment cannot provide information on the potential mobility [7]. Therefore, Arsenic mobility was assessed in this study using the simple extraction method. The results were shown in figure 5. The percentages of

arsenic extracted by HCl were $4.30 \pm 0.63\%$, $3 \pm 2.55\%$, and $2.39 \pm 1.10\%$ of total concentration in the sediments of stations E1, E2, and E3, respectively. With EDTA, $3.77 \pm 0.15\%$ (station E1), $5.54 \pm 0.61\%$ (station E2) et $3 \pm 1.50\%$ (station E3) of total arsenic were extracted. Deionized water (H_2O) has extracted $3.41 \pm 0.26\%$, $2.73 \pm 2.22\%$, and $2.39 \pm 1.06\%$ of total arsenic in the sediments of stations E1, E2, and E3, respectively. The percentages of arsenic extracted by all extracting agents were very low (below 6%). Therefore, arsenic will be most associated with the crystalline structure of the sediments, indicating its low mobility [7]. Nevertheless, the percentage of arsenic extracted with EDTA was found to be the highest in station E2. Thus, arsenic may be most bioavailable in sediments from this station. In addition, EDTA is recognized as a chelating agent that effectively extracts cationic metals [7, 33]. Arsenic exists as anions (arsenate or arsenite). Therefore, it cannot be effectively extracted with EDTA. That may explain the low percentage extracted by EDTA.

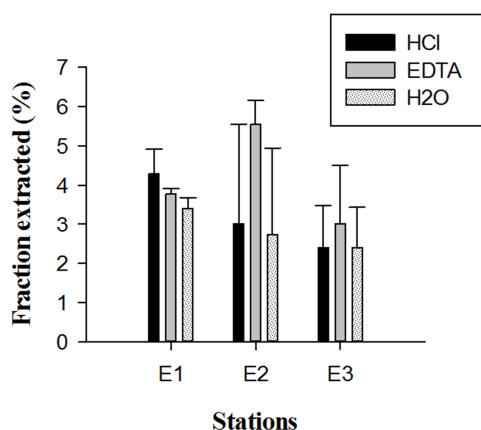


Figure 5. Percentage of arsenic extracted by HCl, H_2O and EDTA.

4. Conclusion

The distribution, ecological, and health risks of arsenic in sediment from the mouth of the Comoé River were investigated. The results showed the arsenic average total concentrations (2.92 ± 0.27 - 5.42 ± 4.6 mg/kg) were higher than the arsenic average value (2 mg/kg) in the Upper Continental Crusts. The sediments from the study area were moderately contaminated by arsenic. Arsenic may derive from an anthropogenic origin. The potential ecological risk indices RI indicated low risks for organisms. The non-carcinogenic risk indices HI showed low adverse effects both for children and adults. The results of total carcinogenic risk TCR indicated that TCR values for adults ($2.78 \times 10^{-6} \pm 2.53 \times 10^{-7}$ and $5.16 \times 10^{-6} \pm 4.37 \times 10^{-6}$) and for children ($6.28 \times 10^{-6} \pm 5.71 \times 10^{-7}$ and $1.11 \times 10^{-5} \pm 9.88 \times 10^{-6}$) were within the acceptable carcinogenic risk value (10^{-6} - 10^{-4}), indicating low potential carcinogenic effects. The study also showed that the arsenic percentages extracted by all extractant agents were very low (below 6%), showing low mobility. This study recommends the decisions making for better management of the Comoé River mouth water resources and also reducing upstream

inputs from human activities to mitigate downstream river water pollution. Further studies including the determination of arsenic total concentrations in fish, the assessment of the ability of fish to accumulate arsenic from the sediments, and the mobility assessment using in situ diffusive gradients in thin films (DGT) method will be investigated to better understand the fate of arsenic.

Competing Interest

The authors declare no competing interests.

Authors' Contributions

Mamadou Coulibaly: Conceptualization, data curation, formal analysis, investigation, methodology, validation, writing-original draft, writing-review draft, and editing.

N'guessan Louis Berenger Kouassi: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, writing-original draft, writing-review draft, and editing.

Koffi Pierre Dit Adama N'goran: Conceptualization, data curation, formal analysis, investigation, methodology, validation, writing-original draft, writing-review draft, and editing.

Donourou Diabaté: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, writing-original draft, writing-review draft, and editing.

Albert Trokourey: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, writing-original draft, writing-review draft, and editing.

Acknowledgements

We are thankful to the President of the Peleforo Gon Coulibaly University, Korhogo for his encouragement and support. Unconditional help (to determine total metal concentrations in the sediments by AAS) from the Director of Laboratoire National d'Appui au Développement Agricole (LANADA), Abidjan, is gratefully acknowledged.

References

- [1] Qiu Y. W. (2015). Bioaccumulation of heavy metals both in wild and mariculture food chains in Daya Bay, South China. *Estuarine, Coastal and Shelf Science* 163: 7-14. <https://doi.org/10.1016/j.ecss.2015.05.036>
- [2] El-Magd S. A. A., Taha H. H., Pienaar P., Breil R. A., Amer P. N. (2021). Assessing heavy metal pollution hazard in sediments of Lake Mariout, Egypt. *J. Afr. Earth Sci* 176: 104116. <https://doi.org/10.1016/j.jafrearsci.2021.104116>
- [3] Martin R., Dowling K., Pearce D., Sillitoe J., Florentine S. (2014). Health effect associated with inhalation of air bone arsenic arising from mining operations. *Geosciences* 4: 128 - 175. <https://doi.org/10.3390/geosciences4030128>

- [4] Ali M. M., Ali M. L., Islam M. S., Rahman M. Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environmental Nanotechnology, Monitoring & Management* 5: 27-35. <https://doi.org/10.1016/j.enmm.2016.01.002>
- [5] Kouassi N. L. B., Yao K. M., Trokourey A., Soro M. B. (2015). Distribution, Sources, and Possible Adverse Biological Effects of Trace Metals in Surface Sediments of a Tropical Estuary. *Environmental Forensics* 16: 96-108. <https://doi.org/10.1080/15275922.2014.991433>
- [6] Han D., Cheng J., Hu X. (2017). Spatial distribution, risk assessment and source identification of heavy metals in sediments of the Yangtze River Estuary, China. *Marine pollution bulletin* 115: 141-148. <https://doi.org/10.1016/j.marpolbul.2016.11.062>
- [7] Kouassi N. L. B., Yao K. M., Sangare N., Trokourey A., Soro M. B. (2019). The mobility of the trace metals copper, zinc, lead, cobalt, and nickel in tropical estuarine sediments, Ebrie Lagoon, Côte d'Ivoire. *Journal of Soils and Sediments* 19: 929-944. <https://doi.org/10.1007/s11368-018-2062-8>
- [8] Kinimo K. C., Yao K. M., Marcotte S., Kouassi N. L. B., Trokourey A. (2018). Distribution trends and ecological risks of arsenic and trace metals in wetland sediments around gold mining activities in central-southern and southeastern Côte d'Ivoire. *Journal of Geochemical Exploration* 190: 265-280. <https://doi.org/10.1016/j.gexplo.2018.03.013>
- [9] Ouattara A. A., Yao K. M., Soro M. P., Diaco T., Trokourey A. (2018). Arsenic and Trace Metals in Three West African rivers: Concentrations, Partitioning, and Distribution in Particle-Size Fractions. *Archives of Environmental Contamination and Toxicology* 5: 449-463. doi: <https://doi.org/10.1007/s00244-018-0543-9>.
- [10] Kone Y. J. M., Abril G., Delille B., Borges A. V. (2010). Seasonal variability of methane in the rivers and lagoons of Ivory Coast (West Africa). *Biogeochemistry* 100: 21-37. <https://doi.org/10.1007/s10533-009-9402-0>
- [11] Hakanson L. (1980). Ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research* 14: 975-1001. [https://doi.org/10.1016/0043-1354\(80\)90143-8](https://doi.org/10.1016/0043-1354(80)90143-8)
- [12] Wedepohl K. H. (1995). The composition of the continental crust. *Geochimica et cosmochimica Acta* 59: 1217-1232. [https://doi.org/10.1016/0016-7037\(95\)00038-2](https://doi.org/10.1016/0016-7037(95)00038-2)
- [13] Zhang Y., Chu C., Li T., Xu S., Liu L., Ju M. (2017). A water quality management strategy for regionally protected water through health risk assessment and spatial distribution of heavy metal pollution in 3 marine reserves. *Sciences of the Total Environment* 599-600: 721-731. <http://dx.doi.org/10.1016/j.scitotenv.2017.04.232>
- [14] Song D., Zhuang D., Jiang D., Fu J., Wang Q. (2015). Integrated Health Risk Assessment of Heavy Metals in Suxian County, South China. *Int. J. Environ. Res. Public Health* 12: 7100-7117. <https://doi.org/10.3390/ijerph120707100>
- [15] US Environmental Protection Agency. (2004). Risk Assessment Guidance for Superfund, Vol. 1, Human Health Evaluation Manual. Part E (supplemental guidance for dermal risk assessment), EPA/540/R/99/005. Office of Superfund Remediation and Technology Innovation, Washington, DC, USA.
- [16] US Environmental Protection Agency. (2013). Regional screening level (RSL) summary Table. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/docs/master_sl_table_run_NOV2013.pdf. Accessed November 2013.
- [17] Kaur M., Kumar A., Mehra R., Kaur I. (2020). Quantitative assessment of exposure of heavy metals in groundwater and soil on human health in Reasi district, Jammu and Kashmir. *Environmental geochemistry and health*, 42: 77-94. <https://doi.org/10.1007/s10653-019-00294-7>.
- [18] Pecina V., Brtnický M., Baltazár T., Juříčka D., Kynický J., Galiová M. V. (2021). Human health and ecological risk assessment of trace elements in urban soils of 101 cities in China: A meta-analysis. *Chemosphere* 267: 1-42. <https://doi.org/10.1016/j.chemosphere.2020.129215>
- [19] US Environmental Protection Agency. (2001). Drinking Water Standards and Health Advisories, 2001.
- [20] Penteado J. O., Brum R. L., Ramires P. L., Garcia E. M., Santos M. D., Junior F. M. R. D. S. (2021). Health risk assessment in urban parks soils contaminated by metals, Rio Grande city (Brazil) case study, *Ecotoxicology and Environmental Safety* 208: 111737-111744. <https://doi.org/10.1016/j.ecoenv.2020.111737>
- [21] US Environmental Protection Agency. (2018). Edition of the Drinking Water Standards and Health Advisories, Washington, DC, USA.
- [22] World Bank. (2019). The World Bank Group: Average Life Expectancy in Côte d'Ivoire: 2009-2019. <https://data.worldbank.org/indicator/SP.DYN.LE00.IN?locations=CI>. Accessed 12 July 2021.
- [23] Leleyter L., Rousseau C., Biree L., Baraud F. (2012). Comparison of EDTA, HCl and sequential extraction procedures, for select metals (Cu, Mn, Pb, Zn), in soils, riverine and marine sediments. *Journal of Geochemical Exploration* 51: 116-117. <https://doi.org/10.1016/j.gexplo.2012.03.006>
- [24] Zhang J., Liu C. L. (2002). Riverine composition and estuarine geochemistry of particulate metals in China weathering features, anthropogenic impact and chemical fluxes. *Estuarine, Coastal and Shelf Science* 54: 1051-1070. <https://doi.org/10.1006/ecss.2001.0879>
- [25] Biati A., Karbassi A. R. (2011). Flocculation of metals during mixing of Siyahrud River water with Caspian Sea water. *Environmental Monitoring and Assessment* 184: 6903-6911. <https://doi.org/10.1007/s10661-011-2466-z>
- [26] Even J. E., Masuda H., Shibata T., Nojima A., Sakamoto Y., Murasaki Y., Chiba H. (2017). Geochemical distribution and fate of arsenic in water and sediments of rivers from the Hokusetsu area, Japan. *Journal of Hydrology: Regional Studies* 9 34-47. <http://dx.doi.org/10.1016/j.ejrh.2016.09.008>
- [27] DeVore C. L., Rodriguez-Freire L., Mehdi-Ali A., Ducheneaux C., Artyushkova, K., Zhou Z., Latta D. E., Lueth V. W., Gonzales M., Lewis J., Cerrato, J. M. (2019). Effect of bicarbonate and phosphate on arsenic release from mining-impacted sediments in the Cheyenne River watershed, South Dakota, USA. *Environmental Science Processes & Impacts* 21: 456. <https://doi.org/10.1039/c8em00461g>
- [28] Wang J., Xu J., Xia J., Wu F., Zhang Y. (2018). A kinetic study of concurrent arsenic adsorption and phosphorus release during sediment resuspension. *Chemical Geology* 495: 67-75. <https://doi.org/10.1016/j.chemgeo.2018.08.003>

- [29] Usese A. I., Chukwu L. O., Naidu R., Islam S., Rahman M. M. (2020). Arsenic fractionation in sediments and speciation in muscles of fish, *Chrysichthys nigrodigitatus* from a contaminated tropical Lagoon, Nigeria. *Chemosphere* 256: 127134. <https://doi.org/10.1016/j.chemosphere.2020.127134>
- [30] Borah R., Taki K., Gogoi A., Das P., Kumar M. (2018). Contemporary distribution and impending mobility of arsenic, copper and zinc in a tropical (Brahmaputra) river bed sediments, Assam, India. *Ecotoxicology and Environmental Safety* 161: 769–776. <https://doi.org/10.1016/j.chemosphere.2020.127134>
- [31] Cunha D., Muylaert S., Nascimento M., Felix L., Andrade J. J. D. D., Silva R., Bila D. (2021). Concentration and toxicity assessment of contaminants in sediments of the Itaipu–Piratininga lagoonal system, Southeastern Brazil. *Regional Studies in Marine Science* 46: 101873. <https://doi.org/10.1016/j.rsma.2021.101873>.
- [32] MacDonald D. D., Ingersoll C. G., Berger T. A., (2000). Development and evaluation of consensus-based sediment guidelines for freshwater ecosystems. *Archives of Environmental Contamination and Toxicology* 39: 20–31. <https://doi.org/10.1007/s002440010075>
- [33] Oh S. Y., Yoon M. K., Kim I. H., Kim J. Y., Bae W. (2011). Chemical extraction of arsenic from contaminated soil under subcritical conditions. *Science of the Total Environment* 409: 3066–3072. <https://doi.org/10.1016/j.scitotenv.2011.04.054>