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RESEARCH

Preliminary analysis of the presence of metals and metalloids in cigarette butts and fibers discarded on a tourist beach in Cartagena, Colombia

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Abstract Cigarette butts are classified as plastic waste due to their composition of cellulose acetate fibers and are commonly found in beach sand. Their persistence in the environment, low biodegradability, and potential to interact with metals and metalloids during the aging process make them a significant subject of interest for research on coastal marine ecosystems. The aim of this study is to investigate the presence of metals such as hexavalent chromium Cr (VI), cadmium (Cd), and the metalloid arsenic (As) in cigarette butts (CBs), cigarette butt fibers (CBFs), and sand on a tourist beach in Cartagena, Colombia. The goal is to establish a baseline for potential contamination on the beach due to these elements. The methodology includes collecting samples of CBs, CBFs, and sand from different beach usage zones (active, rest, and service) and conducting standardized laboratory tests using atomic absorption spectroscopy for As and Cd and the standard colorimetric method for Cr (VI). The main findings indicate that arsenic levels reached 7.69, 5.75, and 3.47 mg As/kg in the sand, CBs, and CBFs, respectively. Cadmium and hexavalent chromium were found to be below the detection limit for the applied methodology. Additionally, mercury was detected at a concentration of 0.37 mg Hg/L in CBFs in the active zone in October.

Keywords Cigarette butts · Cigarette butt fibers · Metals · Pollution · Beach · Sand · Metalloids

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Introduction

Cigarette filters, made of cellulose acetate, are classified as plastics commonly found in marine environments. The toxicity of these plastics is primarily associated with residual monomers and toxic additives used during manufacturing. Additionally, the toxicity can be linked to partial degradation processes and persistent organic pollutants present in seawater, which concentrate on microplastics (MPs) fragments (Andrady, 2011). MPs refer to plastic

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particles that are less than 5 mm in size. These particles are either created in micro-sizes and released into the environment (primary MPs) or result from the breakdown of larger plastics due to environmental factors (secondary MPs), thus producing pollution in coastal marine areas (Andrady, 2011; De-la-Torre et al., 2022).

CBs, as well as plastic films and plastic fragments like polypropylene (PP), polyethylene (PE), and cellulose acetate (CA), may behave like other plastics when transporting metals in marine environments (Asensio-Montesinos et al., 2020). The heavy metals and chemicals in the leachate from cigarette butts can be acutely toxic to marine species (Dobaradaran et al., 2017). CBs are potential sources of microplastics (MPs) containing varying concentrations of metalloids, primarily originated by the presence of charged additives on the surface of plastics or by interactions between organic matter and microplastics, which can modify the hydrophobicity and surface of the plastics. This represents a significant risk to the environment, marine organisms, and human health (Fred-Ahmadu et al., 2022).

Heavy metals and metalloids (e.g., As, Ni, Cd, Pb, and Hg) are harmful to organisms even at low concentrations (Akhbarizadeh et al., 2021). Metals remain only to a lesser extent as dissolved ions in the water. They can adsorb to particulate matter that settles in the sediments. They are also adsorbed directly by the sediments (Dauvalter & Rognerud, 2001). Briefly, 64% of the samples along the coast of Guinea (Nigeria) contained high concentrations of Al, As, Cd, Cr, Cu, Fe, and Mn associated with foamed plastics, including polystyrene (PS), polyurethane (PUR), and polyethylene-vinyl acetate (PEVA). The results showed values of 0.08–0.11 mg As/kg in sediments and 0.04–0.16 mg Cd/kg in sediments. Another important consideration is that high waterline microplastics were found to have higher metal concentrations than drift waterline microplastics. Metal concentrations varied at Elegushi and Oniru beaches, with concentrations of 0.09–0.11 mg As/kg, 0.04–0.08 mg Cd/kg, and 0.06–0.12 mg Cr/kg. However, under certain environmental conditions, the metals adsorbed on plastics can be released back into the environment and marine ecosystems. This suggests that microplastics could be a significant source for the distribution of toxic metals in the environment (Fred-Ahmadu et al., 2022), which is significant because microfiber is one of the most commonly found types of microplastics in the environment.

The two most prevalent forms of chromium found in the environment are trivalent chromium Cr (III) and hexavalent chromium Cr (VI), which exhibit markedly different toxicity and environmental mobility. Cr (III) complexes are quite inert, stable, and possess low solubility and mobility; thus, they are regarded as being 1000 times less toxic than Cr (VI) (Kazakis et al., 2018). Cr (VI) is a harmful pollutant. Due to its prolonged use in agricultural activities and industrial wastewater treatment systems, the concentrations of Cr (VI) in soil and aquatic environments are constantly increasing. This increase has significant implications for both human health and ecological systems (Zha et al., 2024).

Cigarette filters could release 0.3 million tons of microfibers annually and show a low degradation rate (Das et al., 2023). The toxic metals present in CBs are associated with particles, making their release into the air from CBs unlikely. However, there is a possibility that organometallic compounds (i.e., such as nickel tetra carbonyl, which is necessary to write the chemical structure) may volatilize. Additionally, heavy metals and chemicals in CBs could reach bodies of water, leading to the contamination of aquatic environments (Soleimani et al., 2022).

In the present study, the presence of microplastics in the sand and levels of Cr (VI), Cd, and metalloid As were analyzed, detecting their presence in both the sand and CBs and CBFs. A preliminary analysis was conducted to verify the presence of mercury as a metal of interest on the beaches. The current findings highlight the need for further research, especially concerning metals like mercury, and specific analytical tests for arsenic speciation (Reid et al., 2020), aiming to understand the environmental behavior, metabolism, and toxicity associated with arsenic in the sand, CBs, and CBFs.

Materials and methods

Study beach and monitoring campaigns

The study area is Bocagrande Beach (Cartagena, Colombia), located at coordinates 75° 33′ 42.0″ W 10° 28′ 56.7″ N (Fig. 1). This urban beach with sun, sand, and sea tourism has a history of environmental

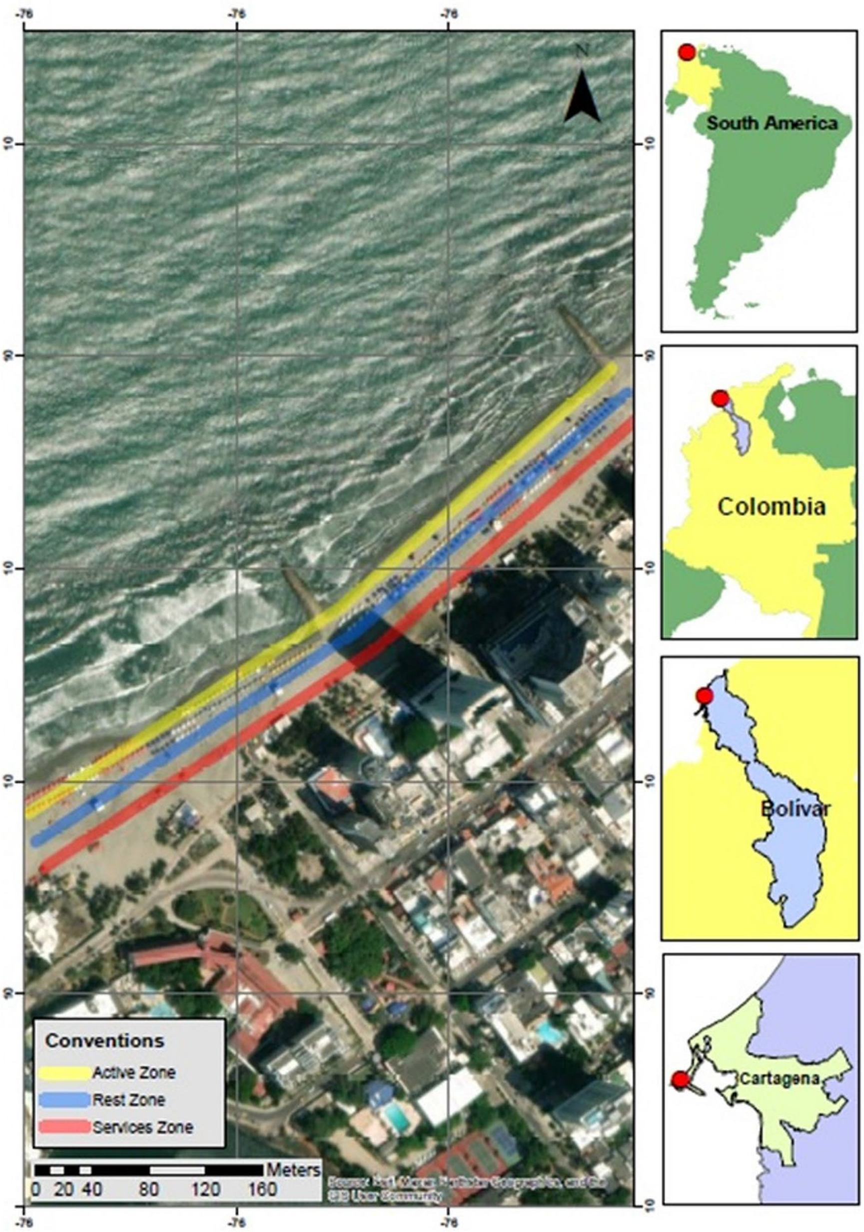

Fig. 1 Location of study beach Cartagena (CO)

quality monitoring for tourist beaches as part of research projects by the Ibero-American Network of Beach Certification (PROPLAYAS).

The monitoring campaigns included five field surveys at the study beach from August to December 2022, covering both the rainy and dry seasons. The selected sampling area covered a beach length of 500 m, where previous studies had confirmed the high abundance of cigarette butts (0.5–1.0 CB/m^2) and cigarette butts fibers (0.1–0.2 CBF/m^2) (Díaz-Mendoza et al., 2023).

In the 500 linear m of the selected beach, three study areas were identified based on the activities conducted in each, considering the recreational and tourist nature of the beaches under investigation. The following considerations were applied to the project. (A) Active area: along the coastline, around the waterline; intended for sports and recreational activities such as walking, running, beach soccer, and beach volleyball. This area allows access to the bathing zone. (B) Rest area: designated for the relaxation and rest of visitors, equipped with umbrellas, chairs, and other services. (C) Service area: occupies the innermost part of the beach, where tourist and support services like bars, restaurants, and souvenir shops are located (Díaz-Mendoza et al., 2023; Valdemoro & Jiménez, 2006). Zoning was considered to identify potential differences in the concentrations of metals found in cigarette butts, butt filters, and sand, and their potential direct contact with beach users.

Methodology for metals and metalloids analysis

A composite sample of each material was collected from each sampling zone (active, rest, and service zones) during the monitoring conducted between August and December. A total of 45 samples were analyzed for Cd, Cr(VI), and As, consisting of 15 sand samples, 15 cigarette butt (CB) samples, and 15 cigarette butt fiber (CBF) samples. In accordance with laboratory requirements, each sample consisted of 500 g of sand, 200 g of CBs, and 200 g of CBFs; for each sample, tests were conducted to determine As, Cd, and Cr(VI). Precautions were taken to prevent cross-contamination during sample collection by using sterile disposable gloves. The samples were stored in sterile Ziploc bags and refrigerated until reaching the laboratory for analysis. The samples were processed at LMB LABORATORIO S.A.S. in Colombia, a laboratory certified with the ICONTEC 1806–1 Quality Management Certificate under ISO 9001:2015 standards.

All samples were analyzed to detect the presence of As using the Atomic Absorption Hydride Generation method USEPA 3050 B (1996), Standard Methods AWWA, APHA, WEF 3114 C (ED 23. 2017) modified. Cd was determined using Atomic Absorption, as per USEPA 3050 B (1996), Standard Methods AWWA, APHA, WEF 311 1B (ED 23. 2017) modified, while Cr (VI) was measured using the Colorimetric method Standard Methods APHA-AWWA-WEF 3500 Cr B (ED 23. 2017).

Results

This current research included Cd, Cr (VI), and As based on the reported studies mentioning the impact of discarded cigarette butts in beach environments and the potential effects of these elements on the ecosystem and human health risks. Table 1 presents the results obtained for the sand, CBs, and CBFs samples collected during the sampling months. It includes the values reported by the laboratory, the reporting units, and the detection limit for the analytical technique employed.

In the present study, the quantification limit for the method used for Cd was 2.5 mg Cd/kg (μg/g) of sand. Remarkably, no values exceeding this quantification limit were reported in either any of the 5 months of sampling or in any of the samples of sand, CBs, and CBFs in the different beach usage zones. This study presents, for the first time, the analysis of Cd on Colombian beaches, with simultaneous measurements in sand, CBs, and CBFs.

For Cr (VI), the limit of quantification was 0.098 mg Cr/kg (μg/g) of sand. No values above the limit of quantification were reported either in the five months of the study or in any of the fifteen samples collected from each of the analyzed components of sand, CBs, and CBFs in the different zones of the pilot beach.

The concentrations of As in the sand, CBs, and CBFs were analyzed by usage zone (Fig. 2a), where the highest concentrations were found in the sand in all the monitoring months. The concentration of As was 80% higher in the CBF samples compared to those in the CBs. Arsenic concentrations in the recovered CBFs varied between 0.84 and 3.47 mg As/kg of CBFs.

A two-factor ANOVA (month and environmental matrix) was conducted. The comparative analysis of As content across months and environmental matrices (CBFs, sand, and CBs), as shown in Fig. 2b and Table 2 (ANOVA), revealed significant differences (p-value < 0.05) for both factors. Notably, the sand matrix exhibited the highest average As content in almost all months, except for August and September, where its values were similar to those of CBFs. Conversely, CBs were characterized by consistently low average As values throughout the analyzed months. The comparative analysis across months collectively indicated that September recorded the highest average As values across all analyzed matrices.

Statistical analyses were performed to better understand the behavior of the data. A cluster analysis was conducted to identify the clustering patterns

Table 1 Laboratory results for As, Cr(VI), and Cd

Month	Sample	Zone	Code	As*			Cr (VI)**			Cd ***		
				Unit	Result	LCM	Unit	Result	LCM	Unit	Result	LCM
August	Sand	Active	37485–2	mg As/Kg	2.52	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37485–1		3.78			< 0.098			< 2.5	
		Service	37485–3		1.78			< 0.098			< 2.5	
	CBs	Active	37485–6	mg As/Kg	0.87	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37485–5		0.65			< 0.098			< 2.5	
		Service	37485–4		2.01			< 0.098			< 2.5	
	CBFs	Active	37485–7	mg As/Kg	1.61	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37485–8		1.54			< 0.098			< 2.5	
		Service	37485–9		0.84			< 0.098			< 2.5	
September	Sand	Active	37487–1	mg As/Kg	6.74	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37487–3		5.42			< 0.098			< 2.5	
		Service	37487–2		7.69			< 0.098			< 2.5	
	CBs	Active	37487–4	mg As/Kg	1.91	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37487–5		5.75			< 0.098			< 2.5	
		Service	37487–6		1.37			< 0.098			< 2.5	
	CBFs	Active	37487–9	mg As/Kg	2.90	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37487–8		3.02			< 0.098			< 2.5	
		Service	37487–7		3.47			< 0.098			< 2.5	
October	Sand	Active	37682–1	mg As/Kg	3.98	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37682–2		4.34			< 0.098			< 2.5	
		Service	37682–3		4.07			< 0.098			< 2.5	
	CBs	Active	37,682–4	mg As/Kg	0.87	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37682–5		0.99			< 0.098			< 2.5	
		Service	37682–6		0.53			< 0.098			< 2.5	
	CBFs	Active	37682–7	mg As/Kg	1.66	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37682–8		1.24			< 0.098			< 2.5	
		Service	37682–9		0.96			< 0.098			< 2.5	
November	Sand	Active	37682–10	mg As/Kg	3.72	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37682–11		3.69			< 0.098			< 2.5	
		Service	37682–12		3.04			< 0.098			< 2.5	
	CBs	Active	37682–13	mg As/Kg	1.07	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37682–14		1.36			< 0.098			< 2.5	
		Service	37682–15		1.21			< 0.098			< 2.5	
	CBFs	Active	37682–16	mg As/Kg	1.32	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37682–17		1.67			< 0.098			< 2.5	
		Service	37682–18		1.84			< 0.098			< 2.5	

Table 1 (continued)

Month	Sample	Zone	Code	As*			Cr (VI)**			Cd ***		
				Unit	Result	LCM	Unit	Result	LCM	Unit	Result	LCM
December	Sand	Active	37682–19	mg As/Kg	4.31	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37682–20		5.32			< 0.098			< 2.5	
		Service	37682–21		4.80			< 0.098			< 2.5	
	CBs	Active	37,682–22	mg As/Kg	1.56	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37682–23		0.60			< 0.098			< 2.5	
		Service	37682–24		0.54			< 0.098			< 2.5	
	CBFs	Active	37682–25	mg As/Kg	1.00	0.2	mg Cr + 6/kg	< 0.098	0.098	mg Cd/Kg	< 2.5	2.5
		Rest	37682–26		1.57			< 0.098			< 2.5	
		Service	37682–27		1.24			< 0.098			< 2.5	

*Atomic Absorption Hydride Generation method USEPA 3050 B (1996), Standard Methods AWWA, APHA, WEF 3114 C (ED 23. 2017) modified

**Colorimetric method Standard Methods APHA-AWWA-WEF 3500 Cr B (ED 23. 2017)

***Atomic Absorption, as per USEPA 3050 B (1996), Standard Methods AWWA, APHA, WEF 311 1B (ED 23. 2017) modified

of the various elements analyzed during the study months, as well as the behavior of parameters such as environmental temperature, sand temperature, and the abundance of CBs and CBFs. The paired-groups algorithm was utilized, employing the Euclidean distance as the similarity index. This metric quantifies the distance between two datasets in a multidimensional space, with lower values indicating greater similarity and higher values reflecting greater dissimilarity (Fig. 3a). Figure 3a shows a higher concentration of As in September, primarily associated with a decrease in environmental and sand temperatures, attributed to the rainfall events observed in the days preceding and during the monitoring period. The PCA presented in Fig. 3b identified that the first two principal components account for 73.9% of the data variability, with Component 1 explaining 42.5% and Component 2 explaining 31.4%. In the same figure, it can be observed that the variables with the highest weights in Components 1 and 2 were the As content in CBFs, sand, and CBs, which had their greatest influence in September. In contrast, the other analyzed variables did not exhibit a distinct temporal pattern, suggesting that they vary independently of the temporal dynamics of the area (Fig. 3b).

Considering the arsenic levels found in the monitoring (Fig. 2a, b and Table 1) and correlating them with the abundance and density data shown in Table 3 obtained from the study months, the month with the highest abundance and density of CBs found in the studied transect was September, during which there were no previous or during-monitoring precipitations; a similar behavior is observed in Fig. 4, which shows the highest abundance of fiber-type microplastics. It is important to highlight the trend in concentration values, which are higher in the sands followed by the fibers; this may be attributed to the decomposition of the cigarette butt into cellulose acetate fibers, presumably increasing its absorption capacity. Therefore, the mechanism potentially occurring in this study is the absorption of arsenic by the fiber. Further arsenic speciation tests are required to determine the nature of the arsenic found and define its toxicological potential.

The stacked area chart shown in Fig. 3 indicates that the highest trend in microplastic abundance over the monitoring months is represented by fiber-type microplastics, with an average of 597 MPs per kilogram of dry soil, followed by fragment-type microplastics, with an average of 243 MPs per kilogram of dry soil. In the case of the present study, the months reporting the highest abundance coincide with those in which monitoring was conducted during the rainy season.

Table 4 presents the detection of mercury in a sample collected from each of the active, rest, and service

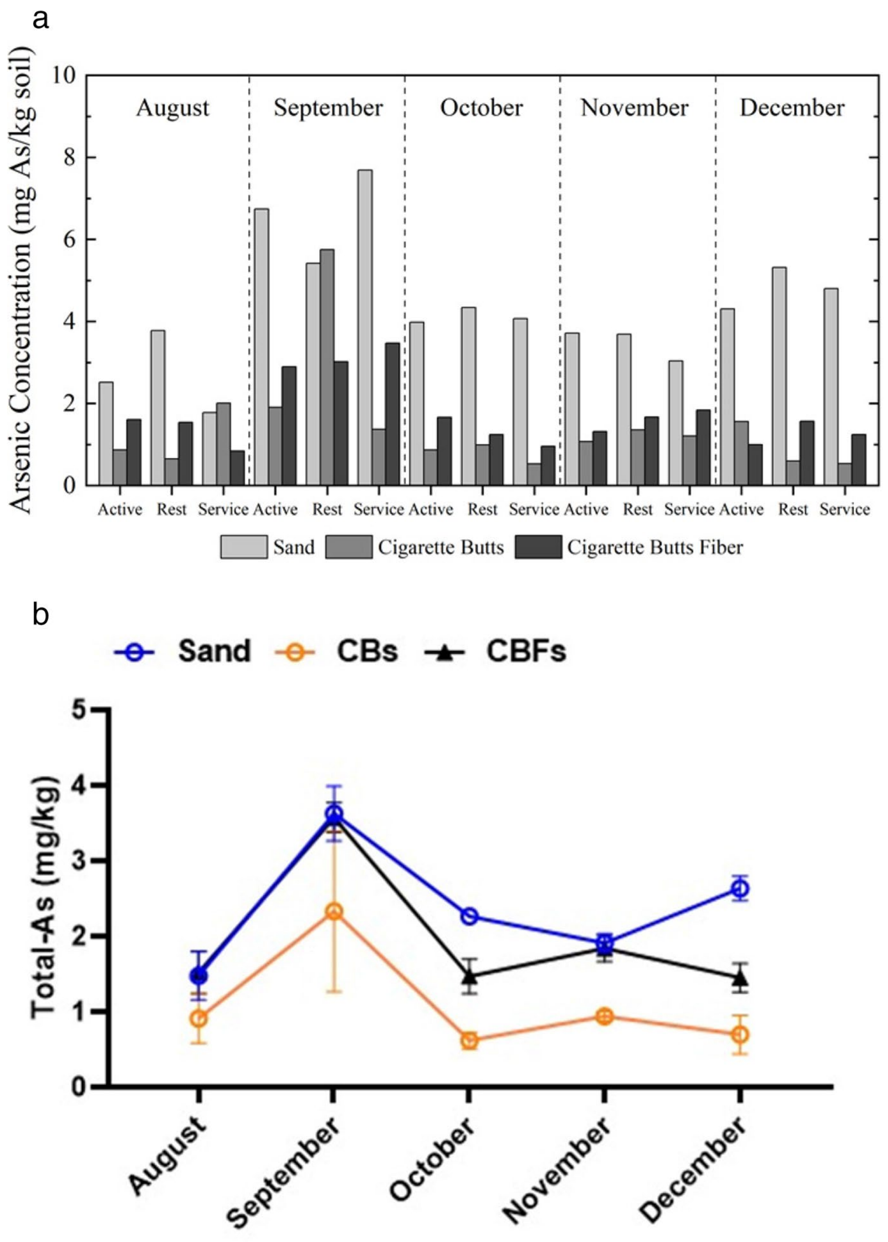

Fig. 2 **a** Concentrations of arsenic in sand, CBs, and CBFs; **b** comparative trend graph of concentrations of arsenic in sand, CBs, and CBFs

Table 2 Two-factor ANOVA para los valores de As en

ANOVA table	SS	DF	MS	*F* (DFn, DFd)	*P* value
Month	21,26	4	5,315	F (1,280, 2,560) = 58,47	P = 0,0077
Environmental matrix (CBFs, sand y CBs)	12,89	2	6,447	F (1,014, 2,027) = 75,73	P = 0,0124
Interaction: month × environmental matrix	2,595	8	0,3244	F (1,371, 2,741) = 0,5605	P = 0,5663

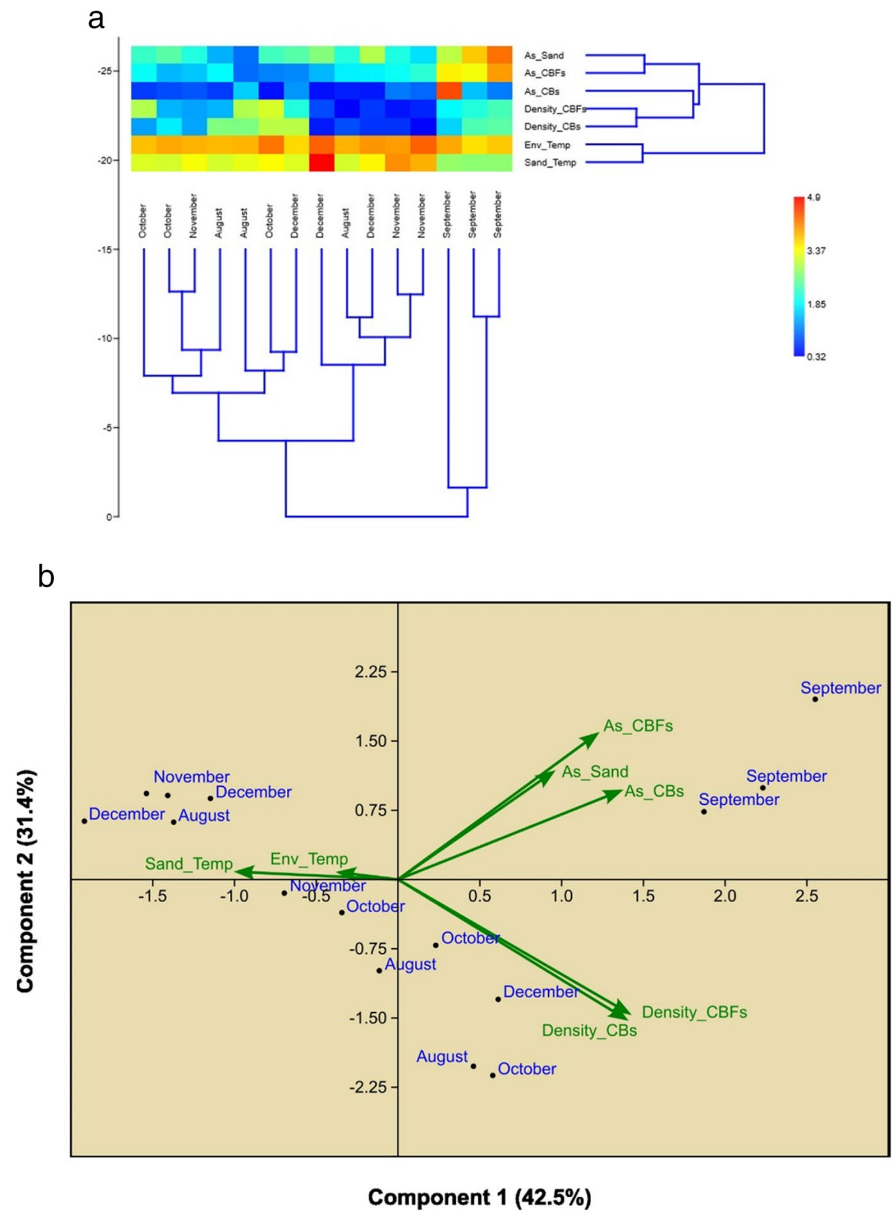

Fig. 3 **a** Cluster analysis for assessing As concentration trends in sand, CBs, and CBFs. **b** Principal component analysis of the variables analyzed in the different study months

Table 3 Abundance and density of CBs and CBFs during the sampling months

Parameter	August	September	October	November	December
Abundance CBs (units)	961	1006	960	364	649
Abundance CBFs (units)	211	282	346	106	459
Density CBs (units/m^2)	0.64	0.67	0.64	0.24	0.43
Density CBFs (units/m^2)	0.14	0.19	0.23	0.07	0.11

zones. Although the analysis of this metal was not initially within the scope of this preliminary study, an identification sample was included to determine the presence of mercury in cigarette butt fibers. Mercury was detected above the detection limit (<0.10 mg Hg/L) only in October, in the active zone, where

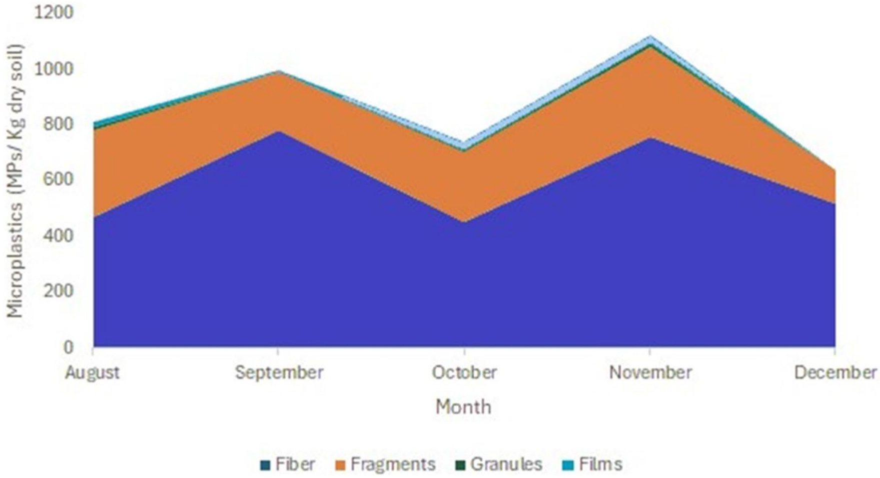

Fig. 4 Distribution of MPs during the sampling months

Table 4 Identification of Hg in CBF samples

Zone	Code	Unit	Result	LCM	Method
Active	37682–7	mg Hg/L	0.370	0.10	Cold Vapor Atomic Absorption—Method 7471 B Mercury in Solid or Semisolid Waste (Manual Cold-Vapor Technique), Revision 2, February 2007. Standard Method for Examination of Water and Wastewater—AWWA, APHA, WEF 3112 B (23rd Edition, 2017), modified
Rest	37682–17		< 0.10		
Service	37682–27		< 0.10		

a value of 0.37 mg Hg/L was reported in the fiber sample.

Discussion

There is an increasing research interest in the presence of metals in beach environments, with 44 articles published to date. Among these, 17 studies (38.6%) were conducted on beach sand in Asia, 10 studies (22.7%) in the Americas, 10 studies (22.7%) in Africa, and 7 studies (15.9%) in Europe, highlighting the research interest in issues related to heavy metal pollution, especially in coastal areas, due to their persistence and potential bioaccumulation in biota, which poses risks to human health and the environment (Buzzi et al., 2022).

International regulatory standards establish specific criteria for each chemical substance, assigning maximum numerical values to assess whether contamination is present in the environment, in this case, soils and sediments. When the concentration exceeds the standard, then the sample is considered contaminated. Sediment quality guidelines setting sediment impact thresholds based on various factors have been developed, as indicated in Table 5.

According to Burton, Jr. (2002), the levels would be below those that could establish a level of probable effect. In previous studies, the concentration of cadmium found in sediments in Dasun Estuary, Indonesia, ranged from 0.21 to 0.29 mg Cd/kg DW (Harmesa & Cordova, 2021). In the Linggi Estuary, Malaysia, 0.01 to 0.18 mg Cd/kg was categorized as low to considerable ecological risk (Elias et al., 2018), while in the coastal environments in Iran, it was reported as 0.306 mg Cd/kg (μg/g) in the dry season and 0.302 mg Cd/kg (μg/g) in the rainy season (Farzadkia et al., 2022). It is crucial to highlight that the concentrations detected in the samples were below the limits established for sediments in various guidelines, as shown in Table 5. Another consideration, based on the study conducted in Iran highlighting differences between seasons, is to continue future research using methods with higher degrees of sensitivity for metal detection. This would enable a more accurate response of the metal to variations in environmental conditions during rainy and dry periods. There is a difference in the concentrations of leachable metals between unused and smoked CBs.

Table 5 Sediment quality guidelines (mg/kg)

Metal/metalloid	Australian and New Zealand Guidelines for Fresh and Marine Water Quality	Ontario Ministry of Environment Screening Level Guidelines	National Oceanographic and Atmospheric Administration (NOAA Guidelines)	Florida Department of Environmental Protection (FDEP Guidelines)	(Burton, Jr., 2002); (MacDonald et al., 2000)*
Cadmium	1.5–10	0.6–10	1.2–9.6	0.68–4.21	0.6–3
Chromium	80–370	26–110	81–370	52.3–160	37.9–100
Mercury	0.15–1	0.2–2	0.15–0.71	0.13–0.7	0.17–1
Arsenic (metalloid)	20–70	6–33	8.2–70	7.24–41.6	5.9–17

*Threshold effect level—extreme effect level (toxicity)

Cigarette butts do not enrich in the same proportion for all elements after being smoked, suggesting that not only the concentration of metals or additives included by the manufacturer in the paper and tobacco can be determinants, but also the chemistry of each element plays a role. In the case of unused CBs, Cr can have values ranging from 0.262 to 0.808 mg/kg, while for Cd, the values can range from 0.001 to 0.003 mg/kg. As for smoked CBs, there is a statistically significant increase in Cd concentration, with values ranging from 0.002 to 0.037 mg/kg. A decrease in concentrations of up to 25% is reported for smoked cigarette butts in As, Cr, and Hg (Santos-Echeandía et al., 2021). Interestingly, the concentration of Cr in discarded CBs in coastal environments in Iran was reported as 1.29 μg/g during the dry season and 1.30 μg/g during the rainy season, thus higher than those recorded in the current study. While Cr (VI) is assumed not to occur naturally, trivalent chromium emitted from various anthropogenic sources undergoes oxidation to form the hexavalent state, which accumulates in soil and water, leading to adverse effects (Bhunia et al., 2022).

This previous investigation suggested that metal concentrations would vary depending on different environmental conditions and levels of persistence in the ecosystem. The highest concentration of metals in the cigarette butts occurred under dry conditions, while the lowest concentration of metals was observed under simulated rainy conditions, therefore suggesting leaching into the environment during rainy conditions (Farzadkia et al., 2022).

The relevance of the previous study conducted on four beaches located on the Mediterranean coast in the Murcia region, southeastern Spain, is emphasized. While this study is not directly related to cigarette butts, it focuses on plastic waste, providing insights into the behavior of materials such as cellulose acetate and plasticizers in coastal environments. The research identified metals and metalloids on the surfaces of plastics and microplastics with significant levels of degradation, factors considered crucial for the absorption of metals in coastal environments, as surface modifications enhance their adsorption capacity. In this context, it was observed that a new plastic item exhibits Cr concentrations on the order of 4.06×10^{-1} (μg/g), whereas plastics collected on the beach showed average values of $2.30 \pm 1.62 \times 10^{1}$ (μg Cr/g). Regarding Cd, concentrations in new plastics were 3.00×10^{-3} (μg Cd/g), while average concentrations in beach-collected residues were 1.21 ± 8.69 (μg Cd/g). Concerning As, concentrations in new plastics were 1.51×10^{-1} (μg As/g), and average concentrations in plastic residues found on the beach were $3.95 \times 10^{1} \pm 2.78 \times 10^{2}$ (μg As/g) (Rodrigues et al., 2023).

To assess the toxicity of cigarette butts, the concentrations of metals in whole, unsmoked cigarettes were measured. Experimental trials revealed a direct relationship between the concentration of leached metals and the soaking period. An increase in the leached metal concentrations for Ba, Fe, Mn, and Sr was observed over time, while a decrease in metal concentrations for Cu, Al, Cr, and Cd was noted. This finding suggests that a cigarette butt serves as a point source of metal contamination for at least 1 month and further implies that an extended presence of the residue in the environment enhances its contamination potential (Dobaradaran et al., 2021).

A previous investigation has observed $3.95 \times 10^{1} \pm 2.78 \times 10^{2}$ μg As/g in plastics and microplastics from beaches. In a study conducted on

Mediterranean beaches in Spain, the concentrations of metals and metalloids were associated with plastics and had a high anthropogenic influence. These plastics have shown extended persistence in the environment, with a moderate to severe degree of degradation, and undergoing various chemical and physical changes (i.e., oxidation), thus increasing the adsorption capacity of these plastics for metals and metalloids (Rodrigues et al., 2023).

The study conducted in Loreto Bay (Marine Protected Area), NW Mexico, observed arsenic in beach sediment samples ranging from 3 to 9 mg As/kg. This is attributed to the presence of geothermally altered volcanic rocks associated with Fe oxides and abundant clay minerals dominated by sulfide minerals (Jonathan et al., 2019). Also, a previous investigation conducted on the urban beach of Sfax, located on the southern coast of the Mediterranean Sea, recorded arsenic concentrations of 6.43 ± 1.97 and 6.39 ± 1.25 μg/L in non-smoked and smoked filters, respectively. However, due to specific physicochemical conditions (pH, salinity) of the coastal environment and the chemical behavior of trace metals, this metalloid may not exhibit significant differences between smoked and non-smoked filters (Quéméneur et al., 2020).

The accumulation of heavy metals can have various origins; Hg, Cd, Pb, and Cu may be prone to be of anthropogenic origin, while the sources of As, Cr, Co, Ni, and Zn may be similar to crustal sources. Another factor to consider is the particle size of sand or sediment; it has been found that fine-grained soils adsorb heavy metals such as Hg, Cd, As, Pb, Co, and Cu. This indicates that fine-grained sediments may serve as a good carrier for trace metals and an indicator to trace the dynamics of accumulative processes. The need to identify the sources of heavy metals, especially As and Cu in beach ecosystems (Pellinen et al., 2021), is emphasized, with this study presenting As levels in both sand and discarded CBs and CBFs. Heavy metals such as As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn have been detected in tobacco cultivation soils and cigarette waste (Xu et al., 2023).

It is important to consider the report of Hg found in the CBFs on the study beach. Due to its high toxicity and very high bioaccumulation factor (up to 10^6) in the food chain, monitoring Hg in the marine environment is of paramount importance (Dobaradaran et al., 2017). Remarkably, there was precipitation on the day of this sampling. The research conducted by Dobaradaran et al. (2018) stands out as one of the few studies addressing the relationships between metals and CBs butts, and it is also the first study to report the release of mercury (Hg) in the marine environment. This study monitored the abundance of cigarette butts and the levels of Hg content along the northern part of the Persian Gulf. The results indicate that discarded CBs are significant sources of long-term contamination by metals such as Hg. The average values of Hg content in cigarette butts were 49.5 ng/g of CBs on the first day and 33.1 ng/g after 10 days of the sampling periods, respectively.

In marine ecosystems, microplastics (i.e., in this study, CBFs are considered fiber-type microplastics) can act as a sink for contaminants (Díaz-Mendoza et al., 2020). A study conducted on the coast of Tarragona, Spain, reported the presence of microplastics in the sand with surfaces modified by the presence of pores and roughness, which was evidenced by the growth of microorganisms. Additionally, the study indicated that microplastics exhibit a high affinity for persistent organic pollutants and heavy metals found in sediments or seawater. In particular, high concentrations of Pb and Hg were reported in the port area (Expósito et al., 2021). Similarly, a study conducted on four beaches located on the Spanish Mediterranean coast reveals how Hg levels in plastics collected in the coastline area are higher, followed by concentrations in the intermediate beach area, and are lowest in the high dune areas. This can be attributed to the exposure of dune areas to high solar radiation, causing Hg (i.e., a volatile metal) to enter the gaseous state, desorb from the surface of the plastics, and reach the atmosphere. Also, the influence of aging on Hg concentrations in plastics was confirmed (Santos-Echeandía et al., 2020). The aforementioned information, combined with the initial findings in Bocagrande Beach, where the presence of mercury in CBF was only detected in the active zone (coastline), underscores the importance of continuing research on this topic, considering that Hg is one of the most toxic elements in the marine environment that can bioaccumulate and bio-magnify to dangerous levels in food chains, with genotoxic consequences for human exposure, mainly through two processes: teratogenesis and carcinogenesis (Crespo-López et al., 2009).

The disposal of CBs in various environments leads to the release of hazardous heavy metals and organic

Table 6 Metal values found in CBs and CBFs

Sample	Metal	Unit	Values	Reference
CBs-CBFs discarded on the beach	Cd	mg Cd/Kg	< 2.5	Present study
CBs-CBFs discarded on the beach		mg/50 CBs	0.923 ± 0.010–1.242 ± 0.009	(Lian et al., 2024)
CBs 25 tobacco brands		µg/g	0–1.56	(Haleem et al., 2020)
Smoke CBs expensive brands		µg/g	0.52 ± 0.01	(Michael et al., 2022)
CBs marine environment		µg/g	0.16 and 0.67	(Dobaradaran et al., 2017)
CBs coastal environment		µg/g	0.302	(Farzadkia et al., 2022)
CBs-CBFs discarded on the beach	As	mg As/Kg	0.53–5.75	Present study
CBs marine environment		µg/g	0.12 and 0.48	(Dobaradaran et al., 2017)
CBs-CBFs discarded on the beach	Cr (VI)	mg Cr + 6/kg	< 0.098	Present study
CBs-CBFs discarded on the beach	Cr	mg/50 CBs	< LOD*	(Lian et al., 2024)
CBs 25 tobacco brands		µg/g	0–6.73	(Haleem et al., 2020)
CBs coastal environment		µg/g	1.30	(Dobaradaran et al., 2017)
CBs-CBFs discarded on the beach	Hg	mg Hg/L	< 0.10–0.37	Present study
CBs coastal environment		ng/g CB	2.5–86.32	(Dobaradaran et al., 2018)

compounds known as polycyclic aromatic hydrocarbons. Furthermore, microplastics originating from cigarette butts, specifically in the form of fibers, have the ability to adsorb or desorb heavy metals in the marine environment, depending on the concentration of these metals in the surrounding matrices, whether it is water or sediments (Vanapalli et al., 2023).

Cigarette butts, composed of cellulose acetate (CA) with added plasticizers, are a highly abundant litter on beaches, and their decomposition is attributed to the presence of a significant percentage of fiber-type microplastics. During the decomposition process from CBs to CBFs, numerous environmental factors associated with the structural characteristics of the filters influence the degradation rate. These environmental factors include temperature, humidity, pH, sunlight exposure, and the availability of oxygen, nutrients, and colonizing microorganisms (Yadav & Hakkarainen, 2021).

It is important to highlight the need for further research on the physical and chemical characterization of the various components of cigarettes and the analysis of different types of cigarette butts (smoked, unsmoked, and those collected from the environment). As proposed by Acarer Arat (2024), research should include the classification of cigarette butts (CBs) into five groups: (i) unsmoked, (ii) unsmoked and exposed to environmental factors, (iii) freshly smoked, (iv) freshly smoked and exposed to environmental factors, and (v) collected from the environment.

Additionally, it must be recognized that the variety of commercial brands presents the challenge of CBs made from different materials. In the case of Colombia, the most discarded brands on the studied beach are Marlboro, Belmont, and Lucky Strike. This is an interesting aspect to investigate to better understand the decomposition processes between CBs and sand on the beach. Finally, Table 6 summarizes different studies conducted on the metal content of CBs in different environments.

Conclusions

The present study analyzed the interaction of cigarette butts (CBs) and cigarette butt fiber (CBF) waste discarded on the sandy beach of Bocagrande (Cartagena, Colombia). Variable densities ranged from 0.24 to 0.67 CB/m^2 and 0.07 to 0.23 CBF/m^2 during the study period. This data is of interest when considering the composition of cellulose acetate plasticized in CBs, highlighting the relationship between the high persistence and low degradability of these wastes in the beach sand.

CBs, when breaking down into CBFs, represent a prevalent source of fiber-type microplastics in beach sand, which, according to the literature, have been reported to have an affinity with heavy metals. In the case of the beach under study in this research, no detectable concentrations of Cr (VI) or Cd were reported in samples of sand, CBs, and CBFs. However, As values were reported, with maximums of 7.69 mg As/Kg in sand, 5.75 mg As/Kg CBs, and 3.47 mg As/Kg CBFs. The presence of arsenic on beaches can have a natural or anthropogenic origin, and further research is needed to determine the source of the arsenic, the transfer process from sand to CBs-CBFs, and the potential risks to human health.

Author contribution • CD-M: Conceptualization, Methodology, Investigation, Writing—Original Draft, Project administration • JM-B: Writing—Review & Editing • CM.B: Conceptualization, Writing—Review & Editing • LG: Data Curation, Writing—Review & Editing.

Data availability The data will be available upon request.

Declarations

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Consent to participate Not applicable.

Consent for publication All authors declare that they agree with the content published in the manuscript.

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