Revista Brasileira de Geografia Física

ISSN:1984-2295

Homepage: https://periodicos.ufpe.br/revistas/rbgfe

Metal mobility after resuspension of contaminated sediments from a tropical urban bay

Ana Paula de Castro Rodrigues[1] ,Christiane do Nascimento Monte[2], Gustavo Filgueira[1], Alexandre Rafael de Freitas[1, 3], Ricardo Erthal Santelli[4], Bernardo Braz[4], Wilson Machado[5]

[1] Dra em Geociências, Professora Adjunta, Biologia Marinha, Universidade Federal do Rio de Janeiro, Avenida Carlos Chagas Filho, 373 CCS.CEP 21941-599, Rio de Janeiro, Rio de Janeiro. ORCID: https://orcid.org/0000-0001-7704-0201 (21) 2562-6306.tantufaz17@gmail.com. [2]Dra. em Geociências, Professora Adjunta C, Instituto de Engenharia e Geociências, Universidade Federal do Oeste do Pará, Av Vera Paz, s/n, CEP 68035-110, Santarém, Pará. ORCID: https://orcid.org/0000-0003-4840-7777 (93) 2101-4985.christiane.monte@yahoo.com.br (autor correspondente). [3]Bolsista de iniciação científica, Universidade Federal do Rio de Janeiro, Departamento de Biologia Marinha, Universidade Federal do Rio de Janeiro, Avenida Carlos Chagas Filho, 373 CCS.CEP 21941-599, Rio de Janeiro, Rio de Janeiro. (21) 2562-6306. ORCID: https://orcid.org/0009-0005-6332-5675 gustavo-filgueira@hotmail.com [4] Doutorando em Geociências, Universidade Federal Fluminense, Departamento de Geologia, Unidade Federal Fluminense, Av. Gen. Milton Tavares s/nº- Gragoatá. CEP 24210-346Niterói,Rio de Janeiro. ORCID: https://orcid.org/ 0000-0003-2262-4140 (21) 2629-1880 freitas.ar23@gmail.com [5] Dr em Química, Professor Titular , Química Analítica, Universidade Federal do Rio de Janeiro, Avenida Athos da Silveira Ramos (antiga Av. 6), 149 Bloco A - 7° andar. CEP: 21941-909 Cidade Universitária - Rio de Janeiro – RJ. ORCID: https://orcid.org/ 0000-0001-9812-6098 resantelli@gmail.[6]Mestre em Química, Química Analítica, Universidade Federal do Rio de Janeiro, Avenida Athos da Silveira Ramos (antiga Av. 6), 149 Bloco A - 7° andar. CEP: 21941-909 Cidade Universitária - Rio de Janeiro – RJ. ORCID: https://orcid.org/0000-0001-8280-2047bernardobraz@id.uff.br [7]Dr. em Geociências, Professor Adjunto Departamento de Geoquímica, Unidade Federal Fluminense,Outeiro São João Baptista s/n, CEP 24.020-141, Niterói,Rio de Janeiro. ORCID: https://orcid.org/ 0000-0003-3117-8584 (21) 2629-1880.wtvmachado@yahoo.com.br

Artigo recebido em 14/03/2023 e aceito em 28/01/2024

ABSTRACT

Dredging activities are recurrent in coastal cities, however, they can cause the remobilization of contaminants, increasing the risk to the biota. Guanabara Bay is a complex eutrophic estuary that undergoes dredging in several areas during the year. The Meriti River estuary is silted up and highly contaminated by metals, such as Cr, Cu, and Zn, due to the discharge of untreated sewage. In this sense, the present study aims to evaluate the remobilization of metals in the sediment (Cr, Cu, Fe, Mn, Ni, Pb, and Zn) and bioavailability after resuspension. Twelve sampling points were collected along 4 transects. The resuspension experiments were performed at two intervals: 1 h (T1) and 24 h (T2) and followed protocols from previous studies. In general, all metals are remobilized after resuspension. - In addition, the bioavailability change (BC) index was applied., which showed 54% remobilization of Cr after T2. The transects closer to the river showed less remobilization after resuspension, which may be related to the saline gradient. Zn was the only metal that exceeded CONAMA Resolution 454/12 level 2 after resuspension, indicating a significant anthropogenic input to the area. Although organic matter (OM) is one of the main regulators of bioavailability in this study, the results suggest that there is an interference of bacterial activity in the dynamics of OM degradation, which directly impacts the bioavailability of metals after resuspension.

Keywords: Dredging, estuary, bioavailability, Guanabara Bay, anthropogenic input

Mobilidade metálica após ressuspensão de sedimentos contaminados de uma baía urbana tropical

RESUMO

As atividades de dragagem são recorrentes nas cidades litorâneas, porém podem causar a remobilização de contaminantes, aumentando o risco à biota. A Baía de Guanabara é um estuário eutrófico complexo que sofre dragagens em diversas áreas durante o ano. O estuário do Rio Meriti está assoreado e altamente contaminado por metais, como Cr, Cu e Zn, devido ao lançamento de esgoto não tratado. Nesse sentido, o presente estudo tem como objetivo avaliar a remobilização de metais no sedimento (Cr, Cu, Fe, Mn, Ni, Pb e Zn) e a biodisponibilidade após ressuspensão. Doze pontos amostrais foram coletados ao longo de 4 transectos. Os experimentos de ressuspensão foram realizados em dois intervalos: 1 h (T1) e 24 h (T2) e seguiram protocolos de estudos anteriores. Em geral, todos os metais são remobilizados após a ressuspensão. - Além disso, foi aplicado o índice de alteração de biodisponibilidade (BC), que mostrou 54% de remobilização de Cr após T2. Os transectos mais próximos ao rio apresentaram menor remobilização após ressuspensão, o que pode estar relacionado ao gradiente salino. O Zn foi o único metal que ultrapassou o nível 2 da Resolução CONAMA 454/12 após a ressuspensão, indicando um significativo aporte antrópico na área. Embora a matéria orgânica (MO) seja um dos principais reguladores da biodisponibilidade neste estudo, os resultados sugerem que há uma interferência da atividade bacteriana na dinâmica da degradação da MO, o que impacta diretamente na biodisponibilidade dos metais após a ressuspensão.

Palavras-chave: Dragagem, estuário, biodisponibilidade, Baía de Guanabara, insumos antropogênicos

Introduction

Coastal zone management has become one of the greatest challenges for environmental management in recent decades. Urban expansion and, consequently, the advancement of the industry, the growing demand for energy and raw materials directly impact the exploitation of natural resources, and consequently the greater discharge of contaminants into the coastal environment (Oliveira & Marins, 2011). Among the most worrying environmental impacts, trace metals are one of the greatest threats to the maintenance of ecosystems in the coastal zone, because they have the characteristic of being persistent pollutants in the environment (Cotta et al., 2006).

Metals are found naturally in aquatic ecosystems. However, due to anthropogenic activities, such as mining and domestic and industrial effluent discharges, excessive amounts of metals can enter aquatic ecosystems, causing contamination of these environments (Verstijnen et al., 2024).

Metals enter rivers through surface runoff, atmospheric deposition, and discharge from point and diffuse sources and are easily adsorbed to suspended particulate material, being deposited in the sediment by the action of gravity, which is carried to the coastal zone (Cui et al., 2021).

The sediment is composed of mineral and organic materials, which over time are deposited at the bottom of aquatic ecosystems. These materials are known as sinks for metallic compounds, which physical and chemical properties play a relevant role in the spatial distribution of metals in the aquatic environment (Monte et al. 2021; Teixeira et al., 2022).

Physicochemical processes retain in the sediment both the weakly bound metals ("exchangeable phases") and those associated with various substrates, such as iron and manganese oxides and hydroxides, carbonates, sulfides, and organic matter (Pestana, 1989; Herms & Gurgel, 2012). Thus, sediments are important in the dynamics of contaminants in the estuarine system, because they act as a sink for trace metals, but also, depending on the physicochemical conditions, they can be considered as a source of contamination to the water column, releasing the metals previously stored, through activities, such as resuspension (Morse et al., 1994; Lima et al., 2001; Oliveira & Marins., 2011; Monte et al., 2017). Resuspension of sediment-bound contaminants can occur naturally, by bioturbation, induction by winds, storms tidal currents and waves (Lacerda et al., 2007; Monte et al., 2019). As well as it can occur by anthropogenic induction, due to dredging events, ship passage, and bottom trawling (Monte et al., 2019).

In the study of resuspension events, chemical and physical aspects of the sediments, such as grain size and organic matter content, as well as pH and salinity of the water and redox conditions, can be very important in explaining the behavior of sediment-bound pollutants. These aspects influence, the chemical forms of the contaminants, thus their bioavailability (Cotou et al., 2005; Zhang et al., 2014; Rodrigues et al., 2017; Monte et al., 2022b). The intensity of resuspension can change over time, which according to environmental changes and the amount of resuspended sediment influences the dynamics of suspended particles (Eggleton & Thomas, 2004; Monte et al., 2022).

Resuspension of contaminated coastal sediments is capable of causing secondary contamination, increasing the risk to aquatic biota (Malferrari et al., 2009; Freitas et al., 2019). However, dredging activities are mainly recommended to decrease siltation and ensure navigability (Wasserman et al., 2016). The rapid siltation process in lakes, rivers, and estuaries is the consequence of deforestation of the banks and uses of the drainage basins. In port areas, dredging is an activity that is present mainly to maintain ship traffic (Guo et al., 2015; Bejarano-Ramirez et al., 2017; Monte et al., 2022b).

Assessing the total concentration of metals did not determine bioavailability and/or toxicity in the sediment. Therefore, evaluating different fractions, such as the bioavailable fraction, is a more reliable criterion for assessing metal toxicity, biogeochemical transformation, and final fate (Ashayeri et al., 2023).

The bioavailability of metals in sediments is controlled by some geochemical processes, such as changes in the chemical element charges, the formation of chemical and complexing substances, adsorption to solid particles, and associations with sulfides, organic matter, and/or Fe and Mn oxides and hydroxides (Caetano et al., 2003; Maddock et al., 2007; Guo et al., 2015; Rodrigues et al., 2017; Freitas et al., 2019). However, dredging can cause a physicochemical imbalance between the water column and the sediment, causing the release of trace metals from the sediment into the water column, and increasing the potential bioavailability of the contaminants (Eggleton et al., 2004; Montero et al., 2013; Freitas et al., 2019; Monte et al., 2022).

Guanabara Bay has 381 km^2 and a drainage basin of 4,081 km^2 (Montero et al., 2013; Monte et al., 2022). The northwestern portion of the Bay's watershed receives the effluents from most of the industries of the industrial complex of the metropolitan area of Rio de Janeiro State, and the Meriti, Iguaçu, and Estrela rivers are the main receptors (Maddock et al., 2007; Machado et al., 2011; Monte et al., 2021). In this region, dredging is recurrent to reduce siltation and avoid urban flooding (Monte et al., 2022b).

The bay is an ecosystem considered eutrophic to hypereutrophic due to its high organic load. The northwestern region of the bay is most affected by metal contamination, such as Cd, Cr, Cu, Hg, Ni, Pb, and Zn, due to the large industrial complex in the surrounding municipalities, where there is no sewage treatment (Monte et al., 2023; Rodrigues et al., 2023).

In this sense, the present study aims to evaluate possible variations in metal concentrations in the bioavailable fraction before and after resuspension events of surface sediments of the Meriti River, located in the northwestern portion of the Guanabara Bay, as well as the application of the ecological index change of bioavailability (BC) after resuspension, as suggested by Rodrigues et al. (2017).

Thus, the hypotheses of this study are as follows: (I) the influence of the salinity gradient on the bioavailability of metals; (II) metals are less bioavailable in estuaries with a higher concentration of organic matter; and (III) resuspension increases the bioavailability of metals.

Materials and methods

Study area and sampling procedures

Guanabara Bay is the second-largest Brazilian bay and one of the most urbanized in the world, with about 11 million inhabitants around it (IBGE, 2010; Fistarol et al., 2015). However, due to the industrial park, located around the bay's watershed, the discharge of untreated industrial sewage is continuous. Thus, metal contamination of the bay has been going on for years, being reported in several previous studies (Rebello et al., 1986; Barrocas & Wasserman, 1993; Machado et al., 2002; Maddock et al., 2007; Machado et al., 2011; Baptista et al., 2013; Monte et al., 2019; Monte et al., 2022).

However, studies on the effect of dredging activities on the bay are few. Most industries are concentrated in Meriti and Iguaçu rivers basins, which flow into the northwestern part of the bay (Monte et al., 2021) (Figure 1). This zone also has poor water circulation (Barrocas & Wasserman, 1993; Monte et al., 2021), being the estuarine zone silted. The Meriti River receives industrial effluents from the Acari River, which receives effluents from a chloralkali plant, besides the pollutants of other industries and from urbanized municipalities (Barrocas & Wasserman, 1993; Monte et al., 2021; Monte et al., 2022b).

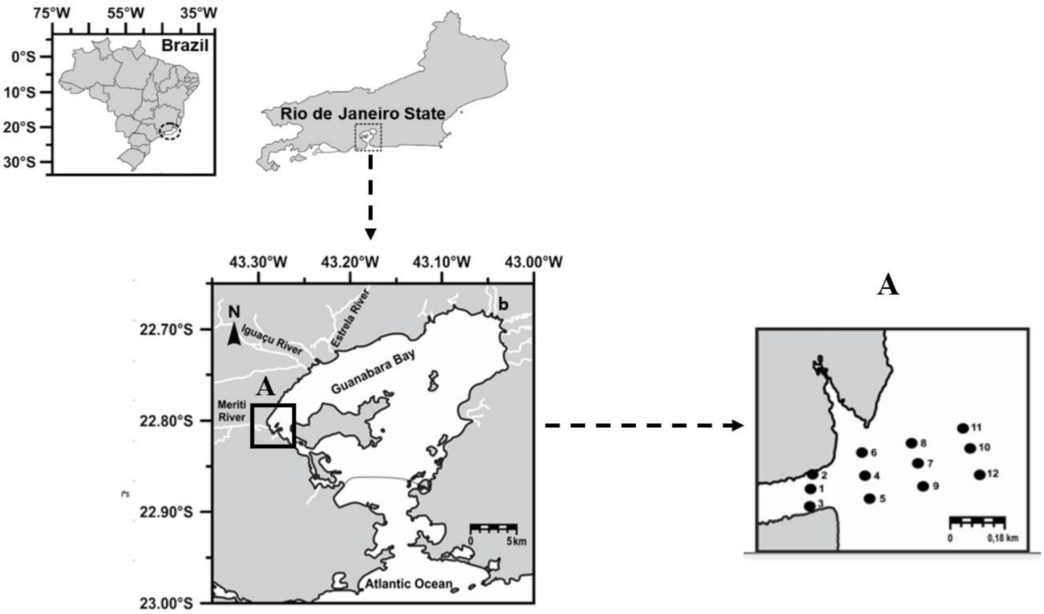


Figure 01- Study Area

The Meriti River is 20.79 km long and its drainage basin is about 650 km^2 in area, contributing 12.3% of the annual freshwater discharge into Guanabara Bay (Coelho, 2007). For the present study, sampling was conducted in July 2012 at 12 sampling points in the Meriti River estuary. The surface sediment samples were collected per study site using a van Veen grab and stored, under refrigeration until arriving at the laboratory,while the water was collected 6 liters in the central channel of Guanabara Bay and conditioned in previously decontaminated âmbar bottles. . The physical-chemical parameters (pH, electrical conductivity, temperature, dissolved oxygen-OD and salinity) were measured on site.The presented results are averages and standard deviations derived from separate analyses of subsamples (duplicates).

Resuspension Experiments

Resuspension experiments were carried out at room temperature (25°C). The experiments compared short and long time periods of resuspension (1h vs. 24h). The intervals choice was based on previous studies, which demonstrated that in the first hour (t1) the most part of changes on bioavailibility occurs (Machado et al., 2011; Monte et al., 2005). The second interval (t2= 24h) has been also previously adopted (Morse, 1994), and was used to evaluate the stability of the contaminant response, simulating longer resuspension events, since dregding resuspension of sediments may occur during many hours, including daily variations (Monte et al., 2022).

For each sampling time along the resuspension experiments, each one of these sediment subsamples was agitated in the sampled water and analyzed in duplicate, per sampling site. The sediment:water proportion used in the experiments was based on previous works (Machado et al., 2011; Monte et al., 2005; Monte et al., 2022b). Approximately 7.0 g of wet sediments were agitated in 125 mL Erlenmeyer flasks containing 100 mL of unfiltered water from the main channel of Guanabara Bay, under oxidizing condition.

After the resuspension test, the physical–chemical parameters of the water were measured (temperature, salinity, dissolved oxygen-OD and pH). An aliquot of the water (about 50 mL) was vacuum filtered using a decontaminated glass kit and a calcined glass fiber filter with a porosity of 0.22 μm. These filtered water samples were destined to total carbon and nitrogen analyzes, being stored in amber glass bottles of 50 mL, acidified with boric acid and kept under refrigeration. For sediment separation, the remaining aliquot (mix of sediment and 50 mL of water) was transferred to a 50-ml Falcon tube and centrifuged at 3000 rpm for 5 min. The supernatant was discarded, and the sediment was dried under.

Metals determinations

The reactive phase (i.e., adsorbed and/or associated to carbonates, monosulfides and Fe and Mn oxides) was extracted by 16h agitation in 1 mol.L^{-1} HCl solution, sediment samples. It is an usual approach for metal bioavailability evaluation (Morse, 1994; Machado et al., 2011; Birch & Hogg, 2011; Peña- ICart et al., 2014; Monte et al., 2005; Rodrigues et al., 2017; Monte et al., 2019). Peña-Icart and co-workers (2014) compared four weak extractions (acetic acid 0.11vv, acetic acid 25% and 1 mol.L^{-1} HCl with and without trypsin and pepsin) to evaluate metals bioavailability and as conclusion they indicated 1 mol.L^{-1} HCl as the most efficient extraction to simulate the digestive system of marine organisms.

The potentially-bioavailable fraction was obtained using a 1 mol.L^{-1} HCl solution, where 40 mL of this solution was added to a polypropylene tube containing 1.0 g of dried sediment. The tubes were stirred during 16h. After this period the samples were centrifuged (3,000 RPM, for 5 minutes), the supernatant was separated for metals determination and the sediment was washed three times with distilled water to remove the acid solution. This extraction was chosen based on (Morse, 1994; Machado et al., 2011; Monte et al., 2005; Monte et al., 2022b; Monte et al., 2021).

Metals concentrations (Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were determined by inductively coupled plasma mass spectrometry (ICP-OES). In order to verify the accuracy of the methods, certified material was also analyzed (CRM NIST 2782). The detection limits were: Cd: 0.01 mg Kg^{-1}; Cr: 0.01 mg Kg^{-1}; Cu: 0.01 mg Kg^{-1}, Fe: 3.00 mg Kg^{-1}; Mn: 0.02 mg Kg^{-1}; Ni: 0.01 mg Kg^{-1}; Pb: 0.01 mg Kg^{-1}; and Zn: 0.01 mg Kg^{-1}. respectively, and the recovery ranged from 95.49 to 107.4%.

Sediment characterization

The sediment grain size was characterized using a particle size analyzer CILAS 1064 and calculated using the software GRADSTAT 1.0. Total organic carbon (TOC) contents in sediments (after carbonate removal by acidification) was determined using a Shimadzu TOC analyzer TOC-V with SSM-5000A module Shimadzu), using 20mg of decarbonated sediment, obtained after HCl 1 mol L^{-1} extraction. Certified material (Potassium Hydrogen phthalate) was used with recovery of 103.4%. The organic matter (OM) in sediments was determined with heating (450°C) by four hours and half.

Nutrients

Nutrients in water, total carbon (TC) and total nitrogen (TN) were obtained by catalytic oxidation under high temperature by a Shimadzu TOC Vcph. For the analysis of total organic carbon in sediments, the carbonate content was removed by acidification (shaken in 1 mol L^{-1} HCl for 16 h). The determination was performed on the Shimadzu TOC-V analyzer using the SSM-5000A module for solids analysis. Potassium hydrogen phthalate certified material (certified concentration 47.1%) was used, obtaining an average concentration of 51.17 ± 0.02%.

Total phosphorus was determined in 0.5 g of dried sediment after being subjected to calcination (450 °C/ 4 hours). The calcined samples were transferred to Falcon tubes and 10 mL of 1 mol L^{-1} HCl was added, then stirred for 16 h. After stirring, the samples were centrifuged for 20 min at 2,500 rpm. After this step, the colorimetric method for the determination of dissolved orthophosphate was used Grasshoff et al. (1983), with absorbance measurment in a spectrophotometer (Thermo Scientific, model Genesys 10S). For method certification, certified material for total phosphorus (PACS-3; 937 µg g^{-1}) was used). The concentration found was 1,099.6±17.3 µg/g (117.3 % recovery).

Bioavailability Changes (BC)

The Bioavailability Change Index (BCI) developed by Monte et al. (2015) was adapted in Rodrigues et al. (2017), and include only the concentrations of metals in reactive phase (BC). Then a simple calculation of reactive trace metals losses and gains as the percentage related to t_0 (in natura samples, before resuspension) was done, as explained in the following equation: $(([Me_{AR}] - [Me_{BR}])/[Me_{BR}])*100$, where $[Me_{AR}]$ is the metal concentration on reactive phase after resuspension and $[Me_{BR}]$ is the metal concentration on reactive phase before resuspension (Monte et al., 2022).

Data analysis

Statistical analysis was performed using SPSS 22.0 software. The Shapiro–Wilk test was applied to verify the normality of the samples, after which it was found that the samples had a non-parametric distribution. Therefore, the Spearman correlations were tested to verify possible relationships between toxic metals with physical and chemical characteristics of the experiment's sediment and water.

Results

Geochemical and sedimentary characterization

The grain size of the sediments is composed of a fine fraction (silt + clay) above 90% (Table 1). In all transects the organic matter (OM) was above 16%, indicating a high organic load. Regarding the physical-chemical parameters, dissolved oxygen (DO), pH, and salinity increased in the transects towards the bay, while temperature showed the opposite behavior (Table 1). Total dissolved solids (TDS) were higher in the first transect.

Table 1 Physico-chemical parameters and concentrations of metals and nutrients in sediment and water

	Transect 1	Transect 2	Transect 3	Transect 4
		Sediment		
Clay (%)	7.3 ± 0.6	7.2 ± 1.0	6.7 ± 1.4	6.4 ± 0.9
	(6.7-7.9)	(6.2-8.1)	(5.10-7.70)	(5.9-7.4)
silt (%)	86.6 ± 3.5	79.9 ± 7.8	74.4 ± 16.8	76.0 ± 3.6
	(82.6-89.3)	(71.0-85.5)	(55.1-85.6)	(73.0-79.9)
Sand (%)	6.1 ± 3.4	12.9 ± 8.8	19.0 ± 18.2	17.7 ± 4.4
	(4.0-10.1)	(6.3-22.8)	(6.7-39.9)	(12.8-21.2)
Organic Matter (%)	24.2 ± 0.4	20.4 ± 5.3	16.1 ± 4.2	19.7 ± 4.9

	(23.8-24.5)	(15.8-26.1)	(11.2-18.9)	(16.6-25.4)
Eh (mV)	-308.3 ± 16.1 (-320.0 - -290.0)	-305.0 ± 6.0 (-311.0 - -299.0)	-323.3 ± 1.5 (-325.0 - -322.0)	-311.0 ± 21.9 (-330.0 - -287.0)
pH	7.4 ± 0.2 (7.2-7.6)	7.4 ± 0.1 (7.3-7.4)	7.1 ± 0.0 (7.1-7.1)	7.2 ± 0.1 (7.1-7.3)
Total Phosphorus (µg g^{-1})	1,137.7 ± 69.6 (1,095.1-1,218.0)	1,051.1 ± 162.6 (870.8-1,186.5)	1,117.7 ± 322.0 (882.4-1,484.7)	1,098.0 ± 139.7 (948.6-1,225.3)
Cd (mg kg^{-1})	0.8 ± 0.1 (0.8-0.9)	0.7 ± 0.1 (0.7-0.8)	0.6 ± 0.2 (0.4-0.9)	0.7 ± 0.2 (0.5-0.8)
Cr (mg kg^{-1})	30.7 ± 2.9 (27.3-32.9)	37.9 ± 14.7 (27.6-54.7)	24.5 ± 8.1 (15.2-29.7)	24.2 ± 6.8 (17.2-30.8)
Cu (mg kg^{-1})	48.1 ± 4.3 (43.1-50.9)	43.8 ± 7.3 (35.4-48.8)	35.4 ± 10.0 (24.8-44.6)	40.3 ± 11.4 (30.0-52.6)
Fe (mg kg^{-1})	11,932.0 ± 454.4 (11,439.7-12,335.3)	7,294.3 ± 3,948.9 (4,231.2-11,751.0)	6,443.2 ± 2,131.0 (4,724.3-8,827.5)	9,087.6 ± 2,287.4 (6,755.3-11,327.3)
Mn (mg kg^{-1})	58.9 ± 5.6 (55.4-65.4)	38.9 ± 17.6 (26.9-59.1)	34.5 ± 14.2 (21.4-49.6)	37.4 ± 9.8 (31.4-48.7)
Ni (mg kg^{-1})	33.7 ± 6.3 (28.3-40.6)	31.3 ± 11.1 (21.9-43.6)	21.3 ± 4.9 (16.0-25.6)	24.8 ± 9.5 (16.9-35.4)
Pb (mg kg^{-1})	53.1 ± 2.9 (50.3-56.1)	70.3 ± 26.9 (50.5-101.0)	49.0 ± 17.2 (29.9-63.2)	51.1 ± 5.5 (44.8-55.3)
Zn (mg kg^{-1})	1,155.2 ± 112.2 (1,036.7-1,259.9)	871.9 ± 364.3 (455.4-1,131.4)	754.8 ± 197.2 (528.2-887.5)	855.3 ± 287.4 (623.0-1,176.7)
water				

pH	7.3 ± 0.1 (7.2-7.4)	7.8 ± 0.4 (7.5-8.3)	8.5 ± 0.1 (8.5-8.6)	8.6 ± 0.2 (8.4-8.8)
Dissolved oxygen (mg L^{-1})	0.0 ± 0.0 (0.0-0.0)	1.9 ± 1.7 (0.4-3.8)	4.4 ± 0.6 (3.8-5.0)	5.1 ± 1.3 (3.6-6.0)
Dissolved oxygen (%)	0.0 ± 0.0 (0.0-0.0)	0.3 ± 0.3 (0.1-0.6)	0.7 ± 0.1 (0.6-0.7)	0.7 ± 0.2 (0.5-0.9)
Conductivity (mS cm)	16.0 ± 11.4 (8.1-29.1)	29.6 ± 10.8 (23.0-42.1)	45.3 ± 1.3 (44.0-46.5)	45.7 ± 0.2 (45.4-45.8)
Temperature (^{0}C)	30.0 ± 1.1 (28.8-30.8)	30.9 ± 2.2 (28.7-33.1)	27.8 ± 0.4 (27.6-28.2)	27.5 ± 0.2 (27.2-27.7)
Salinity (ppt)	8.1 ± 6.9 (4.0-16.1)	16.7 ± 7.2 (11.9-24.9)	27.6 ± 1.0 (26.5-28.5)	28.0 ± 0.3 (27.7-28.3)
Total carbon (mg L^{-1})	34.2 ± 6.1 (29.9-38.5)	27.4 ± 6.6 (19.8-31.8)	19.9 ± 1.9 (17.8-21.4)	17.5 ± 2.0 (15.8-19.8)
Total nitrogen (mg L^{-1})	16.4 ± 2.9 (13.2-18.9)	10.2 ± 5.1 (4.3-13.2)	3.0 ± 0.6 (2.5-3.7)	2.7 ± 0.1 (2.6-2.8)

Total nitrogen in water (TN) showed differences among transects, while transects 1 and 2 (more inland) obtained concentrations above 10 mg L^{-1}, transects 3 and 4 (closer to the bay) showed maximum concentrations of 3.0 mg L^{-1} (Table 1). Total carbon in water (TC) showed the same trend as nitrogen, the inner transects had higher concentrations in relation to the one closer to the bay. Total phosphorus in sediment (TP) showed concentrations above 1,000 mg kg^{-1} in all transects (Table 1), indicating that this environment is eutrophic.

Regarding metals, Cu, Ni, Pb, and Zn exceeded level 1 of the Brazilian legislation about dredging (CONAMA, 2012) (Table 1), which adopts the Effect Range Low (ERL) classification for level 1 and Effect Range Medium (ERM) for level 2 proposed by Long et al. (Long et al., 1995). Zn was the only metal that exceeded the ERM, indicating that the area has high risk to biota for metals. The statistics showed some significant correlations between the parameters studied (Table 2) (Spearman $p < 0.05$ n = 12).

Table 2: Correlation matrix between the parameters before resuspension (T0) . Spearman p< 0.05 n=12

*NS = not significant

	Clay	Silt	Sand	OM (%)	DO (mg/L)	pH	Cr (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
pH	NS	NS	NS	NS	NS	1.00	**-0.60**	NS	**-0.58**	**-0.65**	**-0.67**	NS	**-0.63**
Cd (mg/kg)	NS	**0.67**	NS	NS	**-0.62**	NS	**0.73**	**0.74**	NS	NS	**0.58**	NS	**-0.66**
Cr (mg/kg)	**0.78**	**0.79**	**-0.83**	NS	**-0.62**	**-0.60**	1.00	NS	NS	**0.66**	**0.94**	**0.72**	NS
Cu (mg/kg)	NS	NS	NS	**0.86**	**-0.64**	NS	NS	1.00	**0.66**	**0.66**	NS	NS	**0.94**
Fe (mg/kg)	NS	NS	NS	**0.75**	**-0.58**	**-0.58**	**0.66**	NS	1.00	**0.92**	**0.73**	**0.82**	**0.81**
Mn (mg/kg)	NS	NS	NS	**0.78**	**-0.68**	**-0.65**	**0.66**	NS	**0.92**	**1.00**	**0.76**	NS	**0.79**
Ni (mg/kg)	NS	NS	NS	**0.94**	**-0.72**	**-0.67**	**0.94**	NS	**0.73**	**0.76**	1.00	NS	**0.93**
Pb (mg/L)	NS	NS	NS	NS	NS	NS	**0.72**	NS	**0.82**	NS	NS	1.00	NS
Zn (mg/L)	NS	NS	NS	**0.90**	**-0.68**	**-0.63**	**0.99**	NS	**0.81**	NS	**0.93**	NS	1.00
TN (mg/L)	NS	NS	NS	NS	NS	NS	1.00	NS	NS	**0.68**	NS	NS	NS

Resupension experiment

The percentage of organic matter in the sediment was higher at T0 in transects 1, 2, and 4 (Figure 2). Transects 1 and 2 showed a reduction in the percentage of organic matter after resuspension, while transect 3 showed a tendency to increase the percentage of OM at T1 and T2.

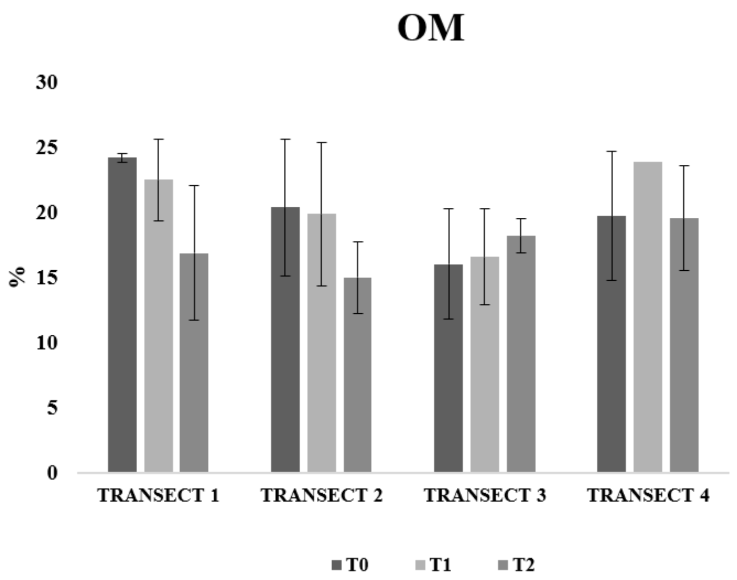


Figure 2:Percentage of organic matter before and after resuspension in the four transects (%)

TC in water showed the highest concentrations at T0 in all transects (Figure 3), suggesting possible remobilization to sediment. TN presented higher concentrations after resuspension in transects 1, 3, and 4 (Figure 3), indicating that there is remobilization of nitrogenous forms into the water column after resuspension. Regarding TP in the sediment (Figure 4), only transect 1 showed higher concentrations after resuspension, while the other transects showed lower concentrations after resuspension compared to T0, suggesting that there is a possible remobilization into the water column after resuspension.

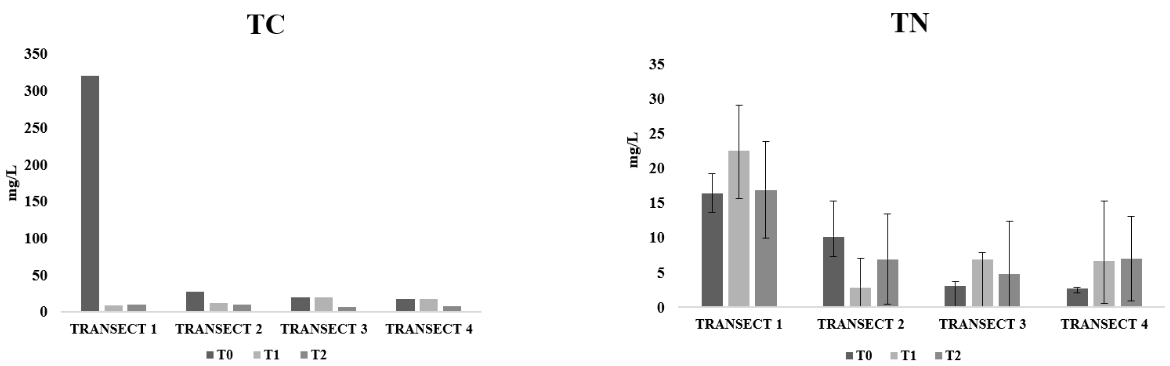


Figure 3: Concentration of total carbon (TC) and total nitrogen (TN) in water before and after resuspension in the four transects (mg/L)

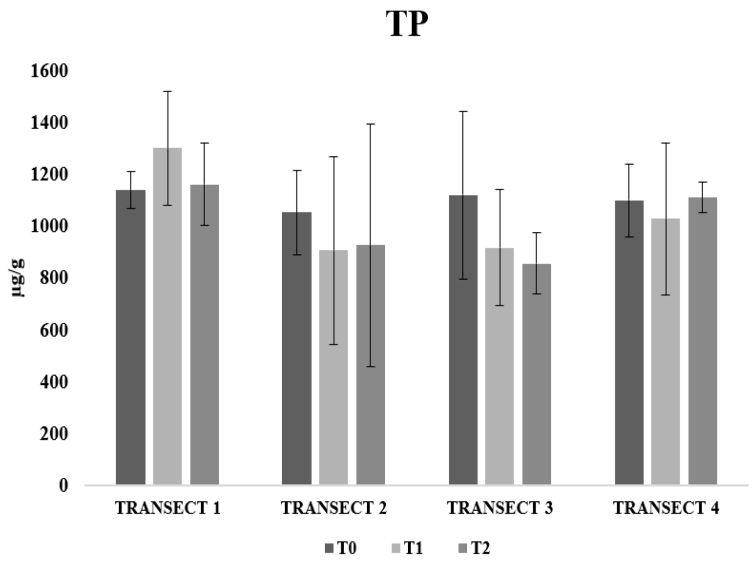
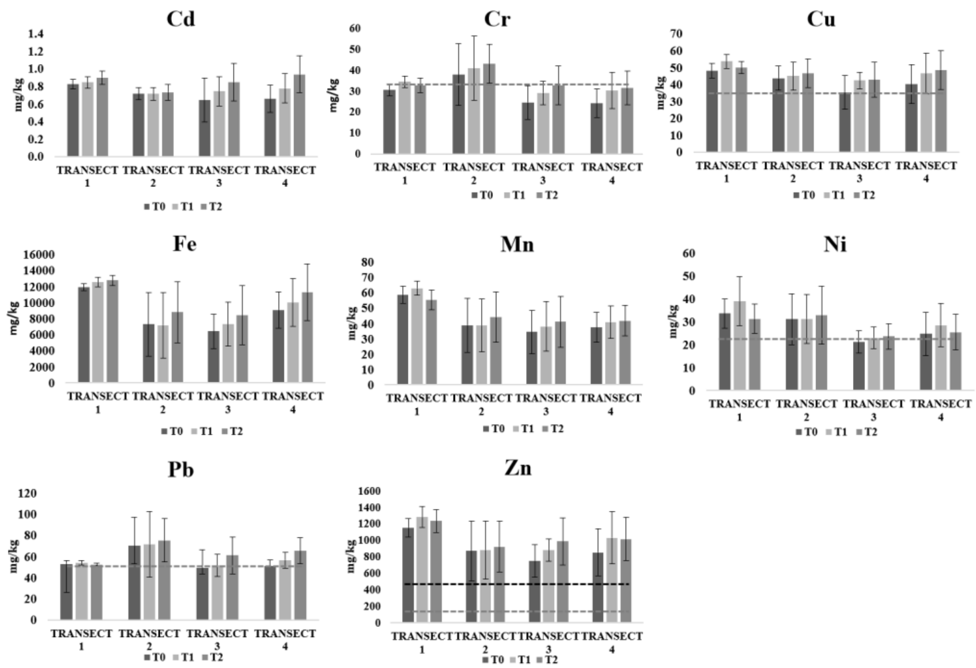


Figure 4: Concentration of total phosphorus (TP) in sediment before and after resuspension in the four transects (µg/g)

Regarding metals, (Figure 5). Mn, Ni, and Pb, in transect 1, were remobilized at T1, but at T2 the concentrations were lower than T0. The results suggest that resuspension increases the risk to local biota. The statistics showed some significant correlations after resuspension (Tables 3 and 4). The statistics suggested that the main correlations were between Fe and Mn and the other metals and OM and the metals mainly after T1, suggesting that Fe and Mn oxides and hydroxides as well as OM are the main regulators of bioavailability after resuspension.



*The grey line is the concentrations above the ERL and the black line is above the ERM

Figure 5- Metal concentrations in the sediment before and after resuspension (mg/kg)

Table 3: Correlation matrix between the parameters after resuspension (T1) . Spearman $p < 0.05$ n=12

*NS= Not Significant

	Clay	**Silt**	**Sand**	**OM (%)**	**DO (mg/L)**	**TC (mg/L)**	**TP (µg/g)**	**Cd (mg/g)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**Mn (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
Clay	1.00	**0.72**	**-0.74**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Silt	**0.72**	1.00	**-0.99**	NS	**0.59**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sand	**-0.74**	**-0.99**	1.00	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cu (mg/kg)	NS	NS	NS	NS	NS	NS	**NS**	**0.68**	NS	1.00	**0.78**	**0.75**	**0.78**	NS	**0.85**
Fe (mg/kg)	NS	NS	NS	NS	NS	**NS**	**0.66**	NS	NS	**0.78**	1.00	**0.81**	**0.58**	NS	**0.78**
Mn (mg/kg)	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.75**	**0.81**	**1.00**	**0.76**	NS	**0.87**
Ni (mg/kg)	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.78**	**0.58**	**0.76**	1.00	NS	**0.92**
Pb (mg/L)	NS	NS	NS	NS	NS	NS	NS	NS	**0.91**	NS	NS	NS	NS	1.00	**0.82**
Zn (mg/L)	NS	NS	NS	NS	NS	NS	**0.64**	NS	NS	**0.85**	**0.78**	**0.87**	**0.92**	**0.82**	1.00
TN (mg/L)	NS	**0.59**	NS	**0.66**	NS	0.90	**0.62**	NS	NS	NS	NS	NS	NS	NS	NS
TP (µg/g)	NS	NS	NS	**0.78**	NS	**0.66**	1.00	NS	NS	NS	**0.66**	NS	NS	NS	NS
TC (mg/L)	NS	NS	NS	NS	NS	**1.00**	**0.66**	NS	NS	NS	NS	NS	NS	NS	NS

Table 4: Correlation matrix between the parameters after resuspension (T2) . Spearman $p < 0.05$ n=12.

	Clay	**Silt**	**Sand**	**OM (%)**	**DO (mg/L)**	**pH**	**TP (µg/g)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**Mn (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
pH	NS	NS	NS	NS	NS	1.00	NS	NS	NS	**0.66**	NS	NS	NS	NS
Clay	1.00	**0.72**	**-0.74**	NS	NS	NS	NS	**0.59**	NS	NS	NS	NS	NS	NS
Silt	**0.72**	1.00	**-0.99**	NS	NS	NS	NS	**0.62**	NS	NS	NS	NS	NS	NS
Sand	**-0.74**	**-0.99**	1.00	NS	NS	NS	NS	**-0.66**	NS	NS	NS	NS	NS	NS
Cr (mg/kg)	**0.59**	**0.62**	**-0.66**	NS	NS	NS	NS	1.00	NS	NS	NS	NS	**0.69**	**0.99**
Cu (mg/kg)	NS	NS	NS	**0.94**	NS	NS	**0.92**	NS	1.00	**0.70**	**0.66**	**0.93**	NS	**0.97**
Fe (mg/kg)	NS	NS	NS	**0.74**	**-0.78**	**0.66**	**0.83**	NS	**0.70**	1.00	**0.66**	**0.74**	NS	**0.97**
Mn (mg/kg)	NS	NS	NS	**0.75**	**-0.65**	NS	**0.80**	NS	**0.66**	**0.66**	**1.00**	**0.73**	NS	**0.75**
Ni (mg/kg)	NS	NS	NS	**0.97**	**-0.65**	NS	**0.93**	NS	**0.93**	**0.74**	**0.73**	1.00	NS	**0.92**
Pb (mg/L)	NS	NS	NS	NS	0.70	NS	NS	**0.69**	NS	NS	NS	NS	1.00	NS
Zn (mg/L)	NS	NS	NS	**0.93**	NS	NS	**0.94**	**0.99**	0.97	**0.97**	0.75	0.92	NS	1.00
TN (mg/L)	NS	**0.59**	NS	**0.67**	**-0.59**	NS	**0.75**	1.00	**0.62**	**0.68**	**0.70**	**0.61**	NS	**0.68**
TP (µg/g)	NS	NS	NS	**0.96**	NS	NS	1.00	NS	**0.92**	**0.83**	**0.80**	**0.93**	NS	**0.94**
TC (mg/L)	NS	NS	NS	NS	NS	**-0.54**	NS	NS	NS	NS	NS	NS	NS	NS

Bioavailability Change

The BC showed significant results for Cd, Cr, Cu, Ni, and Zn at T1 (Table 5). In T2, the results are significant for all metals only in Transect 3. While in Transect 2 the results were significant for Cr, Fe, and Mn and in Transect 4 the results were significant for all metals except Fe and Mn. The results suggest that after resuspension there is remobilization of metals, especially in the transects closest to the bay.

Table 05: Biovailability Change (BC) After T1(1h) and T2 (24h) for surface sediments of Meriti river

Interval		Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
T1 (1h)	Transect 1	3.0	12.7	11.7	5.5	7.4	14.9	1.8	11.1
	Transect 2	0.2	8.3	2.8	-2.6	-0.3	0.9	0.9	2.4
	Transect 3	**21.8**	**23.7**	**24.2**	13.7	12.3	9.2	9.9	**19.8**
	Transect 4	**19.1**	**25.3**	**16.5**	9.4	9.6	**16.9**	11.0	**21.3**
T2 (24h)	Transect 1	4.5	6.3	4.0	7.2	-6.2	-7.1	-0.9	6.8
	Transect 2	5.3	**21.0**	6.7	**28.0**	**16.7**	5.6	13.2	14.0
	Transect 3	**52.3**	**54.8**	**33.5**	**45.5**	**42.7**	**19.3**	**48.0**	**44.8**
	Transect 4	**35.9**	**35.9**	**26.2**	**26.8**	14.3	8.4	**30.0**	**25.0**

*The bold values correspond to results at least 15% different from metal concentrations in surface sediments before resuspension. This criterion was established in Monte et al. (2015).

Discussion

Concerning the bioavailable fraction, the area has a high risk for biota, especially near the estuary (Monte et al., 2021). The northwestern region of Guanabara Bay is characterized by high levels of contamination by metals (Rego et al., 1993; Machado et al., 2011; Cordeiro et al., 2015; Monte et al., 2019; Monte et al., 2021). However, some factors may regulate bioavailability before and after resuspension even in ecosystems with high concentrations of metals in the sediment, such as the Meriti River.

The grain size composed of fines (clay +silt) can regulate bioavailability. The size of the sediment determines the diffusion and deposition of particles in the environment, and is linked to the processes of adsorption and desorption of contaminants (Delgado et al., 2023).The fine fraction and grain surface area may contribute to trace metal adsorption (Zhang et al., 2014; Gibson et al., 2015; Monte et al., 2022). Grain size can be a complexant of metals, as can the distribution of organic matter (Gibson et al., 2015).

The northwestern region of the bay is characterized by a low-energy environment with less wave influence, resulting in an area with a predominance of fines (Monte et al., 2023).Metals in aquatic ecosystems are influenced by grain size distribution, which directly impacts the solubility and bioavailability of metals in the sediment (Singh et al., 2005; Zhang et al., 2016; Jafarabadi et al., 2018).

The highest concentrations of TN and TC were in transect 1, in the innermost part. Similar behavior was found by several authors, Rodrigues et al. (2009) and Freitas et al. (2019) conducted studies in Sepetiba Bay, while Brandini et al. (2016) studied water and sediment from the Iguaçu River estuary, Guanabara Bay. These authors attributed the decrease in TN relative to the saline gradient to primary productivity, that part of the TN is assimilated by the biota (Freitas et al., 2019).

Regarding resuspension, TC was higher before resuspension in all transects, in contrast to TN, which in transects 1, 3, and 4 showed higher concentrations after resuspension. The results suggest that the lower TC concentrations after resuspension may be related to carbonate formation, and in the case of the higher TN concentrations after resuspension may be related to increased primary productivity (Freitas et al., 2019). TN concentrations in bay and brackish water areas are associated with large quantities of industrial and urban sources that generate excessive terrestrial organic materials (Kwon et al., 2022).

TP concentrations were similar to those found by Borges et al. (Borges et al., 2009) in the sediment layer attributed to recent in the northwestern part of the bay. The higher TP concentrations in the innermost transects (1 and 2) may be associated with the saline gradient in the GB. Brandini et al. (2016), suggested that phosphorus may undergo remineralization by bacterial community activity along the saline gradient. In this study, TP concentrations in sediment before and after resuspension were higher than those found by other studies in Guanabara bay (Borges et al., 2009; Aguiar et al., 2021).

The main sources of TP in aquatic ecosystems are related to increased urbanization and industrialization, and consequently the lack of sewage treatment (Coelho et al., 2004; Dan et al., 2020). In addition to the contribution of anthropogenic P to the aquatic environment, coastal sediments can be considered P sinks due to the burial of OM, adsorption of Fe hydroxides, and authigenic precipitation of carbonated fluorapatite (Freitas et al., 2021).

The study on TP enrichment can provide the ecological state of the aquatic ecosystem and can be a good tool to study the impact of eutrophication (Dan et al., 2020).

The negative correlation between metals, except Pb, and pH (Table 3) before resuspension indicates that pH before resuspension can regulate bioavailability. According to Salomons & Förstner (Salomons & Förstner, 1984). According to Layglon et al. (2022), the oxidation of acid volatile sulfides (AVS) during resuspension could induce an increase in dissolved acidic substances, and consequently, a decrease in pH, directly affecting the bioavailability of metals. A reduction in pH may cause an increase in bioavailability, however, in this study this type of correlation was not observed after resuspension.

In this study, Cr showed a significant positive correlation with the fine fraction and a significant negative correlation with sand at T0 and T1. Some studies conducted sequentially in coastal sediments showed that Cr is mainly bound to the residual fraction (Chen et al., 2019; Ferrans et al., 2021), Cr is one of the most abundant metals in the earth's crust, which may explain these results (Baraud et al., 2017; Ferrans et al., 2021; Monte et al., 2022).

However, the Cr found in the present study comes from anthropogenic activity in the GB watershed, such as industries (Godoy et al., 2012; Monte et al., 2022). Chen et al. (Chen et al., 2019) conducted a study of dredged sediments in a port area in China, and according to the results found by the authors, it was concluded that Cr was mainly bound to Fe/Mn oxyhydroxides, opposite to some studies, which report that Cr is mainly bound to the residual fraction, showing low remobilization to other more bioavailable fractions (Neyestani et al., 2016; Schintu et al., 2016; Ferrans et al., 2021).

However, in dredged sediments, the behavior of Cr is different, due to the strong interference of anthropogenic activity, which results in higher percentages bound to Fe/Mn oxyhydroxides (Monte et al., 2022). Typical behavior of surface sediments influenced by anthropogenic activities (Radomirović et al., 2021).

The northwestern region of the bay is characterized by high concentrations of organic matter, demonstrating a eutrophic environment (Kjerfve et al., 1997; Machado et al., 2002; Monte et al., 2021). OM in the sediment is influenced not only by anthropogenic sources (domestic sewage and agricultural waste) as well as by the grain size of the sediment (Tang et al., 2023).

Some authors indicated the importance of OM in the complexation of metals in Guanabara Bay (Kehrig et al., 2003; Covelli et al., 2012) and how it would influence the remobilization of trace metals (Carvalho et al., 1991). Regarding the potential bioavailability of metals, Carvalho et al. (Carvalho et al., 1991) suggested that OM content could cause the low bioavailability observed in Guanabara Bay (Monte et al., 2022).

In this study, OM content showed a positive correlation with Cu, Fe, Mn, Ni, and Zn before and after resuspension, only T1, while T2 showed no significant correlation with any metal. The non-correlation between metals and OM after 24 h may be related to the fact of decomposition and mineralization of OM after long intervals of resuspension.

Disposal of dredged sediments in oxidizing water may cause metals to remobilize into the water column and increase their bioavailability (Machado et al., 2011). In addition, the disposal of dredged sediments in an oligotrophic environment may influence the decomposition and mineralization of organic matter in this environment (Prygiel et al., 2015; Monte et al., 2022).

In eutrophic contaminated environments, such as the GB, there is the formation of sulfides, which in theory regulate bioavailability. In environments with bioavailable metals, some metals (Cd and Pb) can penetrate into tissues as essential elements (Ca, Na, and Mg) due to the exchange capacity between ions, or as in the case of Cu that can be adsorbed from water as hydrated ions (Moiseenko, 2019).

The high concentrations of Cu in MR, some above the ERL, were reported by Cordeiro et al. (Cordeiro et al., 2015), attributed to the large input of domestic and industrial sewage in this estuary, however, the Cu.

However, the copper found in the study by these authors had the highest percentage in unavailable fractions in this study. In environments with a high concentration of organic matter, Cu^{2+} may have lower mobility, due to the high affinity between the ion and organic matter (Reimann & De Caritat, 1998; Ribeiro et al., 2013). Moreover, the bioavailability of the metal can be controlled in an environment rich in organic matter, due to the development of microorganisms, which can influence the speciation of the metal (Ribeiro et al., 2013).

Nagajaran et al. (2023) explained that Fe and Mn oxides have a direct impact on Cu mobility and are also metal complexing agents due to the strong relationship between surface area and volume.

Ni showed a positive correlation with OM at T0 and T1. Ni has an affinity for OM, which explains the correlation before resuspension. However, after resuspension the oxidation of sulfides may have contributed to the high Ni concentrations in the sediment in the present study, as well as the oxidation of organic matter in the sediment, which contributes to the higher metal concentrations after resuspension (Prygiel et al., 2015; Monte et al., 2019).

According to Baptista-Neto et al. (2013), the sources of Ni in GB are related to the discharge of untreated industrial sewage and urban activities. Furthermore, Ni can be related to fossil fuel burning and mining (Jafarabadi et al., 2018), in the surroundings of the study area there are several highways, which can contribute to the contribution of the metal. According to Chaharlang et al. (2021), the burning of oil and its derivatives forms large clouds in humid areas, causing Ni contamination in these regions.

In marine sediments, Ni is mainly bound to Fe and Mn oxides and hydroxides, which regulate bioavailability (Chakraborty et al., 2019) and are produced after the oxidation of sulfides in resuspension processes (Morse, 1994; Machado et al., 2011; Monte et al., 2015), which may explain the positive correlations with Fe and Mn before and after resuspension.

The positive correlations of Pb with Cr before and after resuspension suggest that both metals have similar sources in the study area. The high Pb concentrations in the GB can be explained by the influence of the erosion process, rapid industrialization, domestic and industrial sewage, and fossil fuel burning (Baptista et al., 2013; Monte et al., 2021).

The main sources of Pb in the aquatic environment, apart from burning gasoline, are pesticides, electronic waste, pipelines, ore processing, ceramic dyes and glazes, and recycling of Pb-acid batteries (Yu et al., 2021). The northwestern region of the Bay receives large quantities of waste, which flows down the Iguaçu, Estrela, and Meriti rivers and drains the main industrial center in the state of Rio de Janeiro (Monte et al., 2023). The higher Pb concentrations after resuspension in all transects except Transect 1 may be related to the oxidation of organic matter, which Pb has a high affinity for (Dang et al., 2020).

Zinc was the only metal to show concentrations above the ERM in this study. The metal showed positive correlations with OM at T0 and T1 and with Fe and Mn at T0, T1, and T2. Zn is associated with domestic and industrial sewage (Silveira et al., 2011; Monte et al., 2021). Moreover, Zn may be related to atmospheric deposition in industrial areas, especially, those with metallurgical plants (Ghosh et al., 2019). In the aquatic environment, Zn occurs mainly in the form of Zn^{+2}, the ion shows affinity with organic matter Fe and Mn oxides and hydroxides, and the fine fraction (Fonseca et al., 2013; Vidal-Durà et al., 2018). However, the oxidation of organic matter and sulfides can increase the bioavailability of Zn after resuspension (Caetano et al., 2003; Monte et al., 2005; Freitas et al., 2019) which may explain the remobilization after resuspension.

The BC showed great remobilization in some transects after resuspension, this remobilization may indicate the adsorption of metals that were in the water column or possible phase change, i.e., metals that were in less bioavailable phases after resuspension became bioavailable. The results in this study were different from those found by Monte et al. (Monte et al., 2019) in a study carried out in the Iguaçu River estuary, located in Guanabara Bay. After resuspension in two intervals (1 hour and 24 hours), the authors found negative values of BCI, which they attributed to the oxidation of contaminants adsorbed to the sediment, and consequently mobilization to the water column.

Another study by Monte et al. in a mesotrophic estuary from Brazil, and the values of BCI were positives for majority samples, however with low remobilization after resuspension. In this estuary, the percentage of total carbon organic (TOC) was low for majority samples due to be a mesotrophic estuary, different of Guanabara Bay, which is eutrophic estuary. Furthermore, after resuspension, the percentage of trace metals in strong bound was lower compared to before resuspension, showing change of geochemical phase. Although low percentage, these results showing the importance of OM for bioavailability of trace metals in sediments in mesotrophic estuary (Monte et al., 2022).

The possible difference in the remobilization of metals in the sediment between the Meriti River estuary and the Iguaçu estuary may be related to the organic matter content, although both are considered eutrophic environments, the Meriti River has a much higher percentage of OM. After resuspension, some transects in this study showed higher percentages of organic matter, which may be related to the bacterial community of the area and all the kinetics of production and degradation of OM (Monte et al., 2022b).

Dredging activities in eutrophic environments must be managed, the use of bioavailable extractions along with sediment quality indices after resuspension may be a cheaper and more efficient tool in managing and predicting the behavior of contaminants before and after resuspension. In addition, further study of the bacterial community in the sediment before and after resuspension may expand the knowledge about the dynamics of the remobilization of contaminants after dredging.

Conclusion

The resuspension of sediments in eutrophic environments with high metal contamination, such as Guanabara Bay, can cause the remobilization of contaminants, which increases the bioavailability of metals, and consequently the risk to biota. There was in the remobilization between the transects, transects closer to the bay showed higher remobilization, suggesting that there is a strong influence of the saline gradient on the dynamics of contaminants after resuspension.

Unlike other studies in the area, BC showed positive results, reinforcing that resuspension causes an increase in the bioavailability of metals in the sediment, which can be a major risk for the biota, especially benthic biota.

Organic matter is one of the main complexing agents in this type of environment, regulating bioavailability. The dynamics of organic matter mineralization should be further investigated, together with the type of bacterial community in the sediment, which may be the key to understanding the remobilization dynamics in this type of environment, which should be investigated in future studies.

The contamination in Guanabara Bay is an old and complex problem, dredging activities are recurrent, however, need more understanding of the dynamics of the contamination. The northwest region is the area with the highest contamination by metals, such as Cr, Cu, Ni, Pb, and Zn, due to the discharge of domestic and industrial sewage. In this sense, the investment in basic sanitation programs and the increase of sewage treatment plants around the Bay is necessary. Moreover, the insertion of chemical analysis after resuspension in the norms that regulate the dredging activity will make the activity safer for the aquatic ecosystem.

Acknowledgements

CNM thanks a PhD grant from Brazilian Ministry of Science (CAPES). We thank financial support from CNPq (Proc. No. 481898/2012-3) and CAPES (Financial Code 001).

References

Aguiar, V. M. C., Baptista Neto, J. A., Fonseca, E.M. (2021). Assessment of bottom sediment quality in Niterói harbor (Brazil, South America) through ecological indexes concerning nutrients and trace metals. Environmental Science and Pollution Research.DOI: https://doi.org/10.1007/s11356-021-15173-x

Ashayeri, S.Y., Keshavarzi,B., Moore, F., Ahmadi, A., Hooda, P.S. (2023). Risk assessment, geochemical speciation, and source apportionment of heavy metals in sediments of an urban river draining into a coastal wetland.Marine Pollution Bulletin,186, 114389.

https://doi.org/10.1016/j.marpolbul.2022.114389.

Baptista Neto, J.A.., Peixoto, T. C. S.., Smith, B. J..,MCalister, J. J.., Patchineelam, S. M.., Patchineelam, S. R..,Fonseca, E. M. (2013). Geochronology and heavy metal flux to Guanabara Bay, Rio de Janeiro state: a preliminary study, Anais da Academia Brasileira de Ciências, 85(4),1317-1327. DOI: http://dx.doi.org/10.1590/0001-3765201394612

Baraud, F..,Leleyter, L.., Lemoine, M.., Hamdoun, H.(2017). Cr in dredged marine sediments: anthropogenic enrichment, bioavailability and potential adverse effects. Marine Pollution Bulletin, 120, 303-308. DOI: https://doi.org/10.1016/j.marpolbul.2017.05.039.

Barrocas P.R.., Wasserman J.C. (1993). O mercúrio na Baía de Guanabara: um revisão histórica. Programa de Pós graduação em Geoquímica, UFF, Niterói, RJ, 115-127.

Bejarano-Ramirez,I.., Jurado,J.M.., Muñiz-Valencia,R.., Alcázar,A.., Ceballos-Maganã, S.G.., Olivos-Ortiz,A.., Rangel.O. (2017). Comparative study of As, Cd, Cu, Cr, Mg, Mn, Ni, Pb and Zn concentrations between sediment and water from estuary and port. Int. J. Environmental Science and Technology 14,1333–1342. DOI: https://doi.org/10.1007/s13762-016-1235-5

Birch, G,F, ., Hogg ,T.D. (2011).Sediment quality guidelines for copper and zinc for filter-feeding estuarine oysters? Enviromental Pollution, 159, 108-115 .DOI: https://doi.org/10.1016/j.envpol.2010.09.015

Borges, A.C.., Sanders, C.J.., Santos, H.L.R.., Araripe, D.R.., Machado, W.., Patchineelam, S.R.(2009). Eutrophication history of Guanabara Bay (SE, Brazil) recorded by phosphorus flux to sediments from a degraded mangrove area. Marine Pollution Bulletin, 58(11), 1750-1765. DOI: 10.1016/j.marpolbul.2009.07.025

Brandini,N.., Rodrigues,A.P.C..,Abreu,I.M..,Cotovicz, Júnior,L.C..,Knoppers,B.A..,Machado,W.(2016). Nutrient behavior in a highly-eutrophicated tropical estuarine system. Acta Limnologica Brasilensis, 28,21. DOI: http://dx.doi.org/10.1590/s2179-975x3416

Caetano, M..,Madureira..,M.J.., Vale,C. (2003).Metal remobilization during resuspension of anoxic contaminated sediment: short-term laboratory study. Water air and soil Pollution, 143,23-40. DOI: https://doi.org/10.1023/A:1022877120813

Carvalho, C. E. V.., Lacerda, L. D..,Gomes, M. P. (1991). Heavy metal contamination of the marine biota along the Rio de Janeiro Coast, SE Brazil. Water, Air, and Soil Pollution, 57/58, 645-665. DOI: https://doi.org/10.1007/BF00282928

Chaharlang, B.H., Bakhtiari, A.R., Mohammadi, J. et al. (2021).Modeling Sediment Ni and V Spatial Distribution to Identify Hotspots in the Shadegan Wildlife Refuge, at the Head of the Persian Gulf. Bulletin of Environmental Contamination Toxicology, 106, 475–484. DOI: https://doi.org/10.1007/s00128-021-03108-8

Chakraborty ,P.., Jayachandran, S.., Lekshmy, J.., Padalkar, P.., Sitlhou, L.., Chennuri, K.., Shetye,S.., Sardar A.., Khandeparker , R . (2019). Seawater intrusion and resuspension of surface sediment control mercury (Hg) distribution and its bioavailability in water column of a monsoonal estuarine system.Sci. Total Environment, 660: 1441-144. DOI: https://doiorg/101016/jscitotenv201812477

Chen, C.., Ju, Y.., Chen, C .., Dong, C.(2019) Changes in the total content and speciation patterns of metals in the dredged sediments after ocean dumping: Taiwan continental slope. Ocean Coastal Management, 181,104893. DOI: https://doi.org/10.1016/j.ocecoaman.2019.104893

Coelho, J.P.., Flindt, M.R.., Jensen, H.S.., Lillebø, A.I.., Pardal, M.A. (2004). Phosphorus speciation and availability in intertidal sediments of a temperate estuary: relation to eutrophication and annual P-fluxes. Estuarine Coastal and Shelf Science,61, 583–590. DOI: https://doi.org/10.1016/j.ecss.2004.07.001

Coelho,V.M.B. (2007). Baia de Guanabara–Uma História de Agressão Ambiental. Rio de Janeiro. Rio de Janeiro: Casa da palavra. 278p.

CONAMA (2012) Procedures for the evaluation of dredging materials in Brazilian jurisdictional waters. Res. No. 454/2012 from the Conselho Nacional do Meio Ambiente. Diário Oficial da República Federativa do Brasil, Brasília (in Portuguese)

Cordeiro, R.C.,.,Machado, W..,Santelli, R.E.,Figueiredo Jr,A.G..,Seoane,J.C.S.., Oliveira,E.P..,Freire,A.S..,Bidone, E.D.., Monteiro,F.F.., Silva,F.T.., Meniconi,M.F.G. (2015). Geochemical fractionation of metals and semimetals in surface sediments from tropical impacted estuary (Guanabara Bay, Brazil). Enviromental Earth Science, 74, 1363–1378. DOI: https://doi.org/10.1007/s12665-015-4127-y

Cotou,E..,Gremare,A.., Charles,F.., Hatzianestis,I.(2005). Potential toxicity of resuspended particulate matter and sediments: Environmental samples from the Bay of Banyuls-sur-Mer and Thermaikos Gulf . Continental Shelf Research,25, 2521 -2532. DOI: https://doi.org/10.1016/j.csr.2005.08.005

Cotta,J.A.O.., Rezende,M.O.O.., Piovani,M.R .(2006). Avaliação do teor de metais em sedimento do rio Betari no Parque Estadual Turístico do Alto Ribeira - PETAR, São Paulo, Brasil. Química Nova, 29, 1,40-45.DOI: https://doi.org/10.1590/S0100-40422006000100009

Covelli, S.., Protopsalti, I.., Acquavita,A.., Sperle, M.., Bonard,I.M., Emili A. (2012). Spatial variation, speciation and sedimentary records of mercury in the Guanabara Bay (Rio de Janeiro, Brazil). Continental Shelf Research,35, 29–42. https://doi.org/10.1016/j.csr.2011.12.003

Cui, S., Gao, S., Zhang, F., Fu, Q., Wang, M., Liu, D., Chen, P. (2021). Heavy metal contamination and ecological risk in sediment from typical suburban rivers. River Research and Applications. doi:10.1002/rra.3701

Dan, S.F.., Liua,S.., Yang, B. (2020). Geochemical fractionation, potential bioavailability and ecological risk of phosphorus in surface sediments of the Cross River estuary system and adjacent shelf, South East Nigeria (West Africa). Journal of Marine Systems, 01, 103244. DOI: https://doi.org/10.1016/j.jmarsys.2019.103244

Dang, D.H. ., Layglon,N. ., Ferreto,N. ., Omanovic. ., Mullot,J .., Lenoble,V. ., Mounier,S. .,Garnier, C.(2020). Kinetic processes of copper and lead remobilization during sediment resuspension of marine polluted sediments. Science Total Environment,698, 134120. DOI: https://doi.org/10.1016/j.scitotenv.2019.134120

Delgado,J.F., Lima, L.S., Vieira,K., Baptista Neto, J.A., Fonseca, E.M. (2023). Extração sequencial bcr para frações geoquímicas e avaliação de Zn, Ni, Cd, Cu e Pb nos sedimentos costeiros no complexo portuário de Santos, sudeste do Brasil. Revista Sistema e Gestão, 18, 65-75. DOI: 10.20985/1980-5160.2023.v18n1.1884

Eggleton, J.., Thomas, K.V.A. (2004). Review of Factors Affecting the Release and Bioavailability of Contaminants During Sediment Disturbance Events. Environmental Internacional, 30,973-980. DOI:http://dx.doi.org/doi:10.1016/j.envint.2004.03.001

Ferrans, L.., Jani, Y..,Burlakovs.., Klavins, M.., Hogland, W. (2020). Chemical speciation of metals from marine sediments: Assessment of potential pollution risk while dredging, a case study in southern Sweden. Chemosphere. 2021, 263, 128105. DOI: https://doi.org/10.1016/j.chemosphere.2020.128105

Fistarol, G..,Coutinho, F.H..,Moreira, A.P.B.., Cánovas, A.., PaulaJr, S.E.M.., Coutinho,R.., Moura, R.L..,Valentin, J.L.., Tenenbaum,D.R.,.,Paranhos,R.., Valle,R.A.B.., Vicente,A.C.P..,Pereira,R.C..,Kruger, R..,Rezende,C.E.., Thompson,C.C.., Salomon,P.S., Thompson,F.L. (2015). Environmental and Sanitary Conditions of Guanabara Bay, Rio de Janeiro. Frontiers in Microbiology, 6,1232- 1242. DOI: https://doi.org/10.3389/fmicb.2015.0123

Fonseca, E.M..,Baptista-Neto, J.A.., Silva, C.G..,Mcalister, J.J..,Smith, B.J.., Fernandez, M.A. (2013). Stormwater impact in Guanabara Bay (Rio de Janeiro): Evidences of seasonal variability in the dynamic of the sediment heavy metals. Estuarine and Coastal Shelf Science, 130, 161-168.DOI: https://doi.org/10.1016/j.ecss.2013.04.022

Freitas, A.R.., Rodrigues, A.P.C..,Monte, C.N.., Soares, A.F..,Santelli, R.E..,Machado,W.., Sabadini-Santos, E. (2019). Increase in the bioavailability of trace metals after sediment resuspension. SN Applied Sciences, 1:1288. DOI: https://doi.org/10.1007/s42452-019-1276-8

Freitas, F. S., Montone, R., Machado, E., Martins, C. (2021). Total phosphorus records in coastal Antarctic sediments: burial and evidence of anthropogenic influence on recent input. Marine Chemistry, 237, [104037]. DOI:https://doi.org/10.1016/j.marchem.2021.104037

Ghosh, S.., Bakshi,M.., Kumar,A.., Ramanathan,A.L.., Biwas,J.K.., Bhattacharyya, S.., Chaudhuri,P.., Saheen,S.M.., Rinklebe,J. (2019). Assessing the potential ecological risk of Co, Cr, Cu, Fe and Zn in the sediments of Hooghly–Matla estuarine system, India. Environmental Geochemistry and Health, 41, 53–70. DOI: https://doi.org/10.1007/s10653-018-0119-7

Gibson,B.D.., Ptacek,C.J..,Blowes, D.W.., Daugherty, S.D. (2015). Sediment resuspension under variable geochemical conditions and implications for contaminant release. Journal of Soils and Sediments, 15, 1644–1656. DOI: https://doi.org/10.1007/s11368-015-1106-6

Godoy, J. M.., Oliveira, A. V..,Almeida, A. C.., Godoy, M. L. D. P.., Moreira, I..,Wagner, A. R. .,Figueireido Junior, A. G. (2012). Guanabara Bay Sedimentation Rates based on 210Pb Dating: Reviewing the Existing Data and Adding New Data. Journal of Brazilian Chemical Society,23, 7, 1265-1273. DOI: https://doi.org/10.1590/S0103-50532012000700010

Guo,W,., Huo, S.., Xi, B..,Zhang, J..,Wu, F . (2015). Heavy metal contamination in sediments from typical lakes in the five geographic regions of China: Distribution, bioavailability, and risk. Ecological Engineering, 81243–255. DOI: https://doi.org/10.1016/j.ecoleng.2015.04.047

Herms,F.., Gurgel, M. (2012).Distribuição de metais pesados nos sedimentos da Baia de Sepetiba, RJ. Baia de Sepetiba Estado da arte.Corbã: Rio de Janeiro, 51-177.

IBGE. Censo Demográfico2010. Available at: http://www.ibge.gov.br

Jafarabadi, A,R.., Bakhtiari, A.R.., Spanò, N.C.., Cappello, T. (2018).First report of geochemical fractionation distribution, bioavailability and risk assessment of potentially toxic inorganic elements in sediments of coral reef Islands of the Persian Gulf, Iran. Marine Pollution Bulletin,137, 185-197. DOI: https://doi.org/10.1016/j.marpolbul.2018.09.052

Kehrig,H.A .,Costa,M., I, Moreira ., Malm,O. (2003). Total and methylmercury in a Brazilian estuary, Rio de Janeiro. Marine Pollution Bulletin. 44, 1018-1023

Kjerfve, B.., Ribeiro, C.H.A..,Dias, G.T.M..,Filippo, A.M.., Quaresma, V.S. (1997). Oceanographic characteristics of an impacted coastal bay: Baia de Guanabara, Rio de Janeiro, Brazil. Continental Shelf Research, 17, 1609-1643. DOI: https://doi.org/10.1016/S0278-4343(97)00028-9

Kwon, I., Lee, C., Lee, J., Kim, B., Park, S.Y., Kim, J., Lee,J., Noh,J., Kwon, B., Son,S., Yoon, H.J., Nam,J., Choi., Khim,J.S. (2022) . The first national scale evaluation of total nitrogen stocks and burial rates of intertidal sediments along the entire coast of South Korea,Science of The Total Environment, 827, 154320.DOI: https://doi.org/10.1016/j.scitotenv.2022.154320.

Lacerda,L.D..,ParaquettI,H.H.M..,MolisanI,M.M.., Bernardes, M.C. (2007).Transporte de Materiais na Interface Continente-Mar na Baía de Sepetiba, Rio de Janeiro. Congresso Latino-Americano de Ciências do Mar, Florianópolis.

Layglon, N., Lenoble,V., Longo, L., D'Onófrio,S., Mounier,S., Mullot,J., Sartori,D., Omanović, D., Garnier, C., Misson,B. (2022). Cd transfers during marine sediment resuspension over short and long-term period: Associated risk for coastal water quality. Marine Pollution Bulletin, 180, 113771. DOI: https://doi.org/10.1016/j.marpolbul.2022.113771.

Lima, M, C.., Giacomelli, M, B, O.., Süpp, V.., Roberge, F, D.., Barrera, P, B. (2001).Especiação de cobre e chumbo em sedimento do rio Tubarão (SC) pelo método Tessier. Química Nova, 24, 734- 744.DOI: https://doi.org/10.1590/S0100-40422001000600005

Long ,E.R.., MacDonald,D.D.., Smith, S.L.., Calder, F.D. (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management,19:81–97. DOI: https://doi.org/10.1007/BF02472006

Machado, W.., Moscatelli, M..,Rezende, L. G.., Lacerda, L.D. (2002). Mercury, Zinc, and Copper Accumulation in Mangrove Sediments Surrounding a Large Landfill in Southeast Brazil. Environmental Pollution, 120, 455 – 461. DOI: https://doi.org/10.1016/S0269-7491(02)00108-2

Machado,W..,Rodrigues, A.P.C..,Bidone, E.D..,Sella,S.M..,SantellI, R.E.(2011). Evaluation of Cu potential bioavailability changes upon coastal sediment resuspension: an example on how to improve the assessment of sediment dredging environmental risks. Environmental Science and Pollution Research, 18,1033-1036. DOI: http://dx.doi.org/doi:10.1007/s11356-011-0517-1

Maddock, J.E.L.., Carvalho, M.F.., Santelli, R.E.., Machado, W. (2007). Contaminant Metal Behavior During Re-suspension of Sulphidic

Estuarine Sediments. Water, Air and Soil Pollution, 181 193-200. DOI: https://doi.org/10.1007/s11270-006-9290-z

Malferrari, D,., Brigatti ,M.F,., Laurora, A,., Pini, S. (2009). Heavy metals in sediments from canals for water supplying and drainage: mobilization and control strategies. Journal of Hazardous Materials, 161 723–729. DOI: https://doi.org/10.1016/j.jhazmat.2008.04.014

Moiseenko, T.I.(2019).Bioavailability and Ecotoxicity of Metals in Aquatic Systems: Critical Contamination Levels. Geochemistry International,57, 7, 737–750. DOI: https://doi.org/10.1134/S0016702919070085

Monte,C.N..,Rodrigues, A.P.C..,Cordeiro, R.C..,Freire,A.S.., Santelli, R.E.., Machado,W. (2015). Changes in Cd and Zn bioavailability upon an experimental resuspension of highly contaminated coastal sediments from a tropical estuary. Sustainable Water Resources Management ,1,332-335. DOI: https://dx.doi.org/doi:10.1007/s40899-015-0034-3

Monte,C.N..,Rodrigues, A.P.C.., Freire, A.S..,Santelli, R.E.., Machado, W. (2017).Metal Bioavailability in Contaminated Estuarine Sediments from a Highly-Impacted Tropical Bay. Revista Virtual de Química, 9:52007-2016

Monte, C.N..,Rodrigues, A.P.C.., Freitas, A.R.., Freire, A.S.., Santelli, R.E.., Braz, B.F.., Machado, W. (2019). Dredging impact on trace metal behavior in a polluted estuary: a discussion about sampling design. Brazilian Journal of Oceanography, 67 19227. DOI: http://dx.doi.org/10.1590/S1679-87592019022706701

Monte,C.N.., Rodrigues, APC.., Freitas,A.R..,Braz ,B.F.., Freire,A.S.., Cordeiro,R.C.., Santelli, R.E..,Machado W. (2021). Ecological risks associated to trace metals of contaminated sediments from a densely urbanized tropical eutrophic estuary. Environmental Monitoring Assessment, 193(12). DOI: https://doi.org/10.1007/s10661-021-09552-7

Monte, C.N..,Rodrigues, A.P.C..,Freitas, A.R. ., Braz, BF, Freire A.S, .,Cordeiro,R.C, ., Santelli, R.E. ., Machado, W. Changes in chromium bioavailability on resuspension of contaminated sediments from a tropical estuary. In: Trace Metals: Sources, Applications and Environmental Implications. Org: Thygesen, O.M. Nova Publishers. Nova York. 2022,180p.

Monte, C.N.., Rodrigues,A.P.C..,Galvão, P.M.A.., Ponte,G.C.., Malm,O.., Wasserman, J.C.., Machado, W. (2022b) Mercury methylation upon coastal sediment resuspension: a worst case approach under dark conditions Environmental Monitoring Assessment, 194: 805.DOI: https://doi.org/10.1007/s10661-022-10485-y

Monte, C. N., Rodrigues, A. P.C., Silva, M. C., Ferreira, L.J.S., Monte, G., Silveira, C.S., Cordeiro, R.C., Machado, W. (2023). Assessment of eutrophication from phosphorus remobilization after resuspension of coastal sediments from an urban tropical estuary. Environmental Science and Pollution Research, 30(24), p. 65500-65511. DOI: https://doi.org/10.1007/s11356-023-27099-7

Montero,N.M.J.., Belzunce-Segarra,M.J.., Gonzalez,J-L.., Menchaca, I.., Garmendia,J.M.., Etxebarria,N.., Franco,J. (2013). Application of Toxicity Identification Evaluation (TIE) procedures for the characterization and management of dredged harbor sediments . Marine Pollution Bulletin, 71, 259-268.DOI: https://doi.org/10.1016/j.marpolbul.2013.01.038

Morse ,J.W. (1994).Interactions of trace metals with authigenic sulfide minerals: implications for their bioavailability. Marine Chemistry, 46 1-6. DOI: https://doi.org/10.1016/0304-4203(94)90040-X

Nagarajan, R., Eswaramoorthi, S.G., Anandkumar,A., Ramkumar,M. (2023).Geochemical fractionation, mobility of elements and environmental significance of surface sediments in a Tropical River, Borneo. Marine Pollution Bulletin.192,115090. DOI: https://doi.org/10.1016/j.marpolbul.2023.115090.

Neyestani, M.R.., Bastami, K.D.., Esmaeilzadeh, M.., Shemirani, F.., Kazaali, A.., Molamohyeddin, N.., Afkham, M.., Nourbakhsh, S..,Dehghani, M..,Aghaei, S.., Firouzbakht, M. (2016). Geochemical speciation and ecological risk assessment of selected metals in the surface sediments of the northern Persian Gulf. Marine Pollution Bulletin. 201615, 603-611. DOI: https://doi.org/10.1016/j.marpolbul.2016.05.024

Oliveira, R. C.B.., Marins, R. V. (2011).Dinâmica de Metais-Traço em Solo e Ambiente Sedimentar Estuarino como um Fator Determinante no Aporte desses Contaminantes para o Ambiente Aquático: Revisão. Revista Virtual de Química, 3, 2, 88-102. DOI: https://doi.org/10.5935/1984-6835.20110014

Peña-Icart,M..,Mendiguchia,C..,Villanueva-Tagle,M.E.., Pomares-Alfonso, M.S,.,Moreno,C. (2014).Revisiting methods for the determination of bioavailable metals in coastal sediments. Marine Pollution Bulletin, 89,67-74. DOI: http://dx.doi.org/10.1016/j.marpolbul.2014.10.034

Pestana,M. H.D. (1989). Partição geoquímica de metais pesados em sedimentos estuarinos nas Baias de Sepetiba e da Ribeira, RJ. Rio de Janeiro. Dissertação de mestrado (mestrado em geociências – geoquímica). Universidade Federal Fluminense.

Prygiel, E.., Superville, P.J.., Dumoulin, D..,Lizon, F.., Prygiel, J.., Billon, G. (2015).On biogeochemistry and water quality of river canals in Northern France subject to daily sediment resuspension due to intense boating activities. Environmental Pollution 197, 295-308. DOI: https://doi.org/10.1016/j.envpol.2014.11.022

Radomirović, M., Mijatović, N., Vasić, M. et al. (2021).The characterization and pollution status of the surface sediment in the Boka Kotorska Bay, Montenegro. Environmental Science and Pollution Research, 28, 53629–53652. DOI: https://doi.org/10.1007/s11356-021-14382-8

Rebello, A.L.,.,Haekel, W.,.,Moreira I..,Santelli, R.E.., Schroeder, F. (1986). The fate of heavy metals in an estuarine tropical system. Marine Chemistry,18,215–225. DOI: https://doi.org/10.1016/0304-4203(86)90009-5

Rego, V. S.., Pfeiffer, W. C.., Barcellos, C. C..,Malm, O..,Souza, C. M. M. (1993). Heavy metal transport in the Acari-São João de Meriti River System, Brazil. Environmental Technology,14,167-174. DOI: https://doi.org/10.1080/09593339309385276

Reimann, C.., De Caritat, P. (1998). Chemical elements in the environment: factsheets for the geochemist and environmental scientist. Springer-Verlag, Heidelberg.398p.

Ribeiro, A.P.., Figueiredo, A.M.G..,Santos, J.O.., Dantas, E..,Cotrim, M.E.B.., Figueira, R.C.L.., Silva-Filho, E.V.., Wasserman, J.C. (2013). Combined SEM/AVS and attenuation of concentrations models for the assessment of bioavailability and mobility in sediments of Sepetiba Bay (SE Brazil). Marine Pollution Bulletin, 68,1/2, 55-63. DOI: https://doi.org/10.1016/j.marpolbul.2012.12.023

Rodrigues, R.P.., Knoppers, B.A..,Souza, W.F.L.., Santos, E.S. (2009). Suspended matter and nutrient gradients of a small-scale river plume in Sepetiba Bay, SE-Brazil. Brazilian Archives of Biology and Technology, 52(2):503–512. DOI: https://doi.org/10.1590/S1516-8913200900 0200030

Rodrigues, A.P.C.., Lemos,A.,P.., Monte,C.N..,Rodrigues, S.K.., Cesar,R.G..,Machado, W. (2017). Environmental risk in a coastal zone from Rio de Janeiro state (Brazil) due to dredging activities. In: Araújo, C.V.M & Shinn, C. Ecotoxicology in Latin America. Nova Publishers, New York. 183-200.

Rodrigues, A.P.C.., Pereira, M.M.., Campos, A.., da Silva Quaresma, T.L.., Pova, R.., Vieira, T.C.., Diaz, R.A.., Moreira, M.., Araripe, D.., Monte, C.N., Machado, W. (2023). Bioavailability Assessment of Metals from the Coastal Sediments of Tropical Estuaries Based on Acid-Volatile Sulfide and Simultaneously Extracted Metals. Coasts, 3, 313–327. DOI: https://doi.org/10.3390/ coasts3040019

Salomons,W..,Förstner, U. (1984).Metals in the hydrocycle.Springer Verlag.349p

Schintu, M. .,Marrucci, A. .,Marras, B. ., Galgani, F. ., Buosi, C. .,Ibba, A.a Cherchi, A. (2016).Heavy metal accumulation in surface sediments at the port of Cagliari (Sardinia, western Mediterranean): environmental assessment using sequential extractions and benthic foraminifera. Marine Pollution Bulletin,11, 45–56. DOI: https://doi.org/10.1016/j.marpolbul.2016.07.029

Silveira,R. P.., Rodrigues, A. P. C.., Santelli, R. E.., Cordeiro, R. C.., Bidone, E. D. (2011). Mass balance in the monitoring of pollutants in tidal Rivers of the Guanabara Bay, Rio de Janeiro, Brazil. Environmental Monitoring Assessment, 181, 165–173. DOI: http://dx.doi.org/10.1007/s10661-010-1821-9

Singh, K.P..,Mohan, D.., Singh, V.K.,.,Malik, A.(2005). Studies on distribution and fractionation of heavy metals in Gomti river sediments-a tributary of the Ganges, India. Journal of Hydrology,312, 14–27. https://doi.org/10.1016/j.jhydrol.2005.01.021

Tang, D., Liu, X., Xia,Z., Hou,J., Yang,X., Li,P., Yuan,X. (2023). Sources of organic matter and carbon stocks in two mangrove sediment cores and surface sediment samples from Qinglan Bay, China.Science of The Total Environment,893, 164897. DOI: https://doi.org/10.1016/j.scitotenv.2023.164897.

Teixeira, M., Cesar, R., Abessa, D., Siqueira, C., Lourenço, R., Vezzone, M., Fernandes, Y., Koifman, G., Perina, F. C., Anjos, R. M., Polivanov, H., Castilhos, Z. (2023). Ecological risk assessment of metal and hydrocarbon pollution in sediments from an urban tropical estuary: Tijuca lagoon (Rio de Janeiro, Brazil). Environmental Science and Pollution Research, 30(1), 184-200. DOI: https://doi.org/10.1007/s11356-022-22214-6

Verstijnen, Y.J.M., Lucassen, E.C.H.E.T., Wagenvoort, A.J. et al. (2024). Trophic Transfer of Cd, Cu, Pb, Zn, P and Se in Dutch Storage Water Reservoirs. Archives of Environmental Contamination and Toxicology, DOI: https://doi.org/10.1007/s00244-023-01041-x

Vidal-Durà, A.., Burkea, I.T.., Stewartb,D.I.., Mortimer,R.J.G. (2018). Reoxidation of estuarine sediments during simulated resuspension events: Effects on nutrient and trace metal mobilisation. Estuarine and Coastal Shelf Science ,31,40-55. DOI: https://doi.org/10.1016/j.ecss.2018.03.024

Wasserman, J.C.., Wasserman, M.A. .,Barrocas, P.R.G. .,Almeida, A.M. (2016). Predicting pollutant concentrations in the water column during dredging operations: Implications for sediment quality criteria. Marine Pollution Bulletin, 108 24-32. DOI: http://dx.doi.org/10.1016/j.marpolbul.2016.05.005 0025-326X

Yu, Y., Li, Y., Li, B. et al. (2021). Identification and quantification of lead source in sediment in the northern East China Sea using stable lead isotopes. Journal of Oceanology and Limnology, 39, 1887–1900. DOI: https://doi.org/10.1007/s00343-020-0286-0

Zhang ,C., Zhi-Gang, Y.U., Zeng, Z., Jiang,G., Yang, M ., Cui,F., Zhu,M., Shen,L., Hu, L. (2014). Effects of sediment geochemical properties on heavy metal bioavailability. Environmental International, 73, 270-281. DOI: http://dx.doi.org/10.1016/j.envint.2014.08.010

Zhang, J..,Yang, B.., Chen, T..,Sun, X.., Chen, C. (2016). Metal speciation and pollution assessment of Cd and Pb in intertidal sediments of Donghai Island, China. Regional Studies of Marine Sciences., 6, 37–48.DOI: https://doi.org/10.1016/j.rsma.2016.03.006