Determination of the radioactive nature of the sediments of the bays of the Ebrié lagoon of Abidjan, Ivory Coast

Abstract

In Ivory Coast, the lagoons represent the transit point for the majority of continental inputs. They are thus increasingly vulnerable and their ecological balance is rapidly modified under the influence of certain natural or anthropogenic factors.

The objective of this study is to evaluate the level of presence of lead 210 in sediments.

The sediments were sampled during the campaigns of the National Water Quality Observation Network on the bays spread over thirteen study sites. Analysis by alpha spectrometry was carried out in three stages (mineralization with concentrated acids, self-deposition on a silver disk, counting in an alpha detector with a silicone surface barrier). The highest lead-210 activities were obtained in the bays of Koumassi 1 (228.57 ± 12.21 Bq/kg) and Marcory (198.91 ± 9.46 Bq/kg). However, no seasonal variation in lead-210 contamination of sediments in the bays of Abidjan was observed. We wish to extend this study to other aquatic matrices.

Keywords: bays, mineralization, Lead 210, Radioactivity, sediment, alpha spectrometry.

1. Introduction

With the evolution of time, it is becoming more necessary to take an increasing interest in the study of marine and lagoon ecosystems through the determination and quantification of toxic radioactive contaminants resulting from human activities. At the level of these ecosystems, the conditions influencing the precipitation, adsorption or desorption of elements vary rapidly [**1**]. In Ivory Coast, the lagoons represent the transit point for the majority of continental inputs. They thus become more and more vulnerable and their ecological balance is rapidly modified under the influence of certain natural or anthropogenic factors such as leaching water from agricultural areas, industrial effluents and residues and significant urban waste discharges [**2**]. In the Abidjan area which covers a large part of the Ebrié lagoon, almost all the research carried out has focused on the evaluation of the concentration of heavy metals [**3, 4**]. On the other hand, studies relating to the analysis of toxic radionuclides such as lead 210 (^{210}Pb) and polonium 210 (^{210}Po) originating from anthropogenic activities are very limited. Indeed, these natural radioactive elements resulting from the decay chain of Uranium-238 are part of the biosphere and are present in the soil, sediments, air, water, terrestrial and aquatic organisms as well as the human organism. By decay, lead 210 would give bismuth 210 and polonium 210 would stabilize into lead 206 [**5, 6**]. The β^- particles emitted by lead 210 have very low energies to be easily detected. Thus, the measurement of the activity of lead 210

would be done via its descendants [**5, 6**].In a closed space, lead 210, bismuth 210 and polonium 210 would tend to balance. Thus, the balance between lead 210 and bismuth 210 would practically be reached in one month and that with polonium 210 in two years. Also, in firn, polonium 210 would be in radioactive equilibrium with lead 210. Consequently, the concentration of one of these radionuclides would give that of the other [**5, 6**]. In the literature, almost all studies carried out for the quantification of lead-210 in the environment are carried out using gamma spectrometry. Alpha (α) spectrometry, for its part, is an analytical technique making it possible to better quantify the activities of α-emitting radionuclides in samples [**7**].The determination of ^{210}Pb by alpha spectrometry seems original and very important to us because it provides us with useful information on the state of radioactive contamination of waterways impacted by human activities.

This present work aims to know for the first time the activity of ^{210}Pb in the sediments of the bays of the Ebrié lagoon of Abidjan (Ivory Coast) from 2015 to 2016.

2. Material and Methods

2.1. Study site

With an area of 566 km^2, the Ebrié lagoon constitutes the largest lagoon environment in Côte d'Ivoire and the largest coastal ecosystem in West Africa [**8**]. It occupies a large part of the Ivorian coastline and extends over 130 km along the coastline between 3°40' and 4°50' West longitude and 5°20' and 5°10' North latitude. The Ebrié lagoon is 7 km wide and its average depth is estimated at 4.8 m with some deep pits exceeding 20 m in the urban area of Abidjan [**9, 10]**. The lagoon system is separated from the Atlantic Ocean by a sandy coastal barrier 8 km thick. It has communicated with the Atlantic Ocean permanently since the opening of the Vridi Canal in 1950 (**Figure 1**). The Ebrié lagoon system is influenced to the west by the Agnéby and to the east by the Comoé and Mé rivers. It is made up of numerous bays which occupy almost a fifth of the total surface area [**10**]. The sediments of the lagoon system are fed by the rivers which flow into it and by the runoff water on the banks [**11**]. Around Abidjan the lagoon bays are also dumping grounds for urban waste. These sediments are made up of an organic fraction and a mineral fraction with variable grain size [**11, 12**].

Figure 1. Sediments sampling sites

2.2. Location of sampling sites

The sampling sites are sites referenced as part of monitoring activities for the quality of receiving environments (RNO-Ebrié lagoon). The GPS (Global Positioning System) coordinates of the sampling stations are grouped in **Table 1.**

Table 1. Coordinates of lagoon RNO sampling stations

Stations	GPS Coordinates	Stations	GPS Coordinates
Bay of Yopougon	05°18,316N 04°03,917W	Bay of Marcory	05°18,837N 04°00,003W
Bay of Azito	05°17,821N 04°04,740W	Baie de Chenal Est	05°19,298N 03°59,483W
Bay of Banco	05°19,691N 04°01,969W	Bay of M'badon	05°19,955N 03°55,737W
Bay of Biétry 1	05°16,752N 04°00,098W	Bay of Anna	05°19,166N 05°54,007W
Bay of Biétry 2	05°16,081N 03°58,539W	Bay of Koumassi 1	05°17,882N 03°56,090W
Bay of Cocody	05°19,677N 04°00,833W	Bay of Koumassi 2	05°16,863N 03°56,719W
Bay of Koumassi 3	05°16,457N 03°55,801W		

2.3. Material

The analyses were carried out using the following products: distilled water, hydrochloric acid (degree of purity 37%), nitric acid (degree of purity 65%), hydrofluidric acid (degree of purity 20%), water oxygenated (degree of purity 20%), ascorbic acid.

The technical equipment is composed of: heating plate (STUART), silver disk (for self-deposition), glassware, ORTEC alpha spectrometer (for the analysis of ^{210}Pb).

2.4. Sampling and physical processing

The samples were taken according to the schedule defined as part of the RNO-sediment activities. Samples were taken twice a year during the two years devoted to the study. Sampling was carried out in the months of April and October due to seasonal variations, at the water-sediment interface of the Ebrié lagoon in an area of 1000 cm^2, using a grab levy. The samples taken were dried in an oven at a temperature of 60°C for 06 days, then ground in an agar mortar, sieved using a 45µm sieve and stored in vials.

2.5. Determination of ^{210}Pb activities

The method used in this study is that established by the National Center for Energy, Nuclear Sciences and Techniques of Rabat and used by Béa et *al.* [**13**].

The chemical treatment of the samples was carried out by mineralization with concentrated acids (HCl, HNO_3, HF) and H_2O_2. For each series of analyses, a blank sample (distilled water) and a reference material with PT code IAEA-TEL 2018-03 (Sample 4), resulting from an inter-comparison exercise organized by the International Agency of Atomic Energy (IAEA), were used to validate the results. A quantity of 0.25 g of each sediment sample was collected and plotted with 300 µg of a ^{209}Po solution (0.188 ± 0.004 Bq/g).

Self-deposition was carried out on a silver disk immersed in the solution and left for deposition for 6 hours on a hot plate at 90°C with constant stirring. After 6 hours of self-deposition, the disk was removed, then washed with distilled water and air dried.

The disk was then counted by placing it in a silicone surface barrier alpha detector for counting.

The activity with its uncertainty were calculated as follows:

$$\mathbf{Ae} = \frac{(\mathbf{Se}-\mathbf{SBdFe})\times\mathbf{mt}\times\mathbf{At}}{(\mathbf{St}-\mathbf{SBdFt})\times\mathbf{me}} \text{ (I) et } \mathbf{i_A} = \mathbf{Ae}\sqrt{\mathbf{0,00023} + \frac{\mathbf{1}}{\mathbf{Se}} + \frac{\mathbf{1}}{\mathbf{St}} + \left(\frac{\mathbf{Et}}{\mathbf{AAt}}\right)^2} \text{ (II)}$$

Or

A_e:Sample activity (Bq/g)

i_A: uncertainty about the activity

A_t : Tracer activity (Bq/g)

S_e : Peak surface of the radioelement considered contained in the sample

S_t : Tracer peak area

S_{BdFe} : Surface of the peak of the background noise corrected with respect to the counting time, corresponding to the emission energy range of the radioelement of the sample

S_{BdFt} : Surface of the peak of the background crude corrected with respect to the counting time, corresponding to the emission energy range of the tracer

m_e : Sample mass (g)

m_t: Tracer mass (g)

E_t : Error on current tracer activity

A_{At} : Current tracker activity.

2.6. Statistical analysis

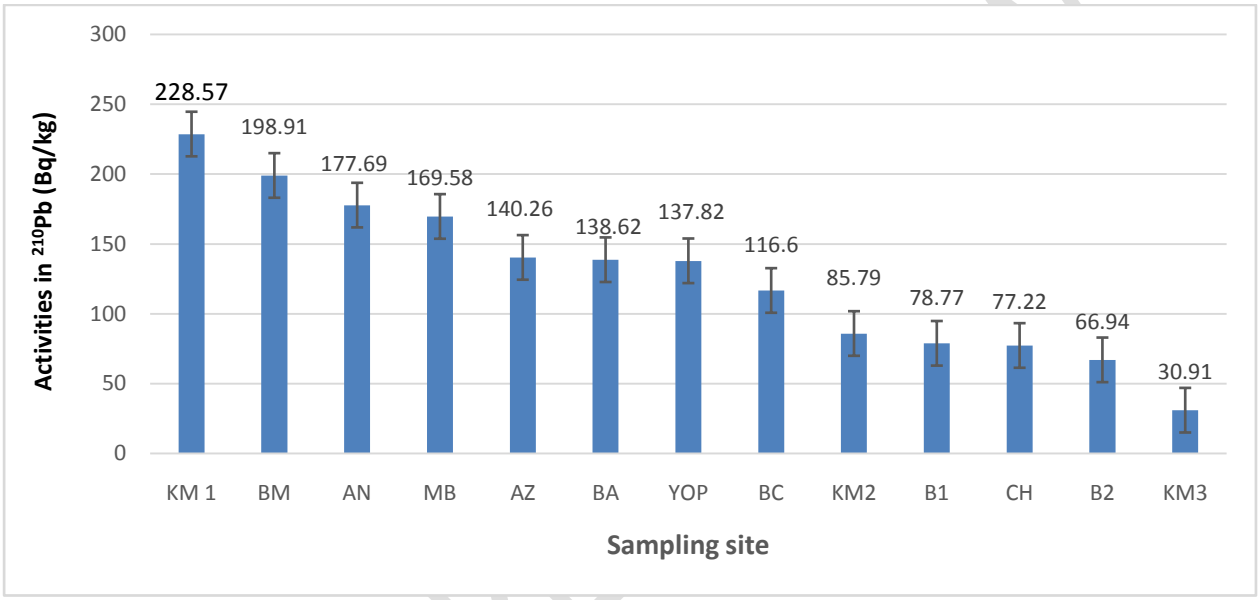
When the comparison showed a significant difference between the determined activities, the multiple comparison of medians test is carried out (Kruskal Wallis and Man Withney) to compare the ^{210}Pb activities obtained in the bay sediments. If the adjusted p value of a

pairwise comparison is below the significance threshold, i.e. P < 0.05, the difference is significant. Otherwise (p>0.05), the difference is not significant.

3. Results and discussion

3.1. Level of presence of ^{210}Pb in the sediments of the bays of Abidjan

The results recorded in **Figures 2** to **4** clearly show that the different bays studied all contain the radioelement ^{210}Pb. The activities of ^{210}Pb vary from one bay to another (**Figure 2**). The lowest activity is observed in Koumassi Bay 3 (30.91 ± 3.43 Bq/kg), while the highest value is obtained in Koumassi Bay 1 (228.57 ± 12.21 Bq/kg).



KM1: Koumassi 1 Bay; **BM:** Marcory Bay; **AN:** Anna Bay; **MB:** M'Badon Bay; **AZ:** Azito Bay; **BA:** Banco Bay; **YOP:** Yopougon Bay; **BC:** Cocody Bay; **KM2**: Koumassi 2 Bay; **B1**: Biétry 1 Bay; **CH:** Chenal Est Bay; **B2:** Biétry 2 Bay; **KM3:**Koumassi 3 Bay

Figure 2. ^{210}Pb activity in bays sediments

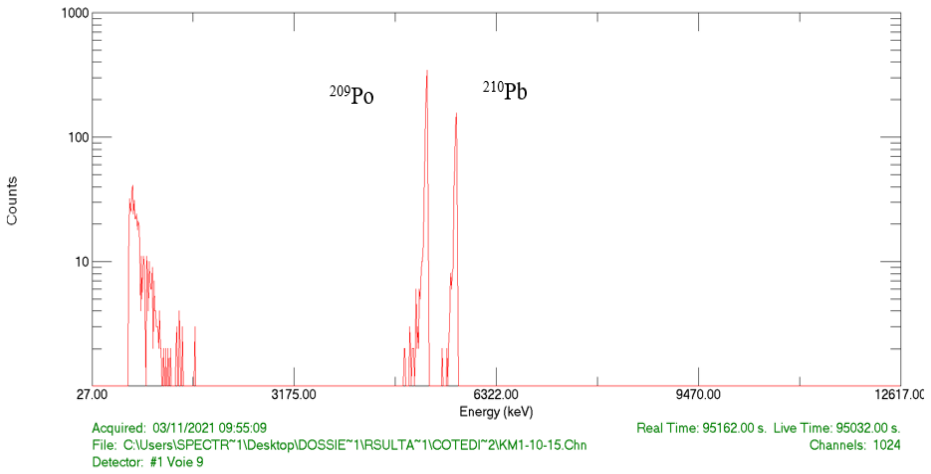


Figure 3. Alpha emission spectra of tracer ^{209}Po and ^{210}Pb in the KM1 sediment

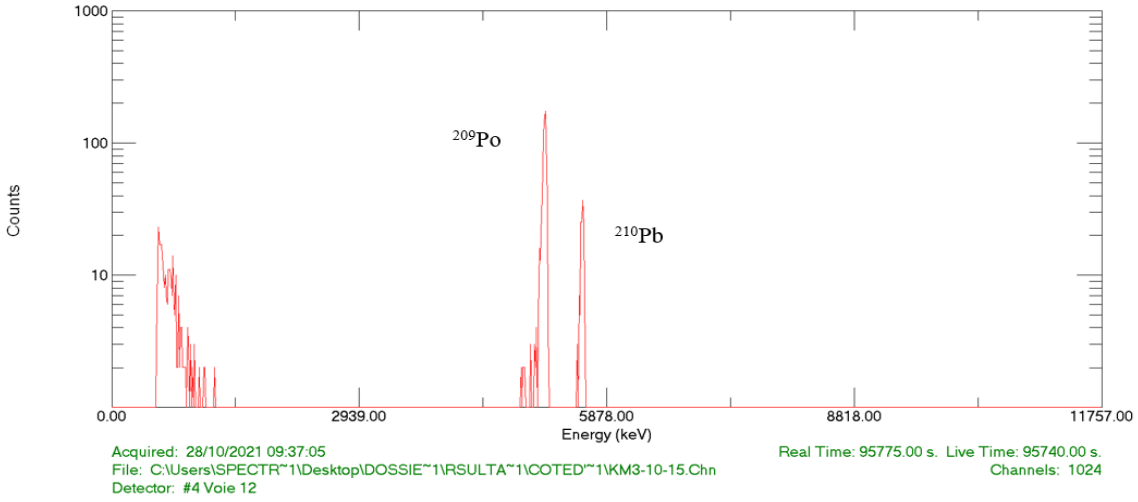


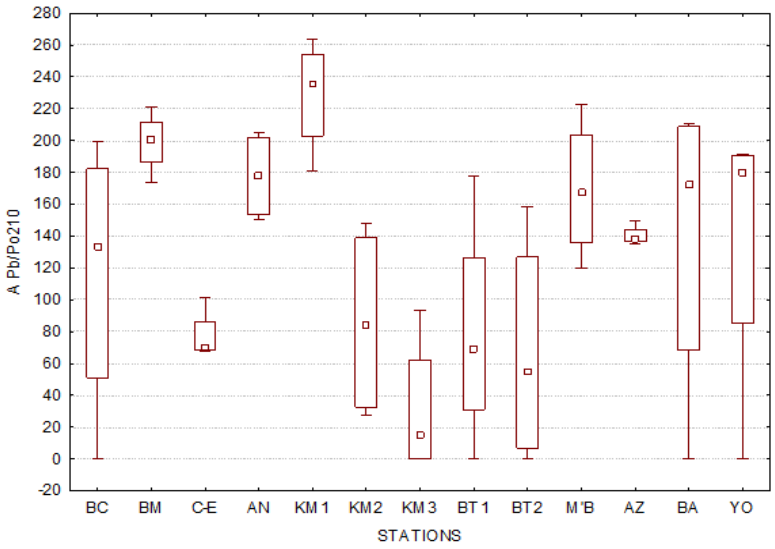
Figure 4. Alpha emission spectra of tracer ^{209}Po and ^{210}Pb in the KM3 sediment

In Ivory Coast, very few studies have been carried out on ^{210}Po and ^{210}Pb in sediments. The ^{210}Pb activities obtained in the different bays vary from 30.91±3.43 Bq/kg to 228.57±12.21 Bq/kg.

Our results clearly show that the Ebrié lagoon is subject to contamination by radionuclides ^{210}Po and ^{210}Pb from the decay chain of Uranium 238. The contamination of the sediments of the bays of the Ebrié lagoon observed in our study would result from the combination of natural factors and anthropogenic factors such as agricultural, petroleum, mining, cement and household waste. According to Miralles [**14**], Lead is brought by atmospheric deposits and by runoff in the marine environment.

3.2. Spatial variation of ^{210}Pb contamination of the sediments of the bays of Abidjan

Figure 5 describes the spatial variation of ^{210}Pb contamination in the sediments of the bays of Abidjan. The Kruskal Wallis test carried out shows that there is a significant difference ($p < 0.05$) in the variation of ^{210}Pb in the sediments of the bays of Abidjan.



KM1: Koumassi 1 Bay; **BM:** Marcory Bay; **AN:** Anna Bay; **MB:** M'Badon Bay; **AZ:** Azito Bay; **BA:** Banco Bay; **YOP:** Yopougon Bay; **BC:** Cocody Bay; **KM2**: Koumassi 2 Bay; **B1**: Biétry 1 Bay; **CH:** Chenal Est Bay; **B2:** Biétry 2 Bay; **KM3:**Koumassi 3 Bay

Figure 5. Spatial variation in ^{210}Pb contamination of sediments from different bays

According to the Man Withney test ($p < 0.05$), the median value of ^{210}Pb is higher in the sediments of the bay of Km 1 compared to that of the sediments of the bay of Km 3. The lowest activity is obtained at Koumassi Bay 3 with an average value of 30.91±3.43 Bq/kg. As for the bay of Koumassi 1, it recorded the highest activity (228.57±12.21 Bq/kg). These results show on the one hand that the bays of Koumassi 1 and Marcory which record a high activity in ^{210}Pb would receive effluents from industries such as NORME and TENORM located in the southern zone of Abidjan [**9, 11**]. On the other hand, Koumassi 3 located in the same area is less contaminated in ^{210}Pb; this could be explained by the fact that this last bay which receives industrial effluents and domestic waste [**11**] is constantly subject to dredging and backfilling activities. Indeed, studies carried out by Kouassi [**3**] revealed that the variation in activities depending on the bay would probably be linked to flooding, industrial pollution and significant urban waste discharges.

3.3. Seasonal comparison of the level of ^{210}Pb contamination in the sediments of the bays of Abidjan

The Kruskal Wallis test carried out indicates that the variations in ^{210}Pb contamination of the sediments of the bays of Abidjan are not significant from one season to another ($p > 0.05$) (**figure 6**).

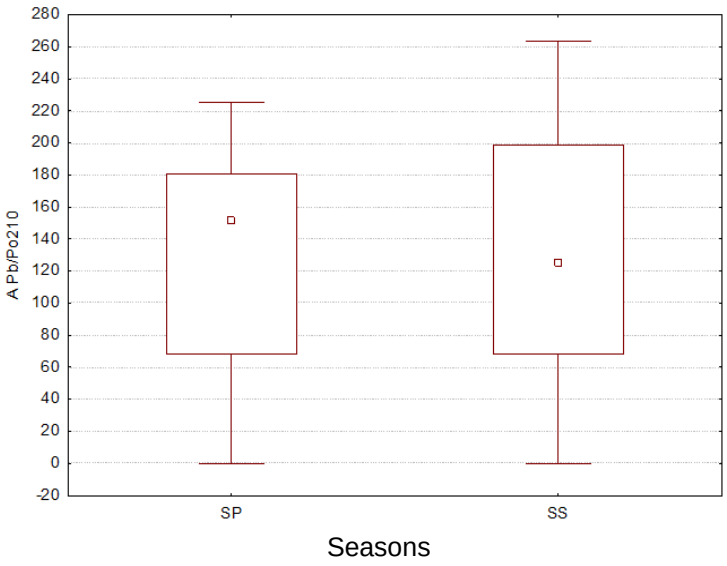


Figure 6. Seasonal comparison of the level of ^{210}Pb contamination in bay sediments

The ^{210}Pb contamination of the sediments of the bays of Abidjan is not significant from one season to another. This indicates that the climatic seasons have no influence on the variation in ^{210}Pb contamination of the sediments of the bays of the Abidjan district. In addition, the weather during these two years was favorable, preventing the transport of lead by runoff in the marine environment.

In view of all these results, it should be noted that the environmental quality of the sediments of the lagoon bays of Abidjan could further be degraded. Indeed, the significant and incessant input of industrial and domestic waste into the Ebrié lagoon continues to increase over the years due to the development of industrial activities and the increase in the population [**11**]. But also, the use of chemical inputs from phosphate rocks.

The significant ^{210}Pb activities detected in the sediments of the various bays of the Ebrié lagoon could lead to the bioaccumulation of this radiotoxic element in aquatic organisms consumed by the Ivorian population and also constitute a risk when swimming. Indeed, studies have shown the exposure of populations to lead linked to water ingestion [**15**].

4. Conclusion

This research work is a contribution to the evaluation of the level of contamination of the lagoon system of Abidjan (Côte d'Ivoire) in radioelement (^{210}Pb) from 2015 to 2016. For this purpose, the radioelement ^{210}Pb in secular equilibrium with the ^{210}Po was chemically analyzed to highlight its activity contained in the sediments of the lagoon system.According to the results obtained, all the samples analyzed contain, among other things, significant ^{210}Pb activities. Which suggests ^{210}Pb contamination of the sediments of the Ebrié lagoon. The

highest value of activity was found in the sediments from the bay of Koumassi 1 (228.57±12.21 Bq/kg) close to the industrial zone and the lowest in the sediments from the bay of Koumassi 3 (30.91±3.43 Bq/kg).However, no seasonal variation in ^{210}Pb contamination of the sediments of the bays of Abidjan was observed.

To assess the level of pollution in the bays of the Ebrié lagoon in Abidjan and the population's exposure to ionizing radiation, it is necessary to carry out a large study on the presence of ^{210}Po in all the bays by determining its activity. This study must also be extended to all matrices of the aquatic environment.

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