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BIOGEOCHEMISTRY, GEOBOTANY AND CONSERVATION OF MANGROVE FORESTS FROM THE TINHARÉ-BOIPEBA ENVIRONMENTAL PROTECTION AREA, BAIXO SUL DA BAHIA (BR): TRACE METALS IN LEAVES OF *Rhizophora mangle* L. (Rhizophoraceae)

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Abstract: This research aimed to investigate the quality of coastal surface waters and the levels of trace metals in the leaves of *Rhizophora mangle* L. in the Tinharé-Boipeba APA, Baixo Sul da Bahia, Brazil. The physical-chemical variables were measured *in situ with the aid of a multiparameter probe and* samples of Rhizophora leaves were collected at *10* sampling points for biometric, visual diagnosis and trace metal analysis (F-AAS). The results of the OD analyzes revealed changes in water quality (70% of the sampling points), associated with forms of land occupation and failures in environmental sanitation. Cluster analysis allowed the classification of samples into biogeochemical groups, according to trace element content and leaf biometry. This multivariate analysis suggested that the variation in leaf area can be explained, in part, by the levels of Cu and Zn, in addition to other ecological-environmental factors different from those investigated. The levels of trace metals in the leaves were considered normal and non-toxic and the levels of trace metals in the sediments of this APA did not characterize a polluted area, however water pollution demands coastal management, improvements in sanitation and environmental monitoring, and biomonitoring.
Keywords: Geosciences, Coastal Ecosystems, Sanitation, Trace Metals.

INTRODUCTION

The pressure of urban-industrial activities, the fragmentation of tropical forests, changes in the landscape and pollution threaten society and coastal and marine ecosystems, such as mangroves (MARCHAND *et al.*, 2016). These authors emphasize that the mangrove ecosystem harbors important biodiversity and provides habitats for juvenile organisms. Furthermore, it is noteworthy that trace metal pollution has attracted the attention of society due to its high reactivity, ecotoxicity, persistence in the environment and health risks (LI *et al. al.*, 2016; ABOU SEEDO *et al.*, 2017; CHAI *et al.*, 2019).

As coastal wetlands are located between land and ocean, they suffer different pressures, such as the input of trace metals from terrestrial, oceanic and atmospheric sources (LI *et al.*, 2022). Based on a systematic review, these authors indicated the increase in studies on the pollution of coastal wetlands by trace metals in recent decades, especially in marshes, mangroves and estuaries in the United States of America and China. The metals Hg, Cd and Cu were the most studied in the world, although the distribution of studies varies geographically, where more studies of Hg were observed in the Americas, of Cd in China or India and of Pb in Western Europe and Australia.

Trace metals reach mangroves from natural sources, or from human sources, such as mining, combustion of fossil fuels, agricultural disposal, aquaculture, inappropriate disposal of solid waste and inappropriate effluents (ANALUDDIN *et al. al.*, 2017; BRANOFF, 2017). Furthermore, mangrove sediments can retain metals from different sources that accompany the dynamics of sea, freshwater and coastal waters (KULKARNI *et al. al.*, 2018; REIMANN *et al.*, 2018; SCHUERCH *et al.*, 2018).

Trace metals play a significant role in mangrove pollution and ecology, which can be absorbed by organisms or remain for a long time in sediments, becoming the main source of these pollutants for water and biota (BASTAKOTI *et al. al.*, 2019; SALIMI *et al.*, 2019). Furthermore, trace metals can be released from mangrove sediments into water or biota if geochemical conditions are unfavorable. retention of these, which can change their chemical speciation and impact the environment and human health (MACHADO *et al.*, 2005; LI *et al., 2005; LI et al. al.*, 2014; AL-MUR *et al.*, 2017). From this perspective, mangrove sediments can be used to indicate trace metal pollution and to understand the transfer of these pollutants from sediments to mangrove plant tissues (GHOSH *et al. al.*, 2021).

This explains that the retention of trace metals by the plant rhizosphere and mangrove sediments influences coastal and marine biogeochemical cycling (REEF *et al. al.* 2010). However, pollution and the tendency to reduce mangrove forests threaten the supply of ecosystem services, such as the retention of trace metals by sediments and the rhizosphere (VALIELA *et al. al.*, 2001; DUKE *et al.*, 2007). In addition, changes in climate and sea level have impacted the distribution of mangrove forests since the appearance of mangroves in the geological record approximately 75 million years before the present and continues into the Holocene (FRIESS *et al.*, 2019).

From the perspective of threats to the protection and conservation of mangroves, Soulé (1985) and Primack and Rodrigues (2001) emphasize the importance of Conservation Biology, by assuming that the diversity of organisms, ecological complexity and evolution have value in themselves., are beneficial to the Planet and offer ecosystem services relevant to human well-being and dignity.

With this, attention can be focused on the issue of trace metal pollution as a challenge to the conservation of mangrove forests in the Southern Lowlands of Bahia, Brazil and worldwide. Oliveira *et al.* (2009) studied the mangrove swamp of Camamu Bay, in the Southern Lowlands of Bahia, under the influence of barite mining. They obtained, locally, levels of trace metals Zn and Pb in the sediments of the Ilhas Region as high as the levels of these metals found in the polluted area of Santo Amaro, due to anthropic activities (QUEIROZ, 1992).

In this way, from the above, the relevance of the environmental assessment of the mangrove forests of the Tinharé-Boipeba Environmental Protection Area (APA) in Baixo Sul da Bahia, Brazil, facing the tensions of tourism, on fishing, mining, oil industry and sanitation failures (ALENCAR, 2011; SILVA *et al. al.*, 2009; GONÇALVES *et al. al.*, 2020; ELLIF; KIKUCHI, 2017; PELLEGRINI *et al.*, 2020 ; VILAR *et al.*, 2021 ; GONÇALVES *et al. al.*, 2022). In this context of tensions over mangrove conservation, this research aimed to investigate the quality of coastal surface waters and the levels of trace metals in the leaves of *Rhizophora mangle* L. in the Tinharé-Boipeba APA, in the municipality of Cairu, which is located in the Southern Bahia Lowlands, Brazil.

MATERIALS AND METHODS

STUDY AREA

This research was developed at the Tinharé-Boipeba APA, which totals 43,000 hectares, in the municipality of Cairu, in the Southern Lowlands of Bahia, Brazil (Figure 1). Cairu had in 2010, according to the IBGE Census (2010), a population of 15,374 thousand inhabitants distributed in the districts of Cairu, Galeão, Gamboa and Velha Boipeba, a Gross Domestic Product (GDP) of R$ 1,397,356 thousand reais and a Municipal Human Development Index (IDHM) of 0.627. In addition, the socio-spatial dynamics of this municipality has changed since 1992 due to the expansion of tourism in the Southern Bahia Lowlands induced by the State Government and/or the exploration of natural gas by Petróleo Brasileiro SA since 2007.

In the Southern Bahia Lowlands, changes in the forms of land occupation and the socio-environmental impacts of tourism have intensified since 1992, as a result of the Tourism Development Program in the Northeast (PRODETUR NE I and II). As a result, due to the socio-environmental impacts resulting from the socio-spatial and environmental changes of the Program, that is, associated with tourism, the government instituted the Tinharé-Boipeba Environmental Protection Area (APA) by State Decree n°.1240. This APA was created with the objective of protecting the ecosystems associated with the Atlantic Forest Biome, such as the mangrove, restinga, in addition to the beach, dunes, coral reefs and coralline algae, that is, the entnogeobiodiversity that integrates the natural heritage.

Regarding the context of climatic phenomena, it is noted that the Tinharé-Boipeba APA, in the Southern Bahia Lowlands, is located in the hot and humid, coastal tropical climate zone, between the Aw and Af bands, based on the classification by Köppen (1948). The annual average temperature is 24.6ºC, with maximum values of 31.2ºC (March) to 27.6ºC (July), and minimum values of 24.4ºC (March) to 19.4ºC (August) and annual rainfall of 2,118.7 mm, with more intense rains distributed between March and August and relative humidity percentages of 80 to 90% (BRASIL, 1995; SEI, 2014).

In the local geology, carbonate rocks, sandstones and shales of Cenozoic or Mesozoic age of the Camamu Basin emerge, superimposed on the gneissic crystalline basement (BARBOSA; DOMINGUEZ, 1996). Among the lithostratigraphic units of the Camamu Basin, the Sergi Formation (Fm.) and the Fm. Aliança, the Brotas Group (from the Jurassic to the Mesozoic), the Taipus and Algodões Groups (Cretaceous) and the Coastal Complex (of Quaternary age) (Figure 2). This sedimentary basin has hydrogeological importance and hosts non-energetic ores (barite), oil and gas in sandstones, reservoir rocks and sealed by Fm shales. Sergi.

The Coastal Complex includes Holocene and Pleistocene marine terraces, dune systems,

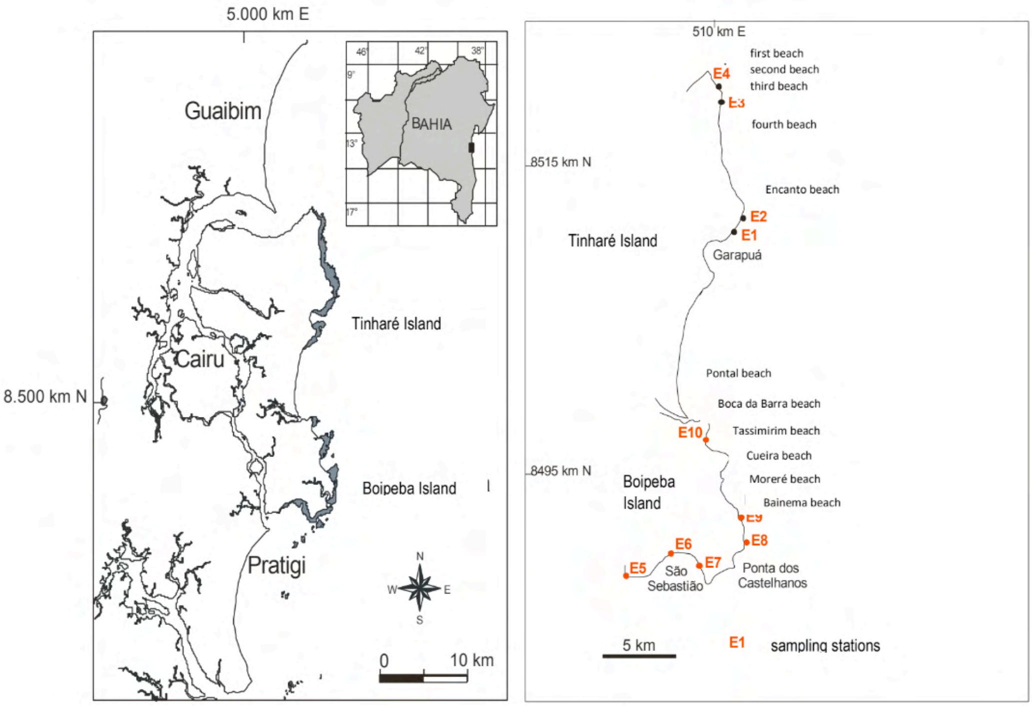

Figure 1 - Map of location, situation and distribution of surface water collection points (E1 to E11) and leaves in the Tinharé-Boipeba APA, Cairu, Baixo Sul da Bahia, Brazil.

Source: Organized by the authors, based on laboratory analyses.

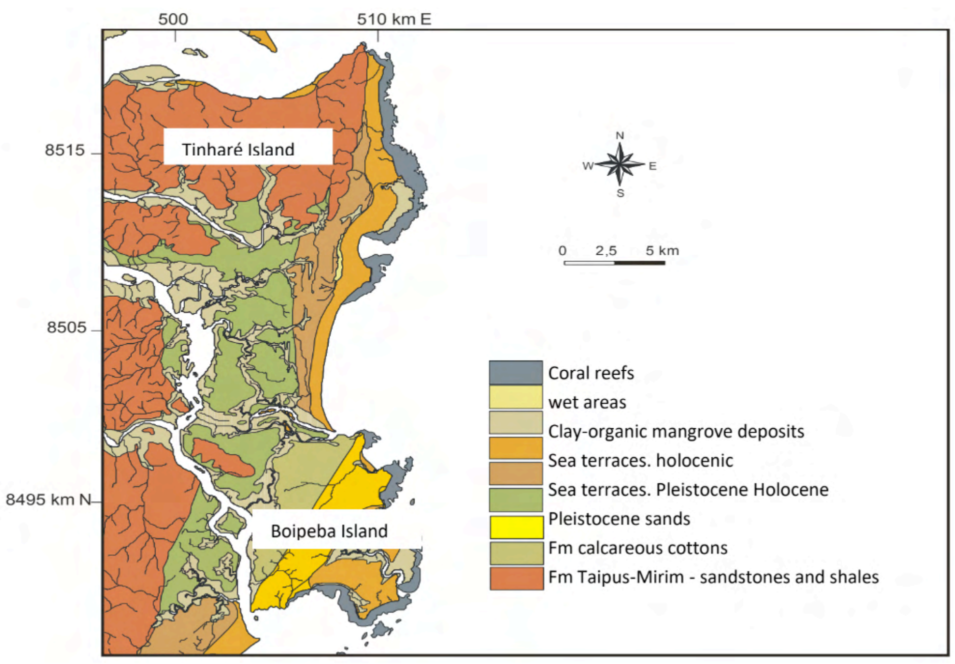

Figure 2 - Simplified local geology, and indication of hydrogeological units, of the Tinharé and Boipeba Islands, belonging to the municipality of Cairu, located in the Southern Lowlands of Bahia, Brazil.

Source: Modified from Rebouças (2006).

stony reefs and mangrove deposits, wetlands, which together constitute the geodiversity and natural heritage of the Tinharé-Boipeba APA (Figure 2). Among the attractions for tourism in the municipality of Cairu, especially the Tinharé-Boipeba APA, the cliffs associated with the sandstone or carbonate rocks of the Camamu Basin, the coves and headlands, beaches, mangrove swamps and stony reefs are highlighted.

The islands of Tinharé and Boipeba constitute an archipelago that has a pattern that varies from flat to gently undulating, or strongly undulating, in the Baixada Litorânea, Plains Marinhas and Fluviomarinhas units. This last geomorphological unit has an enormous diversity of features important to land use and occupation due to the strong interaction between geological processes and socio-spatial processes. In this model, a dense and dendritic hydrographic network is distributed, characterized by its first to third order rivers, where most are perennial and the most relevant rivers are influenced by the environmental dynamics of the ocean and the tides, in which, in this interaction between the coastal fresh waters and the ocean, the estuaries and the mangrove forests that border part of the Tinharé and Boipeba islands.

The landscape ecology of the Tinharé-Boipeba APA is characterized by the presence of neotropical, heterogeneous phytophysiognomies, related to the ecosystem complex of the Atlantic Forest Biome, such as the restinga, mangrove and beach ecosystems, wetlands and vegetation modified according to of socio-spatial dynamics. In addition, Atlantic Forest remnants can be seen in different stages of conservation, bordered by coral reefs and the distribution of estuarine, fringe and transitional mangrove forests. Mangrove forests are expressive in the Garapuá district, on Tinharé island, although they stand out on Boipeba island, which is almost completely bordered by mangrove forests, related to the Catu River.

QUALITY OF COASTAL SURFACE WATERS

Coastal surface water samples were collected in a network of 10 points on the islands of Tinharé (E1-E4) and Boipeba (E5-E9) (Figure 1). Each sampling point was positioned with the aid of a GPS (*Global Positioning System)*, measuring *in situ* the physicochemical variables (pH, salinity, temperature and OD) from a multiparameter probe, on the coastline, in the low -mar, and socio-environmental information was recorded in a field notebook.

GEOBOTANICAL VARIABLES AND TRACE METALS IN LEAVES

Ten sampling points were selected distributed in fringe mangrove zones, mainly estuarine and transition, where four sampling points were obtained on Tinharé Island (E1 to E4) and another five on Boipeba Island (E5 to E10), positioned by a GPS - *Global Positioning* System. Two plots of 10 m ^{2} were randomly assigned at each sampling point and 30 adult leaves were collected per specimen, per plot, of the species *Rhizophora mangle* L. (Rhizophoraceae), from the third node, at the distal end of the branch., at low tide. These samples were stored in pre-identified plastic bags and kept refrigerated at a temperature of ± 4°C.

in loco geobotanical evaluation was carried out, followed by an evaluation in the laboratory that covered the following aspects of leaf blade integrity: galls (swelling), herbivory (grazing), chlorosis (depigmentation), dark spots, perforations and necrosis. Furthermore, the leaf blade area was measured with the aid of a manual caliper. The analyzes of the foliar diagnosis (integrity and biometry) and the reading of trace metals (Cu, Cd, Pb, Zn) were carried out at the Laboratory of Environmental Studies (LEMA) of the Catholic University of Salvador or in the laboratories of the Centro de Excellence in Petroleum Geochemistry (LEPETRO) from the Federal University of Bahia (UFBA).

Trace metals were read in the leaves by Flame Atomic Absorption Spectrometry (FAAS) (*Varian Spectr AA-6440Z)*, after the addition of 3 ml of HNO_3 (1:1) to a mass of 0.5 g of sample (dry weight) and opening in a microwave oven. The analytes were read in duplicates, with 20% triplicates, blanks and the international reference standard (*National Institute of Standards and Technology, Apple Leaves* - NIST-1515). Table 1 summarizes the detection conditions of trace metals and the analytical quality control, whose recovery ranged from 60% to 103%, being higher for Zn.

TRACE METALS IN SEDIMENTS AND CONCENTRATION FACTOR

The Concentration Factor (FC) was calculated from the ratio between the average levels of a certain trace metal in the *R. mangle leaf* and in the sediment. The FC was obtained from the levels of trace metals in the standard shale, according to Turekian and Wedepohl (1961), or from the levels of trace metals in the sediments of the Tinharé-Boipeba APA, according to Silva (2011). Salisbury and Ross (2012) emphasize that FC provides ecological-geoenvironmental information to biogeochemical research by relating the trace metal levels of the plant and the substrate.

STATISTICAL APPROACH

The statistical approach included descriptive analysis and the application of *Cluster Analysis*. Parametric data comparison tests (ANOVA) and non-parametric data comparison tests (*Kruskal-Wallis)* were applied at a significance level of 5%. In addition, the Euclidean distance was chosen as a measure of similarity between the sample points and the Ward method for linking the groups in the Cluster Analysis.

RESULTS AND DISCUSSION

GEOBOTANICAL AND BIOGEOCHEMICAL VARIABLES

Visual diagnosis allowed the classification of changes in leaf integrity in decreasing order of intensity, as follows: chlorosis > dark spots > herbivory > perforations or necrosis > galls (Table 2a). Natural or anthropic stressors promote morphophysiological changes and plant development (BLOM, 1999; MARTINS *et al.*, 2007). Furthermore, the external morphology of plants includes visual diagnosis methods, which describe changes in leaf integrity and biometry (MALAVOLTA, 2006).

In the present study, a profile of changes in leaf integrity was obtained, distinct from the profile of the mangrove forests of Baía de Todos os Santos - BTS, in Bahia, according to the results of the research by Santos (2013). This author obtained in the mangrove forests of Madre de Deus and São Francisco do Conde, in BTS, the following profile of leaf alterations for *R. mangle,* in descending order: necrosis (23-30 leaves) > perforations (8-15 leaves) > chlorosis or galls (0-8 leaves). This profile differs from what was observed in the areas most impacted by petrochemicals in BTS, according to Garcia (2005).

Andrade *et al.* (2012) evaluated the leaf integrity of *R. mangle* in the mangrove swamp of the Passa Vaca River estuary, in Salvador, impacted by urban land occupation, real estate speculation and sanitation failures. They obtained the following profile of leaf changes, in decreasing order of intensity: initial necrosis (median: 26.5) > dark spots (median: 18.0) > advanced necrosis (median: 11.0) > chlorosis (median: 4, 0).

Standard (NIST-1515)	Cu (μg.g -1)	Cd (μg.g -1)	Pb (μg.g -1)	Zn (μg.g -1)
λ (nm)	324.80	228.80	217.00	213.90
NIST 1515	5.64	0.002	0.47	12.50
Standard (average of the value found)	3.87	0.001	0.35	12.92
Recovery (%)	70.00	60.00	74.00	103.00
Detection limit	0.019	0.015	0.0133	0.012

Table 1 - Evaluation of the opening recovery of trace metals in *R. mangle sheets* in microwave oven, using the international reference standard NIST-1515.

Source: Organized by the authors, based on laboratory analyses.

sample point	Minimum	Maximum	median	Mean ± EP	Standard deviation	CV (%)	*Shapiro-Wilk* (*p value*)
Chlorosis (depigmentation)	7.00	23.00	15.00	15.00 ± 1.59	5.01	33.41	*p=0.051* [to]
dark spots	0.00	23.00	14.00	12.40 ±1.94	6.15	49.60	*P=0.32* [to]
Galls (swellings)	0.00	13.00	3.00	4.20 ± 1.51	4.78	113.80	*P=0.02* [b]
Herbivory (grazing)	7.00	15.00	13.50	12.70 ± 0.91	2.87	22.59	*P=0.01* [b]
perforations	7.00	15.00	11.50	11.50 ± 0.99	2.80	24.34	*P=0.57* [to]
Necrosis	6.00	15.00	12.00	11.90 ± 0.85	2.69	22.57	*p=0.36* [a]

[the] Gaussian distribution; [b] non-Gaussian distribution; CV: coefficient of variation.

a) Statistical summary of measurements of changes in leaf integrity of *R. mangle.*

sample point	Minimum	Maximum	median	Mean ± EP	Standard deviation	CV (%)	*Shapiro-Wilk* (*p value*)
E1 - E4 (Tinharé)	17.60	91.12	44.10	45.13 ± 1.09	14.60	32.34	*p=0.006* [b]
E5 - E10 (Boipeba)	9.68	105.70	47.84	48.75 ± 0.81	14.21	29.15	*p<0.001* [b]
E1 - E10 (APA)	9.68	105.70	46.35	47.40 ± 0.66	14.45	30.48	*p=0.99* [to]

[the] Gaussian distribution; [b] non-Gaussian distribution; CV: coefficient of variation.

b) Statistical summary of the results of measurements of the leaf area (cm [2)] of *R. mangle.*

Table 2 - Statistical summary of the results of measurements of geobotanical variables, leaf biometry and leaf blade integrity of *Rhizophora mangle* from the Tinharé-Boipeba APA.

Source: Authors' organization.

The values of the measures of the leaf area of *R. mangle* ranged from 9.68 to 105.70 cm ^{2,} with a median of 47.4 cm ^{2} (Table 2b). Figure 3 shows greater leaf development in the sampling points of Praia do Encanto II (E2), in Morro de São Paulo, on Tinharé Island, or near the mouth of the Bainema (E9) and Santo (E10) rivers, on the Ilha de Boipeba. It was found that the leaf area medians differed significantly between the sampling points.

The smallest leaf area medians of *R. mangle* at points E1, E3 and E4 (Island of Tinharé) and E5 and E8 (Island of Boipeba) (Figure 3). Neumann (1993), Schaeffer-Novelli (1995), Garcia (2005), Silva, Martins and Cavalheiro (2010) and Ruthes *et al. al.* (2021) point out that the reduction in leaf area may result from the action of chronic stressors, such as salinity, organic matter content of the edaphic substrate, toxicity by trace metals and herbivory, which can be used as an ecological indicator. -geoenvironmental.

BIOGEOCHEMISTRY: LEVELS OF METALS -TRACE IN LEAVES AND SEDIMENTS

Leaf levels of trace metals of *R. mangle* were ranked in descending order, in the following order: Zn > Cu > Cd > Pb (Table 3). The highest average Cu level was obtained at point E2 (Praia do Encanto II), located on Tinharé Island, although Cu levels were locally below the detection limit of the analytical method (E1, E4, E5, E6 and E7).

The median values of the trace metals Zn (*p=0.95)*, Cd (*p=0.98)* and Pb (*p=0.60)* did not differ significantly between the sampling points, according to the *Kruskal-Wallis test* (Table 3). It was found that the levels of trace metals in the leaves were, in general, normal and non-toxic, according to Ross (1994) and Kabata-Pendias and Pendias (2001) classifications. Furthermore, the levels of trace metals in the sediments of mangrove areas of the APA were, in decreasing order, as follows: Zn > Pb > Cu (Table 4).

It was found that the median values of trace metals differed significantly based on the composition of the sediments in sand and silt, according to the *Kruskal-Wallis test* (Figure 4). Furthermore, the *box-plot diagram* shows that the highest levels (extremes and *outliers)* in sandy sediments with < 20% silt or with > 20% silt in their composition. The highest levels of trace metals were obtained in sediments with > 20% silt, which characterized levels of toxicity where adverse effects on biota are expected, according to NOAA (1999) (Table 4). However, the medians of trace metals in the sediments do not characterize a polluted area, according to the US EPA classification (1991), for at least half of the samples.

R. mangle leaf samples were normal and non-toxic according to Ross (1994) or Kabata-Pendias and Pendias (2001) classifications, whose levels of trace metals in leaves did not exceed the WHO/FAO (2007) limit (Table 5). Furthermore, Concentration Factor (FC) values < 1.0 (unit) suggested that trace metal levels were more pronounced in sediments than in plants.

In this context, the FC values of the present study, in the Tinharé-Boipeba APA, were compared with previous studies of mangrove forests in coastal areas of Brazil and the world, which contemplated the species *R. mangle, Rhizophora mucronata, Rhizophora stylosa, Rhizophora apiculata, Rhizophora harrisonii, Rhizophora conjugata* (Rhizophoraceae) (Table 5).

The presence of Concentration Factor (FC) values < 1.0 was observed in Brazilian mangrove forests, such as Baía de Camamu, BTS (Bahia), Rio Potengi (Natal), Marapanim (Pará), Vitória (Espírito Santo), the Guanabara Bay (Rio de Janeiro) and the Cubatão River (São Paulo) (Table 5). This biogeochemical condition can also be verified in the

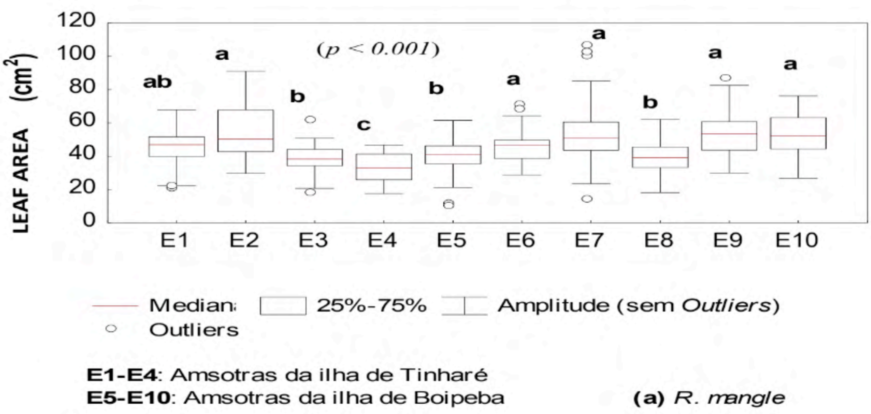

Figure 3 – Distribution of leaf area measurements of *R. mangle* in the Tinharé-Boipeba APA.

Source: Authors' organization, based on field research.

trace metals	**Toxicity Limits**			**Descriptive Analysis**								
	Toxic [to]	normal [to]	normal [b]	(N)	min.	Max.	median	Mean ± Standard Error	Detour Pattern	CV (%)	*Shapiro-Wilk* (*p value*)
Cu (µg.g $^{-1}$)	20.00 -100.00	4.00 - 15.00	5.00 - 30.00	26	0.14	43.94	3.73	12.66 ± 4.31	15.54	122.78	0.01 [b]
Zn (µg.g $^{-1}$)	> 400.00	8.00 - 400.00	27.00 - 150.00	66	2.54	17.13	8.96	9.73 ± 0.71	4.04	41.5	0.04 [b]
Cd (µg.g $^{-1}$)	5.00 - 30.00	0.02 - 0.80	0.05 - 0.20	66	0.02	0.22	0.15	0.13 ± 0.01	0.06	46.34	0.02 [b]
Pb (µg.g $^{-1}$)	30.0 - 300.00	1.00 - 30.00	5.00 - 10.00	56	0.14	2.50	0.31	0.41 ± 0.08	0.43	107.1	0.006 [b]

[to] Ross (1994); [b] Kabata-Pendias and Pendias (2001).

[c] Gaussian distribution; [d] non-Gaussian distribution; CV: coefficient of variation.

Table 3 – Statistical summary of trace metal measurements (Cu, Zn, Cd and Pb) in samples of *R. mangle leaves in the mangrove* forests of the Tinharé-Boipeba APA, Cairu, Bahia.

Source: Authors' organization.

Sample Estimators (III)	**Cu** (µ gg $^{-1}$)	**Zn** (µ gg $^{-1}$)	**Pb** (µ gg $^{-1}$)
Minimum	0.40	6.98	6.67
Maximum	3.90	56.80	20.50
Mean ± Standard Error	1.89 ± 0.48	25.50 ± 9.31	12.25 ± 1.96
median	1.63	14.75	11.50
Standard deviation	1.17	22.81	4.79
Coefficient of variation (%)	61.70	89.43	39.11
Shapiro-Wilk (*p-value*)	0.50 [to]	0.03 [b]	0.70 [to]
US EPA (1991)			
not polluted	<25.00	<90.00	<40.00
Slightly Polluted	25.00-50.00	90.00-200.00	40.00-60.00
Severely Polluted	>50.00	>200.00	>60.00

[the] Gaussian distribution; [b] non-Gaussian distribution.

a) Levels of trace metals in sediments with 100% sandy composition (n=6).

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Sample Estimators (III)	Cu (µ gg -1)	Zn (µ gg -1)	Pb (µ gg -1)
Minimum	0.35	3.19	3.83
Maximum	24.50	259.00	32.70
Mean ± Standard Error	4.10 ± 1.04	55.44 ±.13.65	14.87 ± 18.99
median	2.34	26.10	12.60
Standard deviation	5.11	66.86	9.30
Coefficient of variation (%)	124.78	120.57	62.57
Shapiro-Wilk (p-value)	0.0022 b	0.02 b	0.0014 b
US EPA (1991)			
not polluted	<25.00	<90.00	<40.00
Slightly Polluted	25.00-50.00	90.00-200.00	40.00-60.00
Severely Polluted	>50.00	>200.00	>60.00

[the] Gaussian distribution; [b] non-Gaussian distribution.

b) Trace metal levels in sandy sediments, with < 20% silt (n=24).

Sample Estimators (III)	Cu (µ gg -1)	Zn (µ gg -1)	Pb (µ gg -1)
Minimum	0.12	71.00	7.83
Maximum	102.00	508.00	66.80
Mean ± Standard Error	18.57 ± 9.44	164.84 ± 40.31	34.47 ± 4.71
median	10.87	118.50	35.00
Standard deviation	29.84	127.49	14.88
Coefficient of variation (%)	160.69	43.18	77.33
Shapiro-Wilk (p-value)	p<0.0001 b	0.0004 b	0.25 to
US EPA (1991)			
not polluted	<25.00	<90.00	40.00-60.00
Slightly Polluted	25.00-50.00	90.00-200.00	40.00-60.00
Severely Polluted	>50.00	>200.00	>60.00

[the] Gaussian distribution; [b] non-Gaussian distribution.

c) Trace metal levels in sandy sediments, with > 20% silt (n=10).

Table 4 – Levels of trace metals in the sediments, according to the percentage in sand and silt, of the mangrove forests of the Tinharé-Boipeba APA, Baixo Sul da Bahia, Brazil.

Source: Organization of authors (as), based on data from research by Silva (2011).

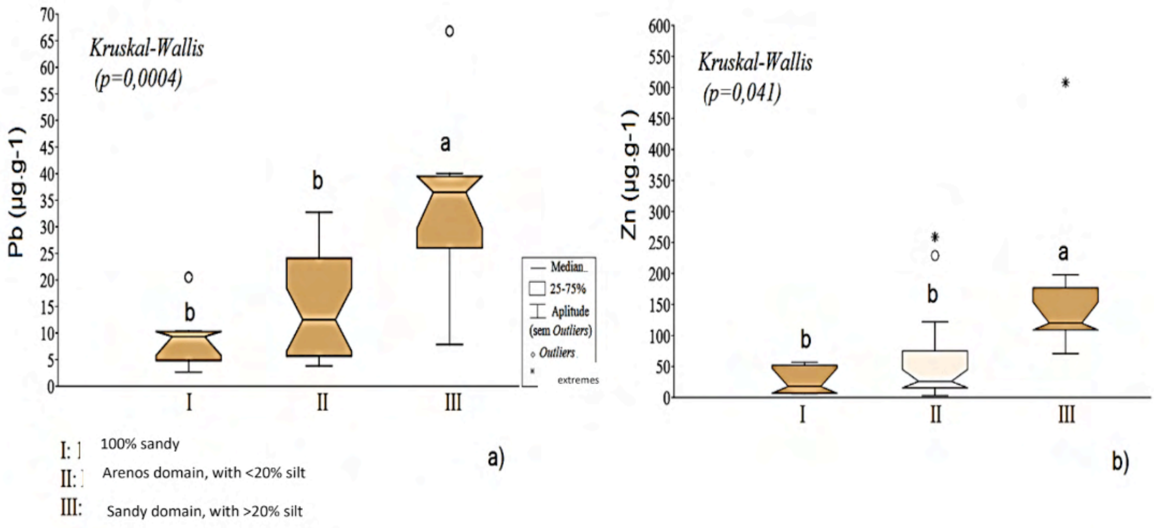

Figure 4 – *Box-plot diagram of* the distribution of levels of trace metals Cu, Zn and Pb (µg.g $^{-1)}$ according to the percentage of sand and silt in the sediments of the mangrove forests of the Tinharé-Boipeba APA, belonging to the municipality from Cairu, Southern Bahia Lowlands, Brazil.

Source: Authors' organization (as), based on data from the research by Silva (2011).

Author/Date	Location	Leaves (µg.g $^{-1}$)				FC			
		Ass	Zn	CD	Pb	Ass	Zn	CD	Pb
Biogeochemistry in Brazilian mangrove forests									
Present Study to	APA Tinharé-Boipeba - BA	12.66	9.73	0.13	0.41	1.73	0.12	0.40	0.02
Madi *et al.* (2015) to	Antonina and Guaratuba, Paraná	1.10	5.41	-	-	0.65	0.68	-	-
Souza *et al.* (2014) to	Santa Cruz - ES	0.37	2.95	-	0.05	0.10	-	-	0.01
Souza *et al.* (2014) to	Vitória Bay - ES	4.71	7.24	-	12.57	0.16	0.45	-	0.01
Santos (2013) to	Mother of God – BA	3.54	3.20	-	0.09	0.49	0.26	-	0.07
Vilhena *et al.* (2013)	Marapanim, Pará (Amazon)	0.08	8.50	-	-	0.01	0.12	-	-
Pinheiro *et al.* (2012) to	Cubatao River, Sao Paulo	4.11	-	<LD	<LD	0.13	-	-	-
Andrade *et al.* (2012) to	Passa Vaca – BA	5.70	9.00	-	-	0.12	0.36	-	-
Ceschini et al. (2011) to	Guanabara Bay – RJ	2.30	0.10	-	0.23	0.23	0.03	-	0.09
Lion *et. al.* (2008) to	Aratu Bay - BA	11.74	24.10	0.10	0.45	0.80	0.64	<0.001	0.004
Queiroz and Celino (2008) to	Itaparica Island, BTS, Bahia	2.80	28.50	0.03	0.10	0.25	0.59	-	<0.001
Rocha (2008) to	Mucuri River – BA	0.141.5	6.55	-	-	0.13	0.57	-	-
Ramos and Geraldo (2007) to	Cubatao, Sao Paulo	2.06	11.60	0.46	<LD	0.06	0.12	0.33	-
Bernini *et al.* (2006)	São Mateus River – ES	1.48	4.36	-	-	0.58	0.84	-	-
Ramos and Silva et al. (2006) to	Potengi River, Natal – RN	3.18	9.87	0.51	9.95	0.12	0.14		0.66
Machado *et al.* (2005) to	southeastern Brazil	-	15.00	-	-	-	0.06	-	-
Fruehauf (2005) to	Cosipa Channel - SP	1.23	5.88	<LD	1.79	0.12	0.36	-	0.08
Fruehauf (2005) to	Cascalho River – SP	1.54	4.64	08.17	0.89	0.16	0.11	0.06	-

Fruehauf (2005) [to]	Mariana River – SP	1.65	4.77	<LD	0.79	0.24	0.09	-	0.06
Cuzzuol and Campos (2001) [to]	Mucuri River – BA	2.00	5.00	-	-	2.00	0.60	-	-
Oliveira *et al.* (2000) [to]	Jaguaribe - BA	1.50	4.00	-	-	1.25	1.43	-	-
Oliveira *et al.* (2000) [to]	Capivara Pequeno River - BA	6.50	9.00	-	-	0.39	0.08	-	-
Oliveira (2000) [to]	Camamu Bay -BA (Islands)	7.00	9.00	-	1.00	0.35	0.11	-	0.01
Oliveira (2000) [to]	Camamu Bay-BA (Estuary)	1.50	5.80	-	3.00	0.09	0.13	-	0.11
Souza *et al.* (1996) [to]	Pati Island – BA	4.43	8.71	-	-	2.09	2.20	-	-
Panitz (1997) [to]	Santa Catarina Brazil	1.60	69.00	0.10	2.70	**0.06**	1.08	1.10	0.09
Silva *et al.* (1990) [to]	Sepetiba Bay - RJ, Brazil	0.10	7.20	-	0.01	<0.01	0.40	-	<0.01
Lacerda *et al.* (1986)	Sepetiba Bay - RJ, Brazil	19.00	22.00	-	16.50	2.15	0.13	1.68	1.08
Biogeochemistry in mangrove forests around the world									
Mahmudi *et al.* (2021) [b]	Bee Jay Bakau Resort, Indonesia	-	-	-	0.49	-	-	-	0.046
Khan *et al.* (2020a) [d]	MMFR, Malaysia	0.07	0.68	-	-	0.64	0.79	-	-
Ariyanto *et al.* (2021) [d]	Asahan, Indonesia	-	-	-	<0.001	-	-	-	<0.001
Ganeshkumar *et al.* (2019) [b]	Southeast coast of India	2.32	7.70	0.25	12.23	0.32	0.32	0.51	1.08
Abdullah *et al.* (2018) [d]	Kuala Sepetang, Perak, Malaysia	0.58	1.14	0.01	0.08	-	-	-	-
Takarina and Pin (2017) [b]	blanakan, indonesia	2.94	46.08	-	6.65	0.32	0.51	-	0.26
Baruddin *et al.* (2017) [b]	Kelantan Delta, Malaysia	-	-	-	0.31	-	-	-	0.01
Analuddin *et al.* (2017) [d]	Southeast of Sulawesi, Indonesia	17.00	2.00	0.40	<0.05	2.14	0.08	1.25	-
Qiu and Qi (2017) [c]	Dongzhay Harbor, South China	1.10	6.00	0.02	0.80	0.09	0.11	0.14	0.03
Qiu and Qi (2017) [c]	Saya Bay, South China	2.20	7.00	0.10	0.70	0.18	0.13	0.71	0.03
Marchand *et al.* (2016) [c]	New Caledonia, France	8.87	9.15	-	-	0.52	0.16	-	-
Isroni *et al.* (2016) [b]	Mlaten Village, Indonesia	-	-	-	0.45	-	-	-	0.12
Kaewtubtim *et al.* (2016) [b]	Pattani Bay, Thailand	3.90	2.80	0.10	6.80	0.18	0.05	0.30	0.14
Liu *et al.* (2015) [c]	Leizhou Peninsula (China)	15.54	78.02	0.15	27.48	0.84	0.90	0.71	0.82
Badarudeen *et al.* (2014) [b]	Kochi, Kerala, India	70.00	140.00	1.00	130.00	1.59	2.64	0.50	4.41
Badarudeen *et al.* (2014) [b]	Kannur, Kerala, India	64.00	86.00	2.00	46.00	1.45	0.86	1.00	1.56
Badarudeen *et al.* (2014) [d]	Kannur, Kerala, India	85.00	142.00	3.00	52.00	1.93	0.98	1.50	1.76
Kamaruzzaman *et al.* (2011) [d]	pahang, malaysia	2.93	-	-	4.30	0.19	-		0.14
Qiu *et al.* (2011) [c]	Hainan Island, China	2.80	8.70	0.03	1.40	0.22	0.23	0.22	0.06
Keshavarz *et al.* (2012) [b]	Marina coast of Oman, Iran	-	-	<LD	6.36	-	-	-	0.92
Pahalawattaarachchi *et al.* (2009) [b]	Alibag, Maharashtra, India	3.41	5.48	1.00	5.50	0.04	0.07	0.19	0.28
Kamaruzzaman *et al.* (2009) [d]	terengganu, malaysia	2.73	-	-	1.43	0.29	-	-	0.12
Agoramoorthy *et al.* (2008) [b]	Tamil Nadu, India	19.90	40.30	-	12.61	0.45	0.43	-	1.12

Agoramoorthy *et al.* (2008) [d]	Tamil Nadu, India	10.25	16.30	-	12.23	0.23	0.18	-	1.09
Sánchez and Olivo (2008) [to]	Cienaga Grand, Colombia	2.50	9.00	1.19	0.10	0.12	0.30	0.15	0.01
Marchand *et al.* (2006)	New Caledonia, France	2.16	<LD	-	<LD	0.12	-	-	-
Saenger and McConchie (2004) [c]	Queensland, Australia (Pol.)	16.45	25.60	0.02	2.20	0.14	0.12	0.22	0.08
Saenger and McConchie (2004) [c]	central queensland, australia	2.20	5.05	-	1.00	0.19	0.02	-	0.36
Alongi *et al.* (2003) [c]	western australia	3.70	6.60	-	-	0.27	0.23	-	-
Sarangi *et al.* (2002) [b]	Orissa, India.	1.63	0.97	-	-	0.58	1.04	-	-
Lian *et al.* (1999) [c]	Hainan Island, China	2.40	5.70	0.05	0.04	0.11	0.08	1.09	0.002
Zheng *et al.* (1997) [c]	Yingluo Bay, China	0.60	5.90	0.22	0.80	0.03	0.12	2.52	0.08
Campos and Gallo (1997) [to]	Cienaga Grand, Colombia	17.87	25.84	2.80	-	0.77	0.28	1.47	-
Campos and Gallo (1997) [to]	Chengue Bay, Colombia	20.59	29.27	2.69	-	0.88	0.36	1.42	-
Soto *et al.* (1992) [to]	Costa Rica	9.75	12.50	-	-	1.12	0.68		-
Soto *et al.* (1992) [and]	Costa Rica	10.90	13.00	-	-	1.25	0.47	-	-
Sanger *et al.* (1990) [c]	northern australia	16.00	26.00	-	2.20	0.42	0.48	-	0.14
Peterson *et al.* (1979) [n]	penang, malaysia	2.83	6.93	-	-	0.13	0.05	-	-
Ross (1994)	Normal or Sufficient Levels	4.0-15	8-400	<0.8	1.0-30				
	Toxic or Excessive Levels	20-100	>400	5-30	30-300				
Kabata-Pendias and Pendias (2001)	Normal or Sufficient Levels	5.0-30	27-150	0.05 -0.20	5.0-10				
	Toxic or Excessive Levels	20-100	100-400	5-30	30-300				
WHO/FAO (2007)	Recommended Maximum Limit	40.00	60.00	0.20	5.00				
CEQG (2001)	Recommended Maximum Limit	18.27	124.00	0.70	30.20				

[The] *R. mangle* ; [B] *R. mucronata* ; [ç] *R. stylosa* ; [d] *R. apiculata* ; [and] *R. harrisonii* ; [f] *R. conjugate.*

Table 5 - Comparison of the levels of trace metals (Cu, Zn, Cd, Pb) in the leaves of mangrove plants from the Tinharé-Boipeba APA, Bahia, with mangrove forests in Brazil and worldwide.

Source: Organized by the authors.

mangrove forests of Costa Rica, Colombia (Ciénaga Grand), France (New Caledonia), Australia (Queensland), Malaysia (Penang), Indonesia (Perak), Thailand (Pattani), India (Maharashtra), Iran (Oman) and China (Leizhou Peninsula).

FC values < 1.0 suggest that mangrove plants avoid the absorption of trace metals, or that they can be associated with the metabolic pathways of attenuation of salinity stress (LACERDA, 1997). Furthermore, it is noted that root respiration oxidizes the rhizosphere and transforms sulfide into sulfate, depositing Mn and Fe oxides and hydroxides in the sediments (PI *et al. al.*, 2011). This process reduces the solubility and toxicity of Fe and Mn metals, creates iron plates on the root surface, immobilizes and (co)precipitates the metals. It prevents, depending on the oxidation-reduction conditions of the environment, the translocation of part of the metal charge from the rhizosphere to tissues and organs, such as leaves.

Contrary to what was described, FC values > 1.0 were observed for Cd and Pb metals in mangrove areas of Santa Catarina and Sepetiba Bay, Rio de Janeiro (Brazil), Kerala (India), from Sulawesi (Indonesia), Ciénaga Grand (Colombia) and from Hainan Island or Yingluo Bay (China) (Table 5). These FC values > 1.0 indicated geoenvironmental conditions unfavorable to the sequestration of trace metals by sediments. In addition, plant metabolism can reduce its selective and excretory capacity for trace metals, accumulating them in tissues under stress situations due to the exposure of its rhizosphere to high levels of trace metals in sediments.

In this context, it should be noted that the levels of trace metals in the leaves of *R. mangle* in the present study were similar to the results of research by Oliveira (2000) in the Camamu Bay (Estuary), located on the coast of the Southern Bahia Lowlands., Brazil (Table 5). However, the highest average level of Pb was observed in the leaves of *R. mangle,* although not toxic, in the mangrove forests of the Ilhas region, in the Camamu Bay, which are under the greatest influence of negative environmental impacts resulting from mining. of barite.

It was observed that the average levels of trace metals in the sediments of the Tinharé-Boipeba APA (Cu, Zn, Pb) or of the Camamu Bay (Estuary) were, in general, close to the standard shale levels (Table 6). In addition, the Pb level in the Camamu Bay estuarine sediments slightly exceeded the standard shale average, but such levels do not characterize a polluted area, based on US Environmental Protection Agency sediment quality assessment guidelines. However, the average level of Pb in the sediments of the mangrove forests of the Ilhas region in the Camamu Bay, under the influence of mining, were characteristic of polluted areas.

In this sense, several polluted coastal areas in the world were indicated, according to the levels of trace metals in the sediments, such as the mangrove forests located in Southeast Brazil (Estuaries of Santos and Cubatão, Sepetiba Bay), in Northeast Brazil. (Santo Amaro, Baía de Aratu and Rio Capivara Pequeno), in Colombia (Ciénaga Grand de Santa Marta), in Ecuador (Estero Salado), in Puerto Rico (Las Cucharillas), Trindade (Caroni Swamp), in Malaysia (Estuary of the rivers Penang, Kelantan, Klang, Matang), Thailand (Pattani Bay), Tanzania (Mtoni Estuary), India (Pichavaram-Tamil Nadu, Kerala, Maharashtra) and areas of Australia (Queensland) (Table 6).

It was also inferred that the average levels of trace metals (Cu, Zn, Cd and Pb) in the sediments of the Tinharé-Boipeba APA and in the Camamu Bay (Estuary Zone) were lower than the values of adverse effect on expected biota (TEL) or probable adverse effect on biota

(PEL) proposed by CCME (2001) or by NOAA (1999) (Table 6). However, it is concluded that the Pb metal level in the sediments of the Ilhas region in Camamu Bay is in the range of values of probable adverse effects on biota (PEL).

It is noteworthy that the levels of trace metals in the sediments and leaves of the species of the genus *Rhizophora* varied as a function of the influence of urban-industrial activities, such as the mangrove forests of the Estuary Zone and the Islands Area in Camamu Bay., or the Baía de Todos os Santos, Bahia, or the Cosipa Channel and Ilha do Cardoso, in São Paulo, Brazil, or the estuary of the Mtoni River, in Tanzania (Tables 5 and 6). It is noteworthy that mangrove geochemistry encompasses plant metabolic demand, climate and geo-environmental and ecological-edaphic conditions (IGNÁCIO *et al.*, 2005).

MULTIVARIATE, ECOLOGICAL-GEOBOTANY AND BIOGEOCHEMICAL APPROACHES

The multivariate approach allowed the classification of samples into ecological-geobotanical (GE) groups (**GE1** to **GE4**), with the aid of cluster analysis, based on visual observation of the dendrogram (Figure 5). Thus, the cut-off line was defined in the dendrogram from a distance of 55° for the variables and for cases, grouping the samples with a connection distance lower than the cut-off line in the ecological-geobotanical groups.

It was verified in relation to the cases that the **G1a group showed** an association between the levels of non-essential trace metals (Cu, Pb) and the ecological-geobotanical variable chlorosis (Figure 5b). It was inferred that although the levels of trace metals Cu and Pb in the leaves of *R. mangle* were non-toxic, they may have an influence on leaf changes, along with other stressors, such as nutrients and salinity, on leaf integrity.

Based on the above, a possible influence of Cu levels on leaf area, an association of leaf Zn levels and plant-animal-fungus relationships responsible for galls and perforations were pointed out (Figure 5a). Furthermore, the multivariate approach indicated that other stressors, in addition to those studied, may influence the distribution of necrosis, stains and herbivory in mangrove plants. Furthermore, one should consider the role of herbivory on the integrity of the leaf blade of *R. mangle* and its relationship with other natural (nutrition, salinity) or anthropic (pollutants) stressors.

Another contribution resulting from the application of multivariate analysis was to allow the differentiation of ecological-geobotanical groups (cases) based on the levels of essential (Cu) and non-essential essential (Pb) trace metals and on ecological-geobotanical variables (chlorosis, area leaf) (Figure 5b). It also allowed the identification of the GE2b and GE3b groups **that** exhibited **the** highest level of Cu and leaf area, where the **GE3b group** was less affected by galls (mean: 1.0 leaf) than the **GE2b group** (mean: 7.25 sheets). Furthermore, the **GE4b group** presented the lowest loss of the highest leaf integrity when compared to the ecological-geobotanical groups **GE1a, GE2b** and **GE3b.**

In this horizon of meanings and discussion, Epstein and Bloom (2006) were reported to understand the relevance of the micronutrients Zn and Cu for plant metabolism, and, by extension, for mangrove plants in the APA. The oligonutrients Zn and Cu are important enzymes for the biosynthesis of substances, in fruiting and in plant growth and development. Zn represents an oligonutrient that participates as a cofactor of enzymes in respiration, photosynthesis and the synthesis of plant growth hormones (BROADLEY *et al.*, 2007). Furthermore, the nutritional deficiency of Zn interferes with plant growth,

Author/Date	Location	Sediments (μg.g $^{-1}$)				Aspects and Impacts
		Ass	Zn	CD	Pb	Ecological-Environmental
Silva (2011) (Reference)	APA Tinharé-Boipeba - BA, Brazil	7.29	78.17	-	18.90	Rural-urban, oil, tourism.
Oliveira (2000)	Camamu Bay -BA - (Islands), Brazil	20.20	81.00	<1.00	156.00	Barite Mining (↑ Pb).
Oliveira (2000)	Camamu Bay - BA - (Estuary), Brazil	16.50	45.80	<1.00	28.00	Tourism (Unpolluted).
Araújo (2000)	Itanhém River, Alcobaça - BA, Brazil	8.73	5.43	-	29.10	Urban, tourism (Effluents)
Kim *et al.* (2017)	Baixada Santista - SP, Brazil	10.20	56.72	-	12.11	Urban-Industrial.
Madi *et al.* (2015)	Guaratuba and Antonina, Paraná, Brazil	1.70	7.98	-	-	Urban (Not Polluted).
Souza *et al.* (2014)	Vitória Bay - ES, Brazil	4.22	-	-	9.36	Urban-Industrial (↓Cu, Zn, Pb).
Vilhena *et al.* (2013)	Rio Marapanim, Pará (Amazon), Brazil	11.00	69.00	-	-	Geogenic; Urban-Industrial.
Andrade *et al.* (2012)	Passa Vaca – BA, Brazil, Brazil	45.60	24.60	-	-	Urban (sewer) (↑Cu).
Gonçalves *et al.* (2012)	Estuary of Santos and Cubatão – SP, Brazil	66.50	380.00	-	76.00	Urban-Industrial (↑Cu, Zn, Pb).
Ceschini (2011)	Guanabara Bay – RJ, Brazil	13.98	75.08	-	26.92	Urban (garbage, sewage) (↑ Zn, Pb).
Reitermajer *et al.* (2011)	Estuary of the River Sauipe - BA, Brazil	14.15	1.05	-	8.26	Rural-Urb. (sewage). Not polluted.
Luiz-Silva *et al.* (2008); Luiz-Silva *et al.* (2006)	Estuary of Santos and Cubatão – SP, Brazil	25.40	93.00	0.20	25.75	Urban-Industrial (Steel and Fertilizers) (↑Cu, Zn, Pb).
Lion *et. al.* (2008)	Aratu Bay – BA, Brazil	14.73	37.61	416.5	112.71	Urban-Industrial (↑Cd, Pb).
Queiroz and Celino (2008)	Itaparica Island, BTS, Bahia, Brazil	11.00	49.00	<LD	19.50	Rural-Urb. (tourism). Not polluted.
Correa (2008)	Potengi River Estuary, Natal - RN, Brazil	26.60	69.66	0.06	02.15	Urban-Industrial (↑Cu).
Rocha (2008)	Mucuri River – BA, Brazil	1.05	11.32	-	-	Urban (Not Polluted).
Silva (2005)	Cosipa Channel - SP, Brazil	11.67	83.94	-	21.50	Urb.-Ind. (garbage, sewage) (↑ Zn, Pb).
Bernini *et al.* (2006)	São Mateus River – ES, Brazil	2.54	5.23	-	-	Urban (Waste, Effluents).
Oliveira *et al.* (2000)	Rio Capivara Pequeno - BA, Brazil	15.20	109.30	-	-	Industrial (Effluents) (↑Cu Zn).
Machado *et al.* (2002)	Southeast Brazil, Brazil	43.25	238.25	-	65.68	Urban-Industrial (↑Cu, Zn, Pb).
Lacerda (1998)	Sepetiba Bay - RJ, Brazil	18.50	676.00	5.20	30.50	Urban-Industrial (↑Zn, Pb).
Silva *et al.* (1996)	Santa Catarina, Brazil	25.50	64.00	0.09	31.15	Urban-Industrial (↑ Cu, Pb).
Ribeiro (1998)	Santa Catarina (Ratones), Brazil	-	-	0.11	16.68	Rural-Urb. (sewage). Not polluted.
Lacerda *et al.* (1993)	Sepetiba Bay – RJ, Brazil	12.50	191.00	3.10	21.50	Urban-Industrial (↑Zn, Cd).
Queiroz (1992)	Santo Amaro – BA, Brazil	56.80	84.90	9.40	95.00	Indust.; mining (↑Cu, Cd, Pb).
Lacerda and Abram (1984)	Sepetiba Bay – RJ, Brazil	6.85	169.00	1.85	15.30	Urban-Ind. (Steel industry). (↑Zn).

Mahmudi *et al.* (2021)	Bee Jay Bakau Resort, Indonesia	-	-	-	10.76	Urban - Ind., tourism, aquaculture.
Khan *et al.* (2020b)	matang, malaysia	31.83	60.30	1.01	12.70	Urban-Indust. (Effluents) (↑Cu).
Ariyanto *et al.* (2021)	Asahan, Indonesia	-	-	-	9.76	Urban-Industrial (Effluents).
Ganeshkumar et al. (2019)	Southeast coast of India	7.31	24.00	0.49	11.28	Urban-Indust.; Agro-aquaculture.
Soraya *et al.* (2019)	Blanakan District, Indonesia	9.33	89.48	-	25.58	Urban-Industrial (↑ Zn).
Baruddin *et al.* (2017)	Kelantan Delta, Malaysia	-	-	-	55.05	Urban-Industrial (↑Pb, As, Cr).
Analuddin *et al.* (2017)	Southeast of Sulawesi, Indonesia	7.94	24.79	0.32	0.01	Rural-Urb. agriculture, mining.
Qiu and Qi (2017)	Hainan Island, South China	12.20	55.60	0.14	23.90	Agriculture (Not Polluted).
Marchand *et al.* (2016)	New Caledonia, France	17.16	56.23	-	-	Urban; mining (↑Pb).
Isroni *et al.* (2016)	Mlaten Village, Indonesia	-	-	3.71	-	Rural-Urban, fishing, agriculture.
Kaewtubtim *et al.* (2016)	Pattani Bay, Thailand	22.10	26.60	0.20	47.30	Industrial, mining (↑Pb).
Ong *et al.* (2016)	Penang River Estuary, Malaysia	21.30	131.00	0.53	25.90	Urban-Industrial, tourism (↑Zn).
Liu *et al.* (2014)	Hainan Province, South China	15.30	35.70	0.36	30.70	Ind., agriculture, tourism (↑Pb).
Badarudeen *et al.* (2014)	Kochi and Kannur, Keraza, India	44.00	52.50	2.00	29.50	Urban-Industrial (↑Cu, Pb).
Fernández-Cadena *et al.* (2014)	Estero Salado, Ecuador	253.80	678.30	1.90	81.30	Industrial (↑Cu, Zn, Pb).
Kanhai *et al.* (2014)	Caroni Swamp, Trinidad	19.20	143.41	<LD	-	Urban-Industrial (↑Zn).
Bodin *et al.* (2013)	Fadiouth, Senegal	3.50	5.60	0.06	2.60	Agriculture, fishing, extractivism.
Mejias *et al.* (2013)	Las Cucharillas, Puerto Rico	89.17	270.60	-	77.60	Industrial (↑Cu, Zn, Pb).
Sany *et al.* (2013)	Klang harbor, Malaysia	17.43	51.05	0.82	59.45	Industrial and Port (↑Pb).
Keshavarz *et al.* (2012)	Marina coast of Oman, Iran	-	-	<0.01	6.90	Industrial (Petrochemical).
Espinosa *et al.* (2011)	Cienaga Grand de Sta. marta, colombia	16.26	42.70	1.87	59.48	Urban-Indust.; mining (↑Pb).
Kamaruzzaman *et al.* (2011)	pahang, malaysia	15.52	-	-	31.23	Rural-Urban, lithogenic (↑Pb).
Qiu *et al.* (2011)	Hainan Island, China	15.00	58.00	0.20	24.00	Urban-Industrial (↑Pb).
Kamaruzzaman *et al.* (2009)	terengganu, malaysia	9.42	-	-	11.66	Urban; Lithogenic (Unpolluted).
Pahalawattaarachchi *et al* (2009)	Alibag, Maharashtra, India	92.59	78.18	5.31	19.51	Urban-Industrial (↑Cu).
Kruitwagen *et al.* (2008)	Mtoni estuary, Tanzania	4050.0	2450.0	28.10	385.00	Industrial Textile (↑Cu, Zn, Cd, Pb).
Kruitwagen *et al.* (2008)	Mtoni estuary, Tanzania	14.70	178.00	14.90	110.00	Industrial The collection points furthest from the source (↑Zn,Pb).
Kruitwagen *et al.* (2008)	Mtoni estuary, Tanzania	5.60	27.23	1.27	01.28	
Parra and Fernanda (2007)	Cienaga Grand de Sta. marta, colombia	-	85.39	0.76	85.35	Urban-Indust.; mining (↑Pb)
Marchand *et al.* (2006)	New Caledonia, France	17.79	164.10	-	26.94	Urban; mining (↑Zn, Pb, Hg).

De Astudillo *et al.* (2005)	Trinidad and Venezuela, Caribbean	07.14	88.96	0.24	12.69	Urban-Indust. (oil) (↑Pb)
Saenger and McConchie (2004)	South East Queensland, Australia	113.30	211.00	0.09	27.80	Urban-Indust. (↑Cu, Zn; *Pb).
Alongi *et al.* (2003)	western australia	13.70	28.90	-	-	Urban (Not Polluted).
Sarangi *et al.* (2002)	Orissa, India.	2.80	0.93	-	-	Urban (Not Polluted).
Ramanathan *et al.* (1999)	Pichavaram, Tamil Nadu, India	43.40	93.00	6.60	11.20	Rural-urb., tourism (↑Cu, Cd, Zn).
Perdomo *et al.* (1999)	Cienaga Grand de Sta. marta, colombia	23.30	91.00	1.90	12.60	Urb.- Ind.; mining (↑Zn, Pb).
Thomas and Fernandez (2007)	Kerala, India	303.7	764.33	-	1483.7	Urban-Industrial (↑ Cu, Zn, Pb).
Zheng *et al.* (1997)	Yingluo Bay, China	18.90	46.60	0.08	10.00	Urban-Industrial (*Cu).
Gonzalez and Ramirez (1995)	Levisa Bay, Cuba	31.00	56.30	-	11.70	Metallurgy, mining (↑ Cu, Ni).
Guzman and Jimenez (1992)	Pacific coast, Costa Rica	8.70	19.00	5.90	28.60	Urban-Industrial (wastewater, petrochemical, port) (↑Pb).
Guzman and Jimenez (1992)	pacific coast, panama	4.10	15.80	7.00	33.20	
Saenger *et al.* (nineteen ninety)	northern australia	39.00	53.00	-	16.00	Urban-Industrial (↑ Cu).
Turekian and Wedepohl (1961)	Standard Brochure	45.00	95.00	0.30	20.00	
NOOA (1999) (reviewed by Long *et al.*, 1995)	Below Effect Level (TEL)	18.70	124.00	0.68	30.20	
	Low Effect Interval (ERL)	34.00	150.00	1.20	46.70	
	Probable Effect Level (PEL)	108.00	271.00	4.21	218.00	
CCME (2001)	Probable Effect Level (PEL)	197.00	315.00	3.50	91.30	
US EPA (1991)	not polluted	<25.00	<90.00	-	<40.00	
	Slightly Polluted	25-50	90-200	-	40-60	
	Severely Polluted	>50.00	>200	>6.00	>60.00	

Table 6 - Comparison between the levels of trace metals (Cu, Zn, Cd, Pb) in the sediments of the forests of the Tinharé-Boipeba APA (BA) and of previous studies in coastal areas around the world.

Source: Organized by the authors.

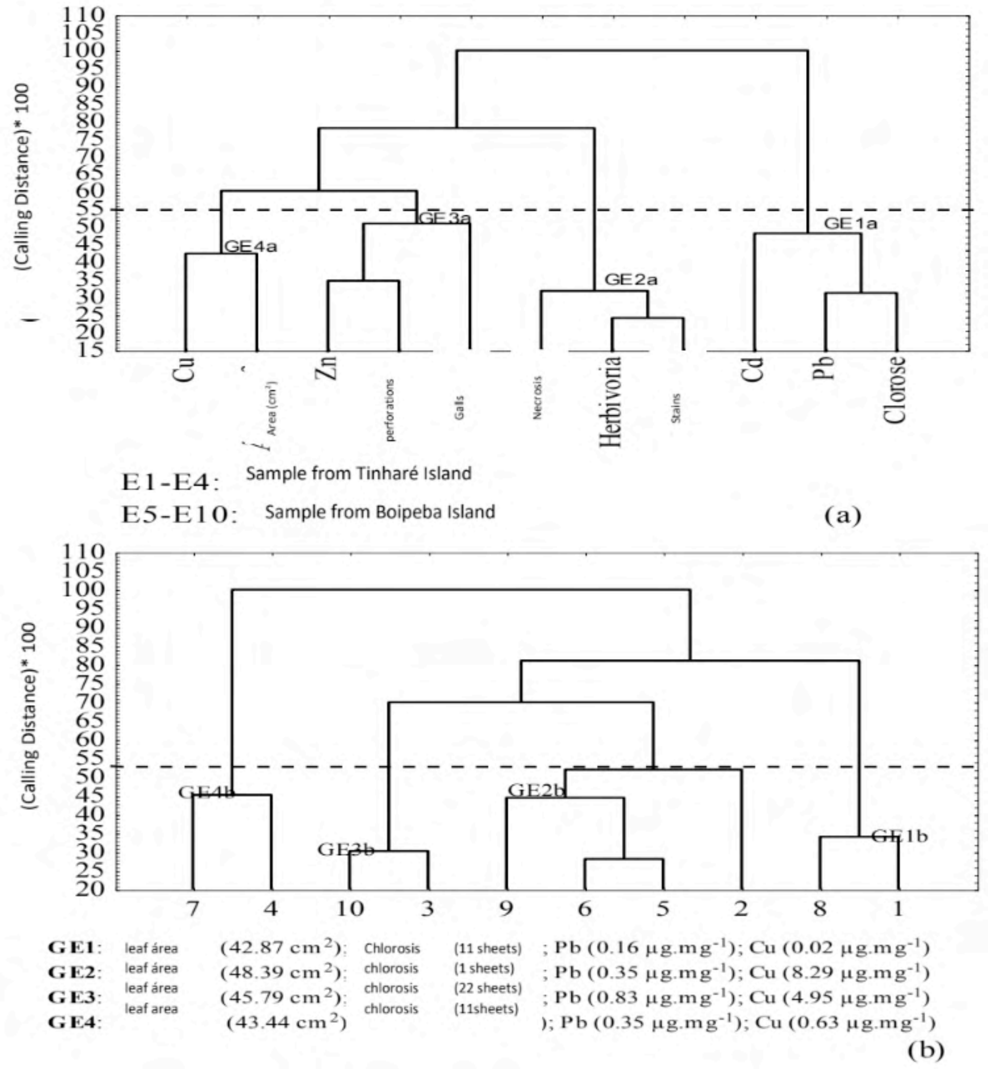

Figure 5 – Dendrogram of identification of ecological-geobotanical groups by the integration of chemical and ecological-geobotanical data from mangrove leaves. a. Variables. **B.** _ cases.

Source: Organized by the authors.

fruit set and promotes a reduction in the leaf blade area.

Ernst, Verkleij; Schat (1992) emphasize that Cu participates in the metabolism of carbohydrates, in mitochondria and chloroplasts, protein synthesis, enzymatic systems of the electron transport chain and lignification of the cell wall. Nutritional Cu deficiency induces changes in leaf integrity, such as depigmentation (chlorosis) and necrosis, reduced plant height, water loss and stress (PARVARESH *et al.*, 2011).

In this context, it is concluded that in addition to the essential (Cu, Zn) and non-essential (Cd, Pb) trace metals investigated in this research, other stressors may be related, in general, to the behavior of ecological-geobotanical variables, such as salinity oscillations, land uses and spatial variables, the contribution of fresh continental waters, the oxi-reduction conditions of the rhizosphere and sediments and the availability of other nutrients (N and P).

Furthermore, by comparing the levels of trace metals in the sediments and leaves of mangrove plants in the Baixo Sul da Bahia, or coastal areas in the world, the relevance of sediments and rhizosphere in the biogeochemistry of metals- traces, in the sequestration and immobilization of pollutants, that is, a geo-environmental filter. MacFarlane *et al.* (2007) and Kříbek *et al. al.* (2011) emphasize the relevance of the rhizosphere of plants and mangrove sediments in the fundamental ecosystem service of sequestering pollutants. However, Yu *et al.* (2010) and Al-Mur *et al.* (2017) point out that trace metals can be released from mangrove sediments into water or biota under geochemical conditions unfavorable to retention, alter the chemical speciation of these potential pollutants and cause damage to the environment, biota and health.

Pahalawattaarachchi *et al.* (2009), Mejías *et al.* (2013), Khan *et al.* (2020a) and by Mahmudi *et al.* (2021) highlight the environmental relevance of mangroves in the sequestration of pollutants and the ability of plants of the *Rhizophora genus to bioaccumulate trace metals,* which can be applied in the diagnosis and assessment of environmental impacts, in environmental monitoring, phytomanagement and phytoremediation and in the recovery of degraded coastal areas.

In addition, even from an anthropocentric perspective, mangrove conservation provides the maintenance of ecosystem services, such as the sequestration of organic matter, greenhouse gases and pollutants, shelter for juvenile fauna, protection of the coastline against erosion marine and nutrient biogeochemistry in coastal and marine ecosystems. These ecosystem services are offered by the unity between sediments, waters, plants, fauna and microbiota, which demand environmental conservation, where the relationship between society and nature cannot be disregarded.

QUALITY OF COASTAL SURFACE WATERS AND ENVIRONMENTAL SANITATION

Temperature values of coastal surface waters of the Tinharé-Boipeba APA were obtained from 27.2 to 31.6 ºC and salinity from 34.0 to 36.90 PSU, which allowed the classification of the samples as Class 1 Saline Waters. and 2 (Table 7), according to Conama Resolution No. 357/05 (BRASIL, 2005). These values of temperature and salinity of the coastal surface waters of this APA suggest that these water bodies are under the influence of the air and the Tropical Water mass, and of the Brazil Current, identified by salinity values that exceed 36.9 PSU and temperatures between 22 and 28 °C.

The DO levels ranged from 1.1 to 6.2 $mg.L^{-1}$, whose lower levels were attributed to the discharge of *in natura* domestic liquid effluents into water bodies, with the lowest DO level being obtained at the 4th Beach (E3), in the locality of Morro de São Paulo (Figure 6). In addition, it was noted that the OD levels of 70% of the samples were in disagreement with the provisions of CONAMA Resolution 357/05 (BRASIL, 2005) for Class 1 saline waters.

CONCLUSIONS

The levels of trace metals in the leaves of *Rhizophora mangle* d The mangrove forests of the Tinharé-Boipeba APA, in the Southern Lowlands of Bahia, NE Brazil, were normal and non-toxic and similar to what was observed in previous research using species of the genus *Rhizophora,* carried out in coastal areas considered not polluted or slightly influenced by pollution. Furthermore, it was concluded that the levels of trace metals in the sediments of this APA do not characterize an area polluted by the trace metals Cu, Pb and Zn. The demand for geoenvironmental monitoring of trace metals, especially Pb in the waters, sediments and biota of mangrove forests is made explicit.

It was observed that the values of the concentration factor of trace metals in the mangrove forests of the aforementioned APA were lower than 1.0 (unit), which indicated that the biogeochemical conditions can promote the retention of trace metals in the rhizosphere of the *Rhizophora* and in the sediments of this ecosystem. Furthermore, research focused on the use of species of the genus *Rhizophora* (Rhizophoraceae) in the assessment of impacts, bioindication, environmental monitoring, phytomanagement, phytoremediation, in the recovery of degraded areas, in ecological restoration and in ethnoconservation.

With this, the conservation of the mangrove is claimed from the socio-philosophical perspective that integrates the human being with nature, where the mangrove has value in itself, in addition to contributing to the support of coastal and marine life. Furthermore, it offers basic ecosystem services for material and symbolic reproduction of life with dignity in traditional communities in the APA, such as environmental filtering services against pollutants and sequestration and trapping of atmospheric carbon dioxide in sediments and biomass.

In this way, this biogeochemistry study contributed to the understanding of the ecological and geoenvironmental dynamics of the mangrove forests of the Tinharé-Boipeba APA, and provided relevant information for territorial management. In addition, it was understood that the loss of coastal surface water quality demanded coastal environmental management and improved sanitation, so that future restrictions on the use of waters and beaches in this APA can be avoided, such as the beaches of Morro de São Paulo., Moreré and Boipeba, which represent important tourist attractions in the Southern Bahia Lowlands, Brazil.

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Author	Location	pH	Temperature (º C)	Salinity (PSU)	OD (mg.L $^{-1}$)
Present Study	**APA Tinharé-Boipeba**	7.2 - 8.2 (x̄=7.7)	27.7 - 31.6 (x̄=30.1)	36.6 - 37.0 (x̄=36.1)	1.10 - 6.20 (x̄=4.1)
Santos (2002)	Garapuá Cove, Tinharé Island	6.8 - 8.6 (x̄=6.7)	22.0 - 31.0 (x̄=26.7)	34.0 - 46.0 (x̄=36.9)	3.85 - 7.60 (x̄=5.8)
Viana (2005)	Garapuá Cove, Tinharé Island	7.3 - 8.2 (x̄=7.9)	23.4 - 30.2 (x̄=27.7)	34.0 - 46.0 (x̄=36.0)	6.43 - 8.43 (x̄=7.4)
Viana (2005)	Garapuá Estuary, Tinharé Island	6.3 - 7.8 (x̄=7.2)	23.2 - 31.6 (x̄=27.7)	2.0 - 21.0 (x̄=19.0)	3.74 - 6.50 (x̄=5.4)
Almeida (2000)	Barra dos Carvalhos, Boipeba Island	7.6 - 7.8 (x̄=7.9)	30.0 - 30.0 (x̄=30.0)	18.0 - 20.0 (x̄=19.0)	5.15 - 6.24 (x̄=5.7)
Santana (2002)	Barra dos Carvalhos, Boipeba Island	7.2 - 8.1 (x̄=7.9)	23.1 - 30.7 (x̄=28.2)	8.9 - 33.1 (x̄=21.7)	3.15 - 6.80 (x̄=4.3)
Range (2003)	Barra dos Carvalhos, Boipeba Island	5.7 - 8.1 (x̄=7.6)	23.0 - 28.2 (x̄=26.5)	23.3 - 33.9 (x̄=31.5)	4.82 - 8.30 (x̄=5.5)
Quaglia (1993)	Taperoá Canal, Taperoá	7.6 - 8.5 (x̄=8.0)	22.5 - 30.9 (x̄=27.5)	24.7 - 34.7 (x̄=29.6)	4.80 - 8.30 (x̄=6.2)
Viana (2005)	Taperoá Canal, Taperoá	7.4 - 8.1 (x̄=8.0)	23.9 - 30.8 (x̄=27.9)	20.0 - 36.0 (x̄=29.0)	3.46 - 7.40 (x̄=5.6)
CONAMA 357/2005 (Brackish Water)	class 1	6.50 - 8.50	-	0.50 - 30.00	> 6.00
CONAMA 357/2005 (Saline Waters)	class 1	6.50 - 8.50	-	≥ 30.00	> 5.00

Table 7 - Comparison between the measurements of the physical-chemical variables of coastal surface waters in the present study and in previous studies (descriptive statistics: minimum, maximum and average: x̄) carried out in rivers and estuaries of coastal areas of the Southern Lowlands of Bahia, Brazil.

Source: Organized by the authors.

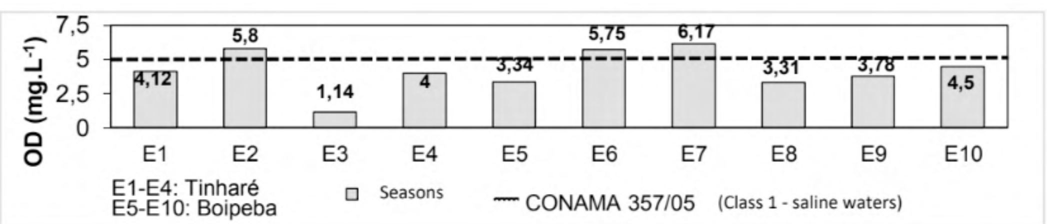

Figure 6 - Dissolved oxygen (DO) levels in the surface waters of the Tinharé-Boipeba APA.

Source: Prepared by the authors, based on field research data.

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