# RISK ANALYSIS OF CADMIUM INTAKE BY FISH CONSUMERS IN A SUB-TROPICAL COASTAL LAGOON, SEPETIBA BAY-SE, BRAZIL

## *Análise de risco da ingestão de cádmio por consumidores de pescado em lagoa costeira sub-tropical, Baía de Sepetiba-SE, Brasil*

**Artigo Original**


***ABSTRACT***

***Objective:*** *To estimate the risk of cadmium (Cd) contamination through the ingestion of fish by a population of fish consumers in Sepetiba Bay-SE, Brazil.* ***Methods:*** *We estimated the risk of cadmium intake for fish consumers in the study area. For control purposes we based it on fish consumption by the population, making it possible to estimate the probability and risk due to cadmium intake by means of the assessment of hazard quotient (HQ).* ***Results****: The risk for cadmium intake was 110 times greater than that found in control population. The HQ was 0.11, and compared with control population, which is located around the area of study, the risk ratio was 0.001. The increased risk may be reflected in renal disease, although these have not been shown to be associated with exposure to Cd.* ***Conclusion:*** *The fishermen who work in Sepetiba Bay have a risk about 110 times greater for cadmium contamination than the population that consumes fish for 48 days per year (average).*



***Descriptors****: Public Health; Environment; Environmental Pollution; Risk.*



**RESUMO**

**Objetivo:** Estimar o risco de contaminação por cádmio (Cd) através da ingestão de peixe em população consumidora de pescado, na Baía de Sepetiba-SE, Brasil. **Métodos:** Estimou-se o risco de ingestão de cádmio para os consumidores de peixe da área de estudo. Para o controle, baseou-se no consumo de peixe pela população brasileira, tornando possível estimar a probabilidade e risco devido à ingestão de cádmio por avaliação do quociente de perigo (HQ). **Resultados:** O risco para a ingestão de cádmio foi 110 vezes maior do que o encontrado no controle populacional. O HQ foi de 0,11; e quando comparado com o controle da população, que está localizado ao redor da área de estudo, o risco obtido foi de 0,001. O risco aumentado pode ser refletido nas doenças renais, embora estas não tenham se mostrado associadas à exposição ao Cd. **Conclusão:** Os pescadores que trabalham na Baía de Sepetiba têm um risco cerca de 110 vezes maior de contaminação por cádmio do que a população que consome peixe por 48 dias por ano (média).



**Descritores:** Saúde Pública; Meio Ambiente; Poluição Ambiental; Risco.



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## INTRODUCTION

Since the dawn of man on earth, humanity little by little has been provoking changes in the environment that they inhabit[1]. At the beginning, these changes were almost imperceptible, but over time, and especially after industrial revolution, the changes became more pronounced generating what we call environmental pollutants, arising from the production of waste and mismanagement. Pollution is the deterioration of environmental conditions, which can reach the air, water and land, by releasing of elements, radiation, vibration, noise and substances or contaminants agents with prejudice to the balance of ecosystems, interfering directly in the health and man welfare[2].

The term risk has different meanings to different people[3,4]. Currently, it can mean an uncertainty associated with a future event or to an alleged event[5-8], including conditions that threaten the safety, welfare and health of individuals or communities[9-13]. Therefore, as a result of both situations, it indicates a perspective subject of quantification, whether in the context of health, safety and environmental decisions, where the concept of risk involves value judgments that reflect much more than the simple probability of a particular event, either besides to the calculation of the dose associated with exposure, or a statistical indicator of accidents.

Cadmium (Cd) is a relatively rare element that is not essential for any biological process in plants or animals. It occurs mainly as a component of minerals in earth's crust at an average concentration of 0.18 ppm[14]. It represents a serious environmental pollutant which can induce a wide spectrum of toxic effects in fish such as imbalance of plasma ion concentrations[15] and alteration of water balance[16,17]. As a consequence, the presence of this pollutant at toxic concentrations in marine environment represents a serious problem for aquatic living organisms for the maintenance of their basic physiological functions[18].

The Cd impact on aquatic organisms depends on its variety of possible chemical forms, which might have different toxicities and bioconcentration factors[19]. In salty waters, cadmium chloride complexes predominate and particles in suspension and dissolved organic material may bind to a substantial portion of the cadmium[20]. It has been observed its ability to accumulate in fish liver and kidney and its low ability to accumulate in muscle tissues[19]. Data were demonstrated in fish kidney denoting this as the main target organ for heavy metals since it can accumulate them even if their concentration in the water is very low[21]. Agah et al.[22] observed fishes with 26.7 µg Cd/g in liver and 0.043 µg Cd/g in muscle for the same fishes. Also, Cd residues in fish reach steady-state only after exposure periods greatly exceeding 28 days[20].

Cd can enter the human body mainly by inhalation and digestive pathways, and the penetration through skin is considered insignificant[1,14].

Prolonged inhalation or ingestion exposure of humans to cadmium at levels causing renal dysfunction can lead to painful and debilitating bone disease in individuals with risk factors such as poor nutrition[23,24]; the occurrence of these bone effects in elderly Japanese women exposed to high levels of cadmium in rice and water was referred to as Itai-Itai disease[25]. Decreases in bone mineral density, increases in the risk of fractures, and increases in the risk of osteoporosis have also been observed in young rats orally exposed to CD. Animal data strongly suggest that Cd exposure results in increases in bone turnover and decreases in mineralization during the period of rapid bone growth. Although animal studies suggest that these effects are due to direct damage to the bone, it is likely that renal damage resulting in the loss of calcium and phosphate and alteration in renal metabolism of vitamin D would compound these effects[26].

Brazilian federal laws regulate the level of acceptable Cd concentrations in marine and fresh water environments as well as the levels of metal in different sorts of food according to the Federal Resolution 518/2004[27] for fishes and fisheries the acceptable limit is 1.0 µg/kg/dia. For salty waters the law determination is at maximum level of 0.005 mg/L. In Sepetiba Bay, a coastal region belonging to the state of Rio de Janeiro, Brazil, it was observed Cd level above the legislation levels. The average in Cd concentration was 1.55 mg/L in water, 7.02 mg/kg in sediment, 6.08 mg/kg and 7.6 mg/kg for kidney and liver of aquatic birds[28].

In this work, we estimated the human health risk for Cd contamination by means of fish ingestion for the population that directly or indirectly uses Sepetiba Bay waters for several purposes. We also analyzed if the local population would be affected by chronic renal diseases by measuring incidence rates and comparing with the other region of the Rio de Janeiro State.

## METHOD

### Study site

Sepetiba Bay is located in the State of Rio de Janeiro, Brazil, (22 º 55 ‘ and 23 º 05'S / 43 º 40' and 44 º 40'W) with an area of 450 km$^2$. This region present its northern and eastern area limited by the continent, a sandbank vegetation on southern limit, and Ilha Grande Bay on the west. Its greatest length is 42.5 km from east to west and its greatest width is 17.2 km from north to south, with a perimeter of 122 km.

The watershed contributing to Sepetiba Bay has two main sources: the Serra do Mar mountain chain and an extensive area of lowland, crossed by many rivers, consisting of 22 sub-basins. The main rivers within the catchment area of the Sepetiba Bay and its respective average flow are Gandu River, also known as channel of San Francisco ($89m^3/s$), Guarda River ($6.8\ m^3/s$), Ita channel ($3.3\ m^3/s$), Piraquê River ($2.5m^3.s^{-1}$), Portinho River ($8.8\ m^3/s$), Mazomba River ($0.5\ m^3/s$) and Cação River ($1.1m^3/s$). The other rivers are water bodies of smaller basins, with very low flows. Guandu River is the most important contributor of the basin and it's responsible for supplying water to several cities, being the main source of Rio de Janeiro city.

The Sepetiba Bay basin has an estimated population of 1,295,000 inhabitants, which generate an output of sewage of about 286,900 $m^3$/day. The majority of the municipalities included in this basin do not have services of solid waste collection and the release is made commonly in landfills, much of which are located on the banks of rivers close to urban areas, resulting in serious environmental degradation. The uncontrolled increase of population without a corresponding expansion of infrastructure and adequate sanitation generates a large volume of domestic and industrial waste and the use, though moderate, of pesticides in agricultural activities, are sources of pollution to waters in the basin. About 1,7 million inhabitants live in this region concentrated mainly in urban area[29] (Figure 1).

## Determination of toxicity levels for cadmium in fish consumers

Considering fishes as organisms that accumulate high concentrations of Cd in organs like kidney, liver and muscle tissue[18,30], we based this study on the probability of being contaminated with Cd when ingesting fish. As sanitary measurements only muscle tissues (the edible part of a fish) are normally consumed by population, and visceral parts (including kidney and liver) are discharged. This fact reduces the probability of contamination by high levels of Cd in the population. Also, Brazilian population in general has a low consumption rate of fisheries when compared to other countries, preferring some other kind of meat like beef or chicken.

The Reference Dose (RfD) is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancerous effects during a lifetime. It is not a direct estimator of risk, but rather a reference point to gauge the potential effects. At exposures increasingly greater than the RfD, the potential for adverse health effects increases.

Thus, based on the fish consumption by Brazilian population, we can estimate the probability or risk of Cd intake by assessing the hazard quotient (HQ)[31], that can be calculated as:

$$HQ = \frac{DCI}{Rfd}$$

Equation 1. The RfD for dietary exposure to Cd is 0.001 per milligrams per kilogram per day mg/kg/d (mg/kg/d). The CDI is chronic daily intake of Cd, which is calculated by

$$CDI = \frac{C*IR*EF*ED}{BW*AT}$$

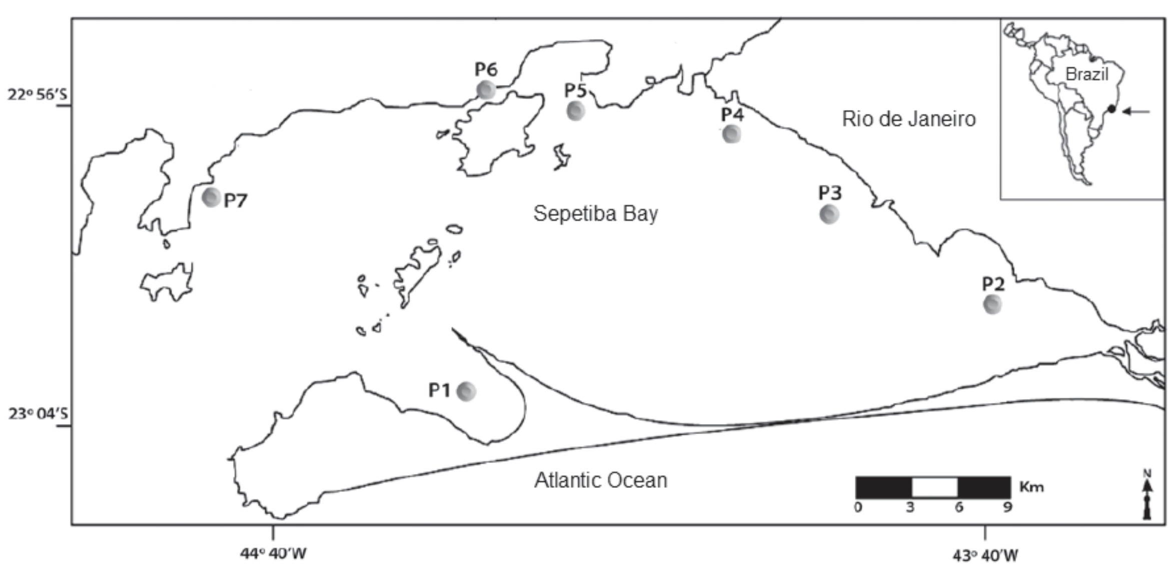


Figure 1 - Study area: Sepetiba Bay, Rio de Janeiro.

Equation 2, where C is average Cd concentration in the environment (considering the concentration estimated in fish muscle tissues). In a study concerning food habits for Brazilian population, the authors estimated the fish consumption in Rio de Janeiro city of 11.4 kg/person/year (219 g/week)[32]. IR is human ingestion rate, EF is exposure frequency, ED is average exposure duration (year, 30 yr), BW is average body weight (the average adult body weight was considered to be 70 kg ), and AT is averaging time (AT = 365 x EDd). In our study, EF is supposed to be (d/y). These equations were calculated considering intakes for two different populations: *a)* fishermen from Sepetiba Bay that regularly consume fishes and *b)* and final consumers from other urban localities in the region that consume fishes a few times a month, following the Brazilian average fish consumption. These populations were, for this study purposes, considered homogeneously mixed, presenting no differences among individuals in relation to the pattern of fish consumption, preferred species and amount ingested. We also considered that the Cd excretion is null and all the Cd intake is consequently accumulated. Cd concentrations were obtained for water and sediment in seven different points in Sepetiba Bay[28].

In order to assess whether the population from Sepetiba Bay region has suffered with renal diseases the last years, we calculated average incidence rates for the municipalities from this region and compared with the other municipalities belonging to the State of Rio de Janeiro. We considered renal diseases as diseases with hospital morbidity classified by CID-10 and used by the health system in Brazil (SUS). Renal diseases were acute and progressive nephritic syndromes, glomerular diseases, kidney diseases from interstitial tubule, renal insufficiency, urolithiasis, cystitis, and other diseases from renal unit. The data were obtained from Data-SUS system and plotted together for the years of 2009, 2009 and 2010. Incidence rates were calculated based on population of 2008 for the municipalities from the State of Rio de Janeiro.

## RESULTS

For Cd concentrations in water samples, some values are above the recommended for Class 2 waters, according to Resolution No. 357/2005[33] (Table 1).

Cd contents were satisfactory at stations P1, P6 and P7, and slightly compromised at P2 and above the levels recommended in stations P3, P4 and P5. In the sediment, the concentrations of Cd showed slightly lower at the P1, and with higher levels at stations P2, P3, P4, P5, P6 and P7.

Table I. Heavy metal levels in the waters of Sepetiba Bay ($\mu g.L^{-1}$).

Table I - Heavy metal levels in the waters of Sepetiba Bay ($\mu g.L^{-1}$).

| Sampling stations | Water | | | Sediment | | |
|---|---|---|---|---|---|---|
| | E1 | E2 | E3 | E1 | E2 | E3 |
| P1 | 0.1 | - | 0.3 | 0.031 | 0.042 | 0.092 |
| P2 | 0.8 | 1.2 | 1.4 | 4.22 | 6.25 | 6.04 |
| P3 | 2.1 | 2.2 | 1.8 | 12.12 | 10.39 | 16.85 |
| P4 | 5.7 | 9.8 | 11.3 | 16.40 | 22.30 | 45.65 |
| P5 | 1.5 | 2.4 | 2.6 | 14.02 | 9.82 | 18.73 |
| P6 | 0.5 | 0.6 | 0.7 | 2.27 | 2.11 | 5.41 |
| P7 | 0.2 | 0.2 | 0.4 | 0.09 | 0.061 | 1.02 |

E1 - season 1- September 2008/ E2-station 2-December 2008 / E3 - season 3 - march 2009.
Maximum levels ($\mu g.L^{-1}$) - Conama 357/2005: Cd – 1.

When comparing fish consumers and fishermen from Sepetiba Bay, both of them have ingested fishes with the estimated concentration of 0.04 mg / kg fish (Table 2). This value would be applied to the Cd concentration in muscle tissues and for the estimation of this value we based on literature data[22]. The Rfd was obtained from USEPA data[20]. IR presented themselves different for studied populations. Fishermen were considered as frequent fish consumers in a rate above the Brazilian average consumption (0.02 kg/day). This parameter highly increased the risk for these fishermen from Sepetiba bay. The EF also showed differences between consumers and fishermen. Fishermen were considered to consume fish the whole year whilst consumers' population were estimated to consume fish only 48 days a year. The chronic daily intake of Cd (CDI) was higher for fishermen, reflecting the HQ values. The calculations showed that fish consumers have a risk of 0.1 % of ingesting Cd when eating fish. However fishermen from Sepetiba Bay have an increased risk of 11% of ingesting Cd when consuming fish food.

A risk ratio between fishermen and consumers might be calculated as $HQ = HQ_{co} / HQ_{fi} = 110$. Fishermen have a risk 110 times greater than the general population of ingesting Cd from the waters of Sepetiba Bay.

Incidence rates of renal diseases obtained for the state of Rio de Janeiro for the last two years showed no increase for the municipalities from Sepetiba Bay (Figure 2).

The cities of Mangaratiba, Itaguaí and Rio de Janeiro presented rates of 28.26/100.000; 3.86/100.000 and 8.63/100.000 respectively. Mangaratiba city showed a higher incidence when compared to Itaguai and Rio de Janeiro, however when compared to other cities from the State of Rio de Janeiro, incidence rates were considerably low.

Table II - Estimated Parameters for the calculation of HQ.

| Parameters | Consumers | Fishermen |
|---|---|---|
| C | 0.04 mg / kg fish | 0,04 mg / kg fish |
| Rfd | 0.001 mg / kg fish / Day | 0.001 mg / kg fish / Day |
| IR | 0.02 kg / day | 0.2 kg /Day |
| EF | 48 / 365 | 365 / 365 |
| ED | 30 years | 30 years |
| BW | 70 kg | 70 kg |
| AT | 30 years x 365 days / year | 30 years x 365 days / year |
| CDI | 1.5 x $10^{-6}$ mg / kg / day | 1.1 x $10^{-4}$ mg / kg / day |
| HQ | 0.001 0.1% | 0.11 11% |

C: Cd concentrations in the environmental media; Rfd: reference dose; IR: interest-rate risk; EF: exposure frequency; ED: exposure duration; BW: body weight; AT: averaging time; CDI: chronic daily intake; HQ: hazard quotient.

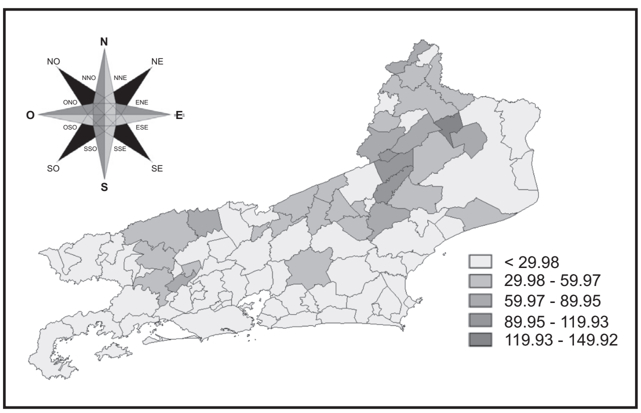


Figure 2 - Incidence rates of renal diseases in 2008 and 2009 for the municipalities in State of Rio de Janeiro.

## DISCUSSION

Cd can enter human body mainly by inhalation and digestive pathways. The penetration through skin is negligible. The water consumption of the inhabitants of Sepetiba Bay comes not from the bay itself, but from the Guandu river. We can therefore conclude that the gastrointestinal pathway, by consuming of fish should be the main route of Cd exposure by the inhabitants of the bay. Inhalation can be a pathway for Cd exposure to the residents of areas nearby industries producing Cd.

Rivers deposit Cd into Sepetiba Bay and before entering inside organisms this metal is deposited in the sediment. Mass balance calculations suggest that, after entering the Sepetiba Bay, metals are not immediately deposited in bottom sediments but suffer various cycles of deposition and resuspension due to relatively low depth, the strong tidal currents and strong wind mostly from the southwest. Zn, Cd, and Pb discharged into Sepetiba Bay, may undergo at least five to ten cycles of deposition and resuspension until being definitively buried in bottom sediments(34).

The impact of Cd deposition into Sepetiba Bay can affect marine wildlife and fauna from the terrestrial ecosystems. Mangroves are the dominant ecosystem along the borders of Sepetiba Bay. This system is of great importance to animal life: breeding places for fish, birds, vital system of crab species and numerous seafood. Ferreira et al.(28) suggest a strong Cd contamination in these wetlands, including other metals. This can have strong impacts on the life cycles of various species. Many fish such as mullet (*Mugil curema*), snook (*Centropomus undecimallis*), sardines (*Sardinella aurita*), and bluefish (*Brevoortia Tyrannus*) use these areas to breed and feed, increasing their exposure. Some studies have detected Cd levels above those permitted by Brazilian law (Maximum Allowable Concentration: 1.0 mg/g): up to 5.1 g/g in oysters (*Crassostrea brasiliana*), 2.8 g/g in snail-leaf (*Littorina angulifera*), 2.2 mg/g in shrimp (*Penaeus smithii*), 1.4 g/g in crabs (*Cardisoma guanhumi*)(35).

From a sample of 120 fish, 60 from Sepetiba Bay and 60 from Ilha Grande Bay, De Souza Lima(36) measured Cd levels in various organs: liver, gonads, muscles. The only mean value above the Maximum Allowable Concentration was found in catfish liver: 5.5 g/g, indicating an accumulation. The average values in muscles (only organs consumed) were 0.1 g/g = 100 mg/kg muscle, the following species: catfish (*Genidens genidens*), mullet (*Mugil lisa*), corvine (*Micropoginias furnieri*) and hake (*Cynocion leiarchus*). This value is below the maximum concentration allowed by Brazilian law (1 g/g)(36). However, Cd excretion being difficult, we conclude that a lifelong accumulation can cause health problems.

Usually, fish accumulate only small amounts of Cd in muscle as compared to most other tissues and organs(31, 36). It is well-known that environmental pollutants, like Cd and other heavy metals may produce toxic effects on target organs by affecting different transport proteins present at the cellular membrane level. Also is argued that at least three different explanations can be taken into account to explain the molecular mechanisms by which Cd inhibited the Na-H exchanger activity(18): (a) a direct interaction of the metals with the transport protein; (b) an increase in H permeability of the membrane vesicles and (c) an increase in Na permeability of the membrane vesicles.

The accumulation of trace metals vary among species and tissues. It was observed that metal accumulation in fish the liver tissues were higher than in muscle. This is probably due to metabolic activities in fish. Organs with higher metabolic activities, like liver and kidney, accumulate more trace metals than organs with lower metabolic activities, such as muscle[22]. Regulatory ability, behavior and feeding habits are other factors that can influence the accumulation in the different organs.

Based on this assumptions described above we might infer if physiological processes like those described for fishes contaminated with Cd would be taking place in human renal systems by inhibiting the activity of Na:H exchanger. Though the incidence rates for renal diseases have not shown an increase for cities around Sepetiba Bay, Cd exposure for these populations might be altering metabolic pathways in renal system provoking alterations not yet detectable by health system. An association study between Cd exposure and alterations in renal functioning is necessary to elucidate several questions concerning human Cd effects.

Fishermen that work in Sepetiba Bay have an estimated risk 110 times greater than the population that consumes fishes 48 days a year (average number). This increased risk may be reflected in renal diseases that are not detected to be associated to Cd exposure, and the health systems attribute these diseases to other causes than Cd. However, when compared to the reference dose of 0.001 mg/kg/day, the Cd chronic daily intake (CDI) for both studied groups is below recommended limit levels.

A concentration of 200 µg Cd/gm wet human renal cortex is the highest renal level not associated with significant proteinuria[20]. A toxicokinetic model is available to determine the level of chronic human oral exposure (NOAEL) which results in 200 ug Cd/gm wet human renal cortex; the model assumes that 0.01% day of the Cd body burden is eliminated per day[31]. Assuming 2.5% absorption of Cd from food or 5% from water, the toxicokinetic model predicts that the NOAEL for chronic Cd exposure is 0.005 and 0.01 mg Cd/kg/day from water and food, respectively (i.e., levels which would result in 200 µg Cd/gm wet weight human renal cortex). Thus, based on an estimated NOAEL of 0.005 mg Cd/kg/day for Cd in drinking water and an UF of 10, an RfD of 0.0005 mg Cd/kg/day (water) was calculated; an equivalent RfD for Cd in food is 0.001 mg Cd/kg/day[20, 31].

In this study we estimated Cd risk intake for populations that differently consume fish, and this pathway to Cd exposure is supposed to be not carcinogenic, however there is evidence of carcinogenicity in rats and mice by inhalation and intramuscular and subcutaneous injection. Studies in rats and mice wherein Cd salts (acetate, sulphate, and chloride) were administered orally have shown no carcinogenic evidence response. Also, studies have observed a 2-fold excess risk of lung cancer in Cd smelter workers[20,31].

## CONCLUSION

The field of risk analysis has assumed increasing importance in recent years given the concern by both public and private sectors in safety, public health and environmental problems.

This study offered an estimate risk of Cd intake by consumption of fish from Sepetiba Bay, where fishermen consume fish in rates above the Brazilian mean level and these fishermen have an increased risk of being contaminated with Cd, besides the consequences of this contamination be still unclear. A data to support this fact is the high levels of Cd found in points spread in the sediment and water column in Sepetiba Bay.

The aspects raised here about contamination by metals in populations indicate that environmental routes and inside human body routes that heavy metals follow are complex and often poorly understood. The behaviour of these elements differs for different ecosystems and populations with different characteristics. The existing database of information for heavy metals in the environment and populations is still insufficient, which stimulates this study.

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