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Baseline

First report of some rare earth elements and trace elements in sands from different islands located in the Marine Natural Monument Archipelago Cayos Cochinos, Caribbean Sea

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ABSTRACT

Rare earth elements (REEs) are a group of chemicals widely used in emerging technologies today, and are often labeled as potential environmental contaminants. The Cayos Cochinos Archipelago is a protected area of Honduras, Central America, with intertidal and supratidal sands, making it a prime candidate for pollution research. In December 2022, sand samples from the Cayos Cochinos area was collected and analyzed by X-ray fluorescence to determine the levels of REEs and some less-studied trace elements (TEs). Based on the findings, REEs mean contents (μg g^{-1} d.w.) fluctuated between 2.96 for Y to 667.1 for Nd, while TEs ranged from 10.37 for Th to 3896.2 for Sr. Also, the results showed significantly higher levels of La, Pr, Y, Sr, Ba, and Th in the supratidal zone than in the intertidal zone. The data are useful as a basis for understanding the presence of chemical elements in near-shore marine areas and subsequently help identify sustainable practices that will reduce the impacts of these chemicals.

In the future, most tropical ecosystems will face dramatic challenges because of poor data availability, strong seasonality, and high-intensity natural events (Maina et al., 2013; Camp et al., 2018). Of these ecosystems, coral reefs are particularly crucial because they provide shelter for many marine species that support human livelihoods and protect shorelines from potential impacts of extreme weather (Cinner, 2014). Human activities are affecting coral reefs worldwide (Nguyen et al., 2013; Briand et al., 2023). The Cayos Cochinos Archipelago belongs to the Meso-American Barrier Reef, the world's second-largest barrier reef system, which has been identified by the Smithsonian Institute, The Nature Conservancy, the Word Wildlife Fund, and the World Bank as one of the key sections of the barrier reef system to preserve (Shrives et al., 2007). In addition, this archipelago is a protected marine reserve known for its natural beauty and biodiversity. The achipelago is located 30 km northeast of La Ceiba, Honduras, Central America, Caribbean Sea. It consists of two main small islands, Cayo Menor and Cayo Grande, as well as a collection of smaller islets. The Cayos Cochinos are usually inhabited by the Garifuna, an Afro-Caribbean community with a unique culture combining African and Caribbean sub-cultures (CRPCC, 2004). However, human activities potentially leading to contamination of these vital boundaries with marine life have been reported in the Cayos Cochinos Archipelago in the past (Montgomery et al., 2011).

There is a growing demand for production of products containing chemicals including both rare earth elements (REEs) and trace elements (TEs), which have become critical technology manufacturing – high-tech devices such as mobile phones, electric vehicles, and many other electronics utilize these elements (Eggert, 2011; Zhang and Gao, 2015). Nevertheless, a significant gap in understanding exists regarding both the presence of these elements in coral reef ecosystems and their overall impact on this sensitive ecosystem (Saha et al., 2021). REEs, which were previously stable in the earth's crust, are presenting an increased risk to these ecosystems with their extraction and dispersion into the environment (Espejo et al., 2018), and have been shown to have potential severe consequences for human health (Pagano, 2017; Celis et al., 2020). The

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use of these chemicals raises particular concerns regarding contaminant management around coastal regions (Kulaksiz and Bau, 2013; Celis et al., 2022; Liu et al., 2023).

The production of REEs and lesser-known TEs such as Ba, Sr, and Th is increasing worldwide, potentially worsening pollution (Gulley et al., 2018). Most prior studies have been done on TEs such as As, Pb, Cd, Hg, and U (Balaram, 2019), but to our knowledge, very few works have been performed on REEs and TEs from the sand of beaches in the Caribbean Sea (Kasper-Zubillaga et al., 2015). Studies have shown that metal contamination from these less studied metals can have toxic and carcinogenic effects – particular evidence links Ce and Y to mutagenic and carcinogenic effects (Cobelo-García et al., 2015; Newman, 2015; Pagano, 2017; Adeel et al., 2019). Many authors have evidenced that the increasing use of REEs will pose a threat to human and animal health (Pagano, 2017; Malhotra et al., 2020; Bu-Olayan and Thomas, 2020; Piarulli et al., 2021). The exposure of Ba, Sr, and Th in humans is associated with cardiotoxicity, skeletal disorders, and dermatitis, but many potential impacts remain unknown (Wexler, 2014). Setting measures to minimize the environmental impacts of REEs and lesser-known TEs involved in high-tech production is important.

The intertidal zone is between the land and sea and limited by the height of the high and the low tides, while the supratidal area is above high tide and only flooded by spring tides or during storm surge (Fan, 2013). Studying intertidal and supratidal sands for analyzing REEs and TEs is important because coastal wetlands usually combine terrestrial and marine ecosystems, acting as natural filters for removing chemicals and contaminants (Mohamed et al., 2015). Commonly, chemical contaminants have a stronger affinity with the solid phase than the liquid phase, which means they tend to accumulate the most in sediments. Moreover, the migration of metals depends mainly on salinity, which influences their accumulation in sands (Bai et al., 2011; Bai et al., 2014). Furthermore, the intertidal and supratidal zones are sensitive to pollution (Wen et al., 2015; Liu et al., 2019). It is important to assess the concentration of REEs in both the intertidal and supratidal sands to understand the source of chemical pollutants to better target future interventions or remediation in the environment (Zhang et al., 2014). In consequence, the goal of this work was to assess the concentrations of some REEs and TEs in sands of the Cayos Cochinos Archipelago, and to test if these chemical elements are influenced by tides.

The area under study includes five islands that belong to the Cayos Cochinos archipelago (Fig. 1). The Marine Natural Monument Archipelago Cayos Cochinos (Fig. 1) is located at 15° 57′ N and 86° 30′ W in the Caribbean off the coast of Honduras and covers an area of 485,34 km^2. Typically, coral reefs, seagrass beds, octocoral formations, rock, sand, algae, and mangroves conform to the habitat for several species. Fishing is the main economic activity, followed by tourism.

During December 2022, 150 sand samples (0–10 cm depth) of about 100 mg each were collected using plastic hand trowels from two zones (supratidal and intertidal) at five locations studied: Cayo Timón (CT), Cayo Bolaños (CB), Cayo Menor (CR), Cayo Mayor (CY) and Cayo Chachahuate (CC). The supratidal zone corresponds to the area above high tide, whereas the site between mean high tide and mean low tide is the intertidal zone. The collected samples were stored in plastic bags until they arrived at the laboratory.

In the laboratory, all samples were dried until dry mass was constant and then homogenized, following the procedure described by Espejo et al. (2017). Afterward, the samples were heated (oven at 100 °C × 12 h) to remove adsorbed water before analysis (Fang et al., 2018). The samples were analyzed for chemical elements according to the EPA method 6200 at the Applied Biogeochemistry Laboratory, Facultad de Agronomía, Universidad de Concepción (Chile), using a portable battery-operated energy dispersive X-ray fluorescence spectrometer (Thermo Scientific Niton XL3t 950 He GOLDD+). The instrument was set up with the instrument tip on a shielded laboratory test stand, which was remotely operated. The blank was a certified 99.99 % SiO_2 dioxide analyzed every 20 samples. The precision and accuracy were verified using international reference standards Rare Earth Ore "CGL 124" (USZ-42 Mongolia Central Geological Laboratory), with precision >98 % and accuracy within 95–99 %. The coefficient of variation (standard deviation over the mean) for standard measurements ranged from 0.052 to

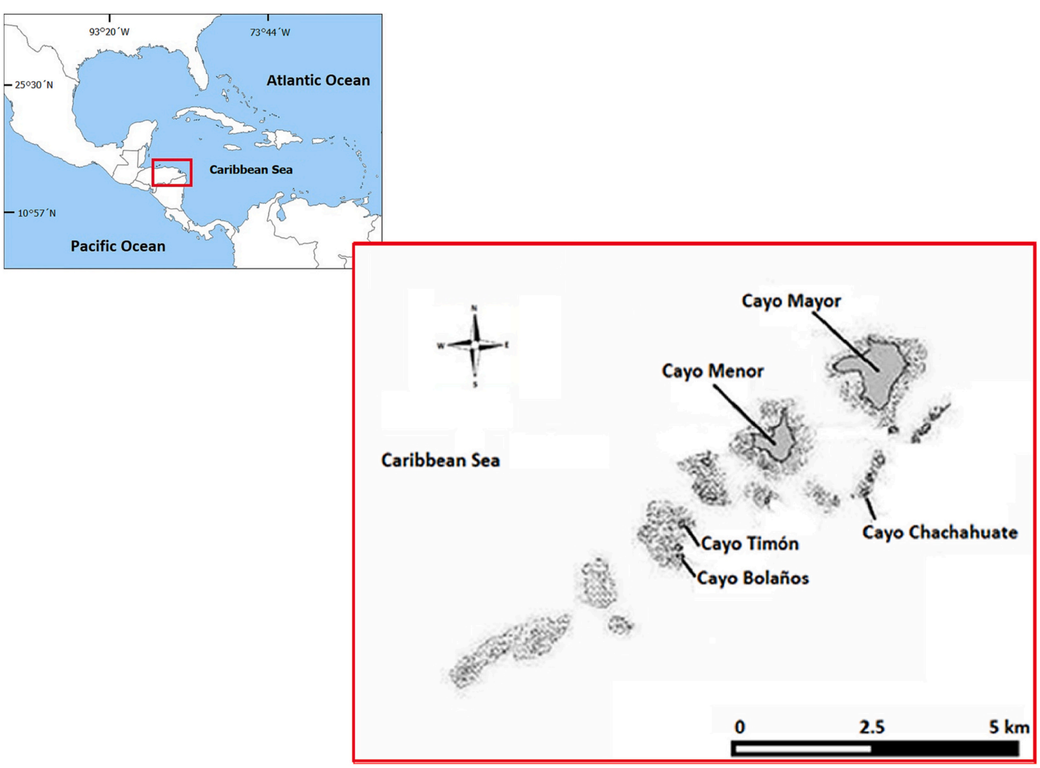

Fig. 1. Geographical location of the sampling of sands from Cayos Cochinos archipelago (15°58′N, 86°28′W), Caribbean Sea, Central America.

0.005 – indicating a high consistency among repeated measurements of samples. The calibration and validation of the device was also completed using this same standard. The limit of detection for these measurements can vary based on the element in question. Table 1 contains the values for the uncertainty and limit of detection for the x-ray fluorescence measurements. Measurement limit of detection values in general were lower than values from samples measured in the study, as indicated in the percent above detection limit values. However, samples with non-detects in this context are valuable, as with industrial contamination, it would be expected that these elements would concentrate to levels above the detection limits from the X-ray fluorescence measurements.

Statistical analyses were carried out using InfoStart software. Before analyzing the data, the Shapiro-Wilk test was carried out to determine the normality of the data. Since data did not pass normality, Mann-Whitney was used to determine the central tendency of the two groups (Kruskal-Wallis ANOVA; *F*-Statistic). The results of the concentrations of REEs and other chemical elements were analyzed in two dimensions. First, it was examined whether there were differences between the supratidal and intertidal zones for each locality, and then whether there were differences between localities for the supratidal and intertidal zones separately. Spearman's correlation coefficients were calculated among the levels of the elements detected in the sands sampled. The results showed that there are positive and significant correlations among all elements analyzed in the supratidal zone. A value α of 0.05 was used to assess significance.

In Table 2 the mean, maximum, and minimum values of REEs found in the sand of intertidal and supratidal zones of the five locations focus of this work. When comparing supratidal and intertidal zones, notable variations in the concentrations of REEs studied here were observed. The mean La, Pr, and Y concentrations found in the sand of the supratidal zone at CT (Kruskal-Wallis ANOVA, $F = 4.61$, $p = 0.0405$), CR (Kruskal-Wallis ANOVA, $F = 19.46$, $p = 0.0001$), and CB (Kruskal-Wallis ANOVA, $F = 6.82$, $p = 0.0143$) are significantly higher than those levels detected in the sand of the intertidal zone, respectively. The contents of Ce and Nd exhibited no significant differences between the supratidal and intertidal zones ($p > 0.05$). The maximum levels detected corresponded to Nd (828.65 μg g^{-1}) in the sand of the supratidal zone at Cayo Timón (CT). On the other hand, Y exhibited the minimum value (1.78 μg g^{-1}) in the sand of the intertidal zone at Cayo Mayor (CY).

Table 3 shows the mean, maximum, and minimum values of TEs found in the sand of intertidal and supratidal zones of the five locations considered herein. In Cayo Timón (CT), the levels of Sr (3778.9 μg g^{-1}; Kruskal-Wallis ANOVA, $F = 5.78$, $p = 0.0231$) and Th (44.8 μg g^{-1}; Kruskal-Wallis ANOVA, $F = 8.76$, $p = 0.0062$) are significantly higher than those Sr and Th values in the sand of the intertidal zone, respectively. In Cayo Menor (CR), the mean concentrations of Ba (208.7 μg g^{-1}) detected in the sand of the supratidal zone are significantly higher than Ba values in the sand of the intertidal zone (Kruskal-Wallis ANOVA, $F = 4.86$, $p = 0.036$). The highest concentrations found corresponded to Sr with 4256 μg g^{-1} in the sand of the supratidal site at Cayo Chachahuante (CC), whereas the minimum values for Sr (2.41 μg g^{-1}) in the intertidal zone of Cayo Mayor (CY). No significant differences existed between the supratidal and intertidal zones for the rest of the elements ($p > 0.05$).

The enrichment levels of REEs in the supratidal zone observed herein might be explained by the exposure of sands to subaerial conditions due to tides, which occur intermittently in the intertidal zone or permanently in the supratidal (Wiedemann, 1969). Tides usually act in the intertidal zone sweeping the sands, which could explain the lower concentrations of the elements compared to the supratidal zone, which is occasionally affected by tides. Moreover, pH, organic matter, temperature, and salinity may affect the mobility of REEs and metals in sands (Liu et al., 2019). This is an issue that requires further investigation.

When comparing the mean REE-levels among locations, there are differences in the levels of the elements depending on the sampling zone (intertidal or supratidal). Fig. 2 shows the contents of REEs in the sands of the intertidal zone from different locations in the Cayos Cochinos archipelago. No significant differences ($p > 0.05$) were noted for La, Ce, Pr, and Nd values in the sand of the intertidal zone among Cayo Timón (CT), Cayo Bolaños (CB), and Cayo Chachahuante (CC). Still, the contents of La ($F = 56.67$), Ce ($F = 54.47$), Pr ($F = 127.55$) and Nd ($F = 74.58$) at CT, CB and CC are significantly higher than those levels at CR and CY (Kruskal-Wallis ANOVA, $p < 0.0001$). However, the La, Ce, Pr, Nd, and Y levels at CR are significantly higher than those at CY ($p < 0.05$). For Y, the concentrations in sand of the intertidal zone are higher at CR than those contents from the rest of the locations, although Y values at CB, CT and CC are higher than Y levels at CY (Kruskal-Wallis ANOVA, $F = 29.1$, $p < 0.0001$).

In Fig. 3, the concentrations of REEs in the sands of the supratidal zone from different locations in the Cayos Cochinos archipelago are shown. From Fig. 3, Ce levels in sands of the supradital zone did not show statistical differences in sand samples obtained from the locations CT, CB, CC and CR ($p > 0.05$), but these values were higher (Kruskal Wallis ANOVA, $p < 0.0001$) than those found in sands from CY ($F = 63.69$). The same was found for the concentrations of Pr ($F = 126.08$) and Y ($F = 21.02$). The contents of La and Nd showed no differences among CT, Cb and CC ($p > 0.05$), but their concentrations were higher than those levels found at CR and CY ($p < 0.05$). The La and Nd levels at CR were estatistically higher than those levels detected in sands on CY ($p < 0.05$).

Similarly, when comparing the mean TE-levels among locations, there are some differences in the levels of the trace elements depending on the zone. Fig. 4 shows the levels of TEs found in the sands of the intertidal and supratidal zones from different locations in the Cayos Cochinos archipelago. As noted, the mean Ba concentrations in the intertidal zone (blue) showed no differences among the sampling sites CT, CB, CR, and CC ($p > 0.05$). However, their levels are significantly higher than the Ba values detected in CY (Kruskal-Wallis ANOVA, $F = 15.8$, $p < 0.0001$). For Sr, the levels in the sand of the intertidal zone at CC are higher than the Sr values found in the sand of the same area from the rest of the locations studied here (Kruskal-Wallis ANOVA, $F = 637.72$, $p < 0.0001$). The contents of Sr between CT and CB showed no statistical differences ($p > 0.05$), but Sr levels at both locations are statistically higher than Sr levels at locations CR and CY. In contrast, Sr values are significantly higher at CR than those levels at CY. For Th, between CB and CC, there are no differences ($p > 0.05$), but their Th levels are significantly higher than the rest of the locations, whereas Th values between CT and CR showed no differences ($p > 0.05$). The contents of Th at Cy were lower than the rest of the locations (Kruskal-Wallis ANOVA, $F = 355.21$, $p < 0.0001$).

The Ba contents in the supratidal zone (Fig. 4, red color) at CT, CB, CR, and CC showed no differences among those locations ($p > 0.05$), but there are higher than those levels detected at CY (Kruskal-Wallis ANOVA, $F = 12.07$, $p < 0.0001$). For Sr, their values found at CT, CB, and CC are higher than those levels at CR and CY, although Sr values at CR

Table 1
The uncertainty and standard deviation (SD) of the uncertainty for measurements in the study, the limit of detection (DL), median, and minimum values for the measurements in study.

Element	Uncertainty ± SD (μg g^{-1})	DL (μg g^{-1})	Median (μg g^{-1})	Minimum (μg g^{-1})	% above DL
La	46.4 ± 22.5	87.5	301	90.1	100
Ce	48.5 ± 36.6	87.7	283.3	101.7	100
Pr	61.9 ± 13	119.9	631.7	227.9	100
Nd	91.8 ± 23.3	177.6	605.7	0	99.4
Y	1 ± 0.8	1.8	5.6	0	92.4
Sr	13.5 ± 10.8	24.2	3455.4	2.4	97.4
Ba	33.2 ± 5.6	65	192.8	100.8	100
Th	5.1 ± 5.6	9.1	36.7	0	82.1

Table 2
Mean levels (μg g^{-1} d.w.) of REEs ± standard deviation in sands of locations from Cayos Cochinos Archipelago.

Location	Zone (n = 15)	La	Ce	Pr	Nd	Y
CT -	Intertidal	**318 ± 26** (357–265)	300 ± 28 (341–226)	665 ± 52 (733–555)	654 ± 63 (798–543)	5.31 ± 0.82 (6.93–3.71)
	Supratidal	**340 ± 29.8** (387–282)	300 ± 20 (335–271)	663 ± 33 (709–586)	651 ± 89 (829–454)	5.94 ± 0.83 (7.03–4.42)
CB -	Intertidal	313 ± 35 (383.1–242.4)	285 ± 31 (334–235)	658 ± 35 (697–588)	636 ± 46 (703–549)	**5.74 ± 0.83** (6.81–4.31)
	Supratidal	321 ± 28 (361–274)	297 ± 33 (341–230)	662 ± 39 (738–602)	614 ± 80 (724–454)	**6.42 ± 0.61** (7.32–5.31)
CR -	Intertidal	**272 ± 29** (326–230)	258 ± 33 (324–207)	**546 ± 63** (681–419)	530 ± 71 (626–383)	7.94 ± 2.22 (13.21–6.02)
	Supratidal	**299 ± 32** (338–214)	275 ± 33 (319–220)	**630 ± 37** (677–537)	573 ± 63 (672–462)	6.83 ± 2.31 (14.71–5.02)
CY -	Intertidal	167 ± 44 (284–90)	153 ± 40 (258–110)	314 ± 58 (474–228)	278 ± 87 (533–182)	3.32 ± 2.31 (8.92–1.81)
	Supratidal	171 ± 33 (226–123)	155 ± 32 (208–102)	342 ± 66 (468–230)	293 ± 65 (445–192)	3.03 ± 1.53 (5.21–2.61)
CC $^{-}$	Intertidal	311 ± 26 (362–279)	298 ± 28 (336–246)	656 ± 45 (750–585)	663 ± 75 (805–530)	5.03 ± 0.72 (6.04–3.72)
	Supratidal^{-}	316 ± 23 (344–268)	282 ± 27 (318–227)	657 ± 58 (760–565)	666 ± 61 (769–564)	5.43 ± 1.61 (10.72–4.21)

CT = Cayo Timón; CB = Cayo Bolaños; CR = Cayo Menor; CY = Cayo Mayor; CC = Cayo Chachahuate. Maximum and minimum values are in parentheses. Bolded values are statistically significant between zones for each element and location ($p < 0.05$).

Table 3
Mean levels (μg g^{-1} d.w.) of TEs ± standard deviation in sands of locations from Cayos Cochinos Archipelago.

Location	Zone (n = 15)	Sr	Ba	Th
CT	Intertidal	**3462 ± 339** (3911 - 2492)	196 ± 25 (246–163)	**34.7 ± 5.3** (45.1–23.8)
	Supratidal	**3691 ± 146** (4025 - 3498)	206 ± 25 (257–174)	**39.8 ± 4.0** (44.6–29.6)
CB	Intertidal	3573 ± 253 (3996 - 2994)	188 ± 17 (216–159)	39.9 ± 3.2 (48.2–34.6)
	Supratidal	3642 ± 174 (3927–3354)	199 ± 22 (231–151)	40.7 ± 2.9 (45.6–35.3)
CR	Intertidal	2842 ± 175 (3111–2524)	**190 ± 23** (220–147)	34.6 ± 3.6 (43.8–29.2)
	Supratidal	2885 ± 245 (3340–2398)	**209 ± 24** (244–169)	32.1 ± 3.2 (36.3–23.7)
CY	Intertidal	188 ± 184 (569–2.4)	136 ± 31 (211–101)	<DL
	Supratidal	336 ± 264 (757–9.6)	150 ± 35 (227–108)	10.4 ± 5.5 (14.2–8.5)
CC	Intertidal	3896 ± 151 (4089–3588)	191 ± 24 (237–157)	43.6 ± 3.6 (49.4–35.3)
	Supratidal	3782 ± 257 (4256–3398)	193 ± 25 (226–124)	44.3 ± 9.0 (72.0–34.3)

CT = Cayo Timón; CB = Cayo Bolaños; CR = Cayo Menor; CY = Cayo Mayor; CC = Cayo Chachahuate. Maximum and minimum values are in parentheses. Bolded values are statistically significant between zones for each element and location ($p < 0.05$).

are significantly higher than Th values at CY (Kruskal-Wallis ANOVA, $F = 12.07$, $p < 0.0001$). Similarly, the levels of Th observed at CT, CB, and CC are higher than those levels at CR (Kruskal-Wallis ANOVA, $F = 136.2$, $p < 0.0001$).

Table 4 indicates Spearman's correlation coefficients among the levels of the elements detected in the sand of the beach from the Cayos Cochinos archipelago. The results showed that there are positive and significant correlations among all elements analyzed in the supratidal zone. Considering that La, Ce, Pr, Nd, and Y are stable and usually occur in the upper crust (Mihajlovic et al., 2019), these findings indicate that these chemicals may come from natural sources and influence each other (Jamshidi-Zanjani and Saeedi, 2013; Liu et al., 2019). The same occurred in the intertidal zone except for Pr, Nd, and Sr, which showed no significant correlations with Y, indicating that these elements might be affected by exogenous input factors (Liu et al., 2019). More research is needed to elucidate this finding, which might be considered in future studies.

The differences between the levels found here must be understood under certain factors affecting the sites that are the object of this study. In Cayos Cochinos there is limited availability of essential public services for tourism operations, such as electricity, potable water, health services, waste management and education; the most important limiting factor is water, while the most critical service is solid and liquid waste management (Courrau, 2004). Cayo Timón (CT) is an uninhabited islet that is not on the usual tourist landing route; Cayo Bolaños (CB) is also an uninhabited islet, but it a regular tourist landing route; Cayo Menor (CR) is a protected area by the authorities, but tourists also visit it; Cayo Mayor (CY) is a partially inhabited island with private properties, where tourism usually take place; Cayo Chachahuate (CC) is the only island that is inhabited by Afro-Caribbean population. The island's population generally lives in several wooden houses, but the island is also frequented by tourists and has several restaurants affiliated with this tourism. Several anthropogenic activities have been registered in Cayo Mayor, such as TV programs, construction, temporary power line work between the islands, notable displacement of local communities, large amount of industrial materials, non-endemic flora introduction, and the use of gasoline, with consequent high levels of rubbish in the surrounding area, likely having an impact on soil and water table in the area (Shrives et al., 2007). Moreover, selective logging, poaching of wild animals, tourism, development of field stations, maintenance of a grass helicopter landing pad, trail clearing, and even the production of a reality television show have been reported (Montgomery et al., 2011). The greater anthropogenic activities observed at Cayo Chachahuate (CC) as compared with the lesser ones at Cayo Timón (CY) appear to be directly related to the levels of the chemical elements detected in their sands, although some external sources of contamination should not be discarded.

Anthropogenic impacts such as agricultural run-off, urban and industrial pollution, along with infrastructure development to sustain human population growth, have dramatically increased along the coastal areas of Honduras (Harborne et al., 2001; Jackson et al., 2014). The distribution and enrichment of heavy metals are variable among sites in the supratidal zone, which mainly originate from the weathering of rocks, their parent materials, anthropogenic activities, and atmospheric deposition (Liu et al., 2019). The concentrations of REEs and TEs can increase in response to anthropogenic activities in coastal environments (Nguyen et al., 2013). Also, it is indispensable to consider that the Caribbean is a region commonly affected by potential stressors such as atmospheric pollutants often found in air masses from Africa such as pesticides, excreted antibiotics, combustion products, and metals, among others (Garrison et al., 2003; Roff and Mumby, 2012).This is an issue that requires more attention.

These findings confirm that the behaviour of REEs and TEs recorded in sand depend on tides, which will be useful for establishing a baseline in less studied matrices such as sands in fragile near-shore coral reef systems. The data obtained herein may be useful for helping to understand the biogeochemical processes that occur in the Cayos Cochinos archipelago.

CRediT authorship contribution statement

José E. Celis: Investigation, Writing – original draft. **Winfred Espejo:** Conceptualization, Investigation, Resources, Writing – original

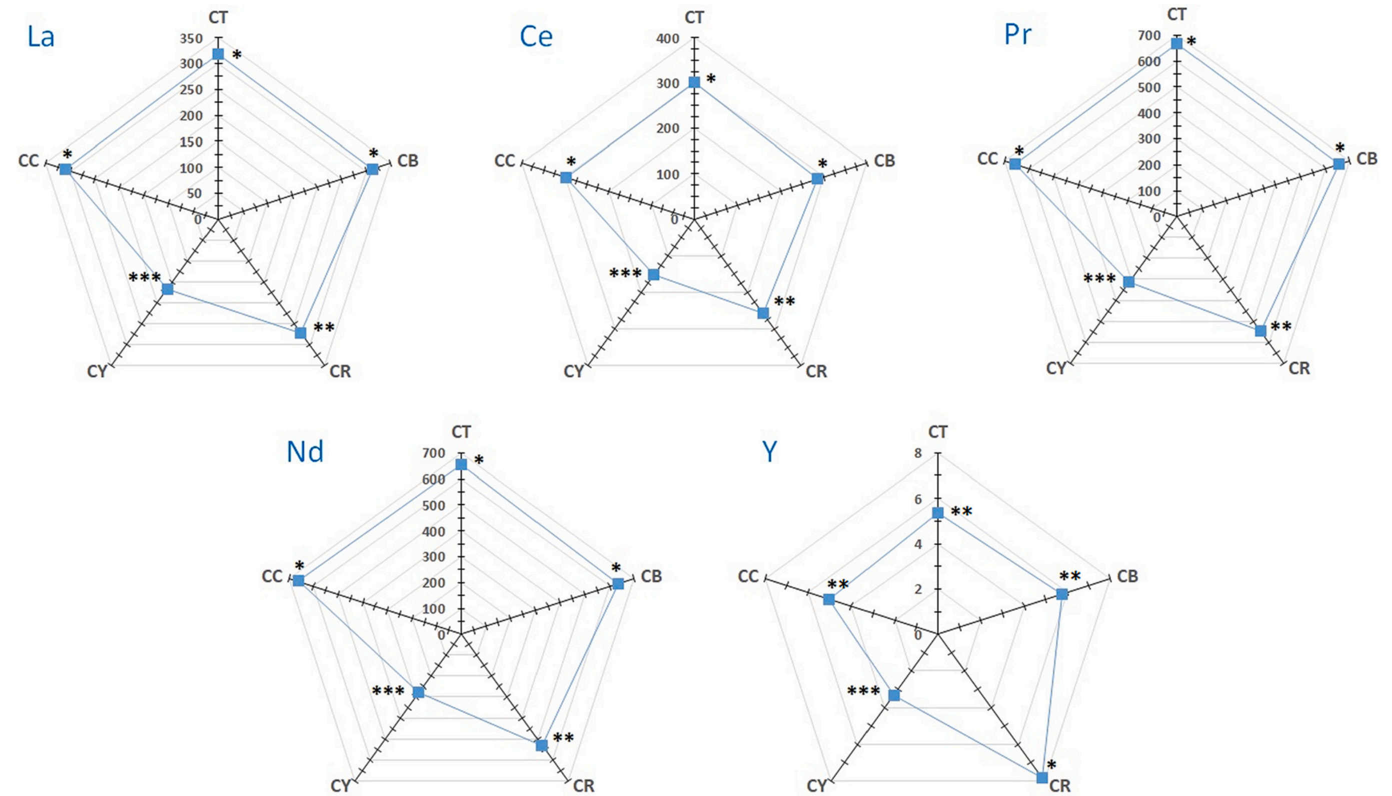

Fig. 2. Mean levels (μg g^{-1} d.w.) of REEs ($n = 15$) in sands of the intertidal zone from different locations in the Cayos Cochinos archipelago. Significant differences between locations for each element are indicated in asterisks ($p < 0.05$). CT = Cayo Timón; CB = Cayo Bolaños; CR = Cayo Menor; CY = Cayo Mayor; CC = Cayo Chachahuate.

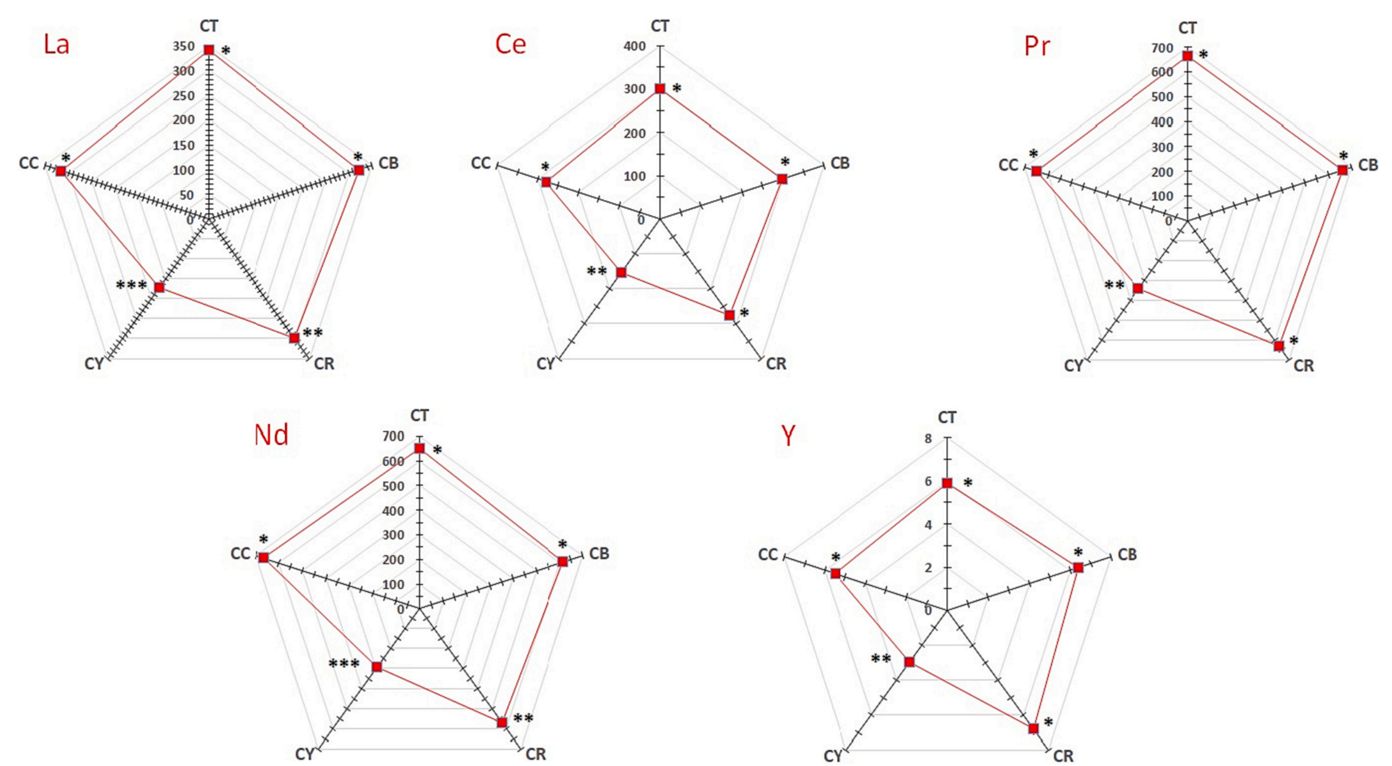

Fig. 3. Mean levels (μg g^{-1} d.w.) of REEs (n = 15) in sands of the supratidal zone from different locations in the Cayos Cochinos archipelago. Significant differences between locations for each element are indicated in asterisks ($p < 0.05$). CT = Cayo Timón; CB = Cayo Bolaños; CR = Cayo Menor; CY = Cayo Mayor; CC = Cayo Chachahuate.

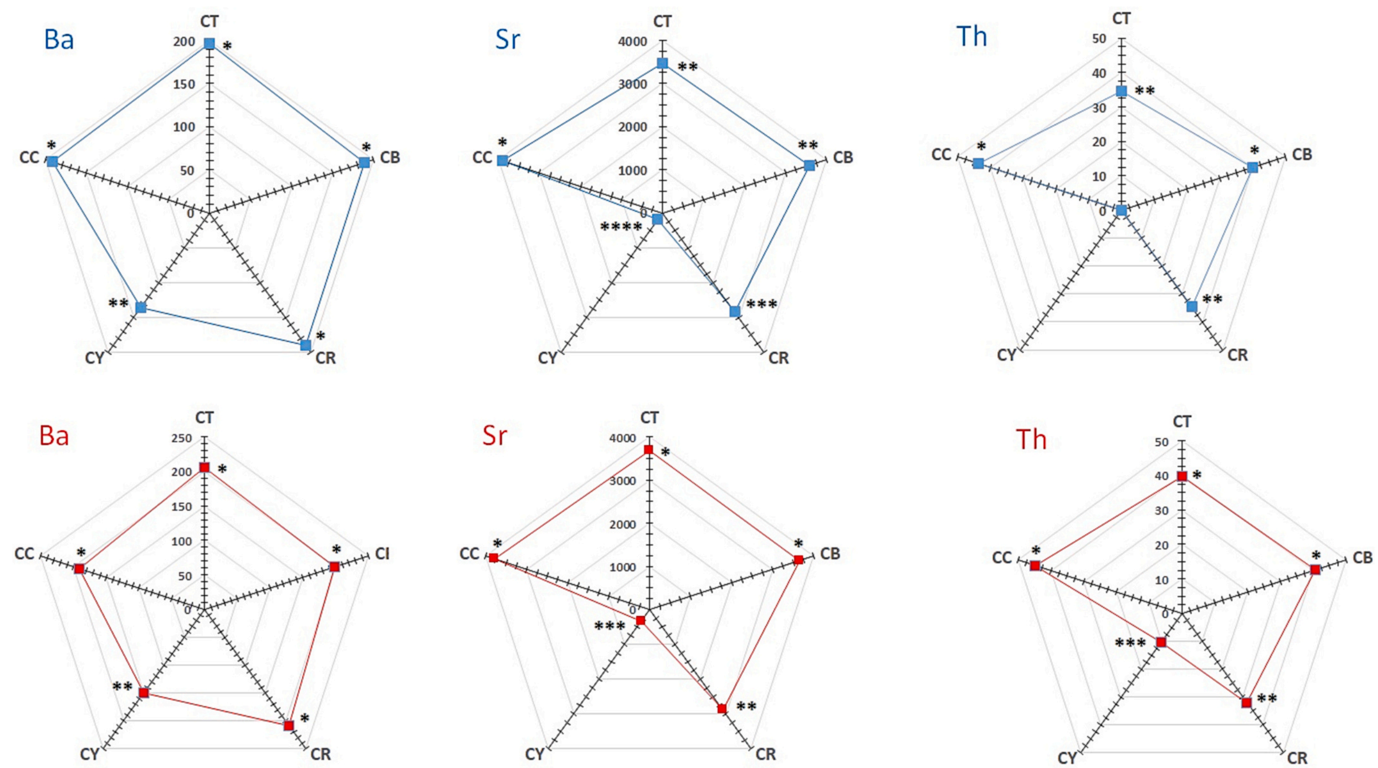

Fig. 4. Mean levels (μg g^{-1} d.w.) of TEs (n = 15) in sands of different locations from Cayos Cochinos archipelago. Intertidal values are shown in blue, while supratidal values are in red. Significant differences between sites for each element are indicated in asterisks ($p < 0.05$). CT = Cayo Timón; CB = Cayo Bolaños; CR = Cayo Menor; CY = Cayo Mayor; CC = Cayo Chachahuate. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 4
Spearman's correlation coefficients of the contents of REEs and TEs in the sand of the supratidal and intertidal zones (significant levels: $p < 0.01$*; $p < 0.05$**). The blue values of the matrix display the correlation coefficients in the supratidal zone, while the brown values indicate the correlation coefficients in the intertidal zone.

	La	Ce	Pr	Nd	Y	Sr	Ba	Th
La		0.80*	0.81*	0.74*	0.46*	0.66*	0.71*	0.63*
Ce	0.71*		0.77*	0.66*	0.58*	0.64*	0.61*	0.53*
Pr	0.86*	0.76*		0.57*	0.47*	0.64*	0.63*	0.61*
Nd	0.81*	0.73*	0.77*		0.30*	0.74*	0.51*	0.66*
Y	0.27**	0.26**	0.18	0.15		0.39*	0.45*	0.38*
Sr	0.59*	0.65*	0.62*	0.65*	0.16		0.43*	0.84*
Ba	0.68*	0.63*	0.65*	0.56*	0.43*	0.37*		0.34*
Th	0.51*	0.57*	0.58*	0.62*	0.22	0.79*	0.43*	

draft. **Isis-Yelena Montes:** Investigation, Resources, Writing – review & editing. **Marco Sandoval:** Investigation, Resources. **Aaron J. Specht:** Resources, Writing – review & editing. **Andy Banegas-Medina:** Conceptualization, Investigation, Resources, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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