Chemosphere 339 (2023) 139594

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Human biomonitoring of inorganic elements in a representative sample of the general population from Cape Verde: Results from the PERVEMAC-II study

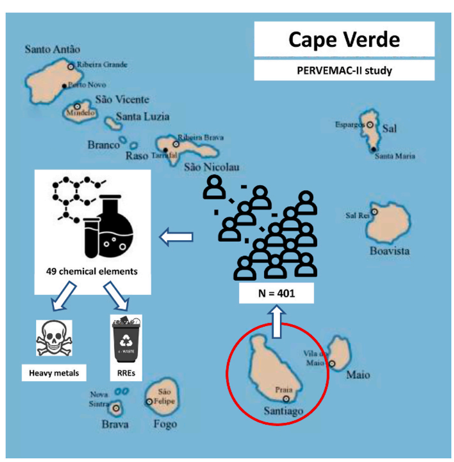
Luis Alberto Henríquez-Hernández [a,b,*], Manuel Zumbado [a,b], Ángel Rodríguez-Hernández [a], Edna Duarte-Lopes [c], Ailton Luis Lopes-Ribeiro [c], Patricia Miranda Alfama [d], Miriam Livramento [d], Ricardo Díaz-Díaz [e], María del Mar Bernal-Suárez [e], Luis D. Boada [a,b], Adriana Ortiz-Andrelluchi [a,b], Lluis Serra-Majem [a,b], Octavio P. Luzardo [a,b]

[a] *Research Institute of Biomedical and Health Sciences (IUIBS), Clinical Sciences Department, Universidad de Las Palmas de Gran Canaria, Paseo Blas Cabrera S/n, 35016, Las Palmas de Gran Canaria, Spain*
[b] *CIBER de Fisiopatología de la Obesidad y la Nutrición (CIBEROBN), Instituto de Salud Carlos III, University of Las Palmas de Gran Canaria, Madrid, Cabo Verde*
[c] *Research, Science and Innovation Department, Instituto Nacional de Saúde Pública, Chã de Areia, CP nº 719, Cidade da Praia, Cabo Verde*
[d] *Food Regulation Directorate, Independent Health Regulatory Authority, Av. Cidade de Lisboa, CP 296, Spain*
[e] *Department of Environmental Analysis, Technological Institute of the Canary Islands, C/ Los Cactus no 68 35118, Polígono Industrial de Arinaga, Agüimes, Las Palmas, Canary Islands, Spain*

HIGHLIGHTS

- 49 inorganic elements were analyzed in blood from 401 subjects from Cape Verde.
- As, Cu, Hg, Pb, Se, Sr and Zn were detected in ≥99% of samples.
- Nb and Ta were the most frequently detected RREs and at the highest concentration.
- 77, 99 and 33% of the participants had values of As, Hg and Pb higher than RV95s.
- Lifestyle has an effect on the concentration of these chemical elements.

GRAPHICAL ABSTRACT



ARTICLE INFO

Handling Editor: Jian-Ying Hu

ABSTRACT

Inorganic elements such as heavy metals and other potentially toxic elements are frequently detected in humans. The aim of the present study was to analyze the blood concentrations of 49 inorganic elements in a cohort of 401

* Corresponding author. Toxicology Unit, Research Institute of Biomedical and Health Sciences (IUIBS), Clinical Sciences Department, Universidad de Las Palmas de Gran Canaria, Paseo Blas Cabrera s/n, 35016, Las Palmas de Gran Canaria, Spain.
E-mail address: luis.henriquez@ulpgc.es (L.A. Henríquez-Hernández).

https://doi.org/10.1016/j.chemosphere.2023.139594
Received 9 March 2023; Received in revised form 31 May 2023; Accepted 19 July 2023
Available online 20 July 2023

Keywords:
Biomonitoring
Inorganic elements
Heavy metals
Rare earth elements
Emerging pollutants
Electronic waste

subjects from Cape Verde. The study was performed in the frame of the Pesticide Residues in Vegetables of the Macaronesia project (PERVEMAC-II). Concentration of inorganic elements, including elements in the ATSDR's priority pollutant list and rare earth elements (RREs) were measured by ICP-MS in the whole blood of participants. A total of 20 out of 49 elements (40.8%) were detected in ≥20% of participants. Arsenic, copper, mercury, lead, selenium, strontium and zinc were detected in ≥99% of samples. Among the REEs, 7 showed detection frequencies above 20%. The median number of different elements detected was 15. In the present series, 77.0, 99.2 and 33.4% of the participants showed values of arsenic, mercury and lead higher than Reference Values 95%. These percentages were much higher than those reported in similar studies. Niobium and tantalum showed the highest median concentrations: 1.35 and 1.34 ng/mL, suggesting an environmental source of these valuable REEs in Cape Verde. Age appeared as the most important factor influencing the blood levels of inorganic elements. Lifestyle had an effect on the concentration of some of these elements. Those subjects whose water source was pond water had significantly higher arsenic levels. The concentration of ∑REEs was significantly higher among individuals who purchase their food in supermarkets (P = 0.013). These variables are of relevance since they can be controlled individually to reduce exposure to these contaminants. Our results may be useful for the implementation of public health measures by the competent authorities.

1. Introduction

Inorganic elements form a large group of naturally occurring substances listed in the periodic table. Some of them are essential for life (e.g. copper, manganese, selenium or zinc), while others are particularly harmful to human and environmental health (e.g. heavy metals). Some of them are among the most dangerous pollutants for health according to the Agency for Toxic Substances and Disease Registry (ATSDR's, 2022). This is the case for arsenic, lead and mercury, which occupy the first three places on the list, respectively. In recent decades, due to the increased use of electronic devices and the exponential generation of electronic waste (e-waste), a new group of elements must be taken into account. These are the rare earth elements (RREs) and other minor elements (MEs), that are crucial for the manufacture of electronic devices and which, extracted from the depths of the planet, are new pollutants located on the surface, whose effects on human health and the environment are still unknown (Tansel, 2017).

REEs conform a group of metallic elements with similar physicochemical properties that includes scandium, yttrium, and the 15 elements of the lanthanide series: cerium, dysprosium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, neodymium, niobium, praseodymium, samarium, terbium, thulium and ytterbium (Rare, 2012). MEs are inorganic elements present in nature in smaller quantities and mostly considered as emerging pollutants, such as gallium, indium or osmium, among others. While only a dozen elements are essential for life (Wada, 2004), more than 60 elements are required to manufacture a mobile phone (Tansel, 2017), including RREs and other MEs because of the magnetic, electrical, chemical and optical properties of them (Rare, 2012). The average lifespan of electronic devices is getting shorter and shorter, resulting in many of them being discarded. The increase in the consumption of this type of devices, together with the low recycling efficiency, has led to an exponential increase in e-waste in recent years. Thus, according to the United Nations Institute for Training and Research, a record 53.6 million metric tons of e-waste was generated worldwide in 2019. This represents an increase of 21% in just five years (UNITAR, 2020). It has to be highlighted that only 17.4% of the total e-waste generated was recycled in the year 2019 (UNITAR, 2020). Research has found that unregulated e-waste recycling is associated with increasing numbers of adverse health effects, especially among children and workers. These include adverse birth outcomes (Zhang et al., 2018), altered neurodevelopment and adverse effects on the immune system (Huo et al., 2019), adverse learning outcomes (Soetrisno and Delgado-Saborit, 2020), adverse cardiovascular effects (Cong et al., 2018), or cancer (Davis and Garb, 2019; Gaman et al., 2021). The few studies published outside of China - the country with the most REEs - show an association of some of these elements with acute ischemic stroke (Medina-Estevez et al., 2020) or SARS-CoV-2 infection (Porta et al., 2023).

Biomonitoring studies are the best tool to know the levels of pollutants in a population. It allows not only to infer the risk derived from exposure to toxics, but also to know the temporal evolution in the case of repeated measurements over time (Henriquez-Hernandez et al., 2021; Porta et al., 2021). Human biomonitoring can determine whether technological changes can affect human exposure, support epidemiological studies or evaluate the efficacy of regulatory actions (Council, 2006). The need for biomonitoring studies is such that there is ample public funding to carry out this kind of research in different populations (Buekers et al., 2018). In this sense, Human Biomonitoring for European Union citizens (HBM4EU) started in 2017. According to the official webpage, HBM4EU is coordinating and advancing human biomonitoring in Europe and so provide better evidence of the actual exposure of citizens to chemicals; providing a robust interpretation of human biomonitoring data and the possible impact of chemical exposure on human health (HBM4EU, 2016). A total of 9 inorganic elements were included in the prioritized compound list: arsenic, beryllium, iodine, lead, manganese, mercury, nickel, titanium and vanadium; although only 3 were finally nominated (arsenic, lead and mercury) (Ougier et al., 2021). Beyond the main heavy metals and metalloids, biomonitoring studies do not usually include rare earth elements or minority elements, with few exceptions (Gaman et al., 2020; Henriquez-Hernandez et al., 2017a, 2018, 2020).

Cape Verde is a volcanic archipelago located about 600 km west of Senegal in the Atlantic Ocean. Together with the Canary Islands, the Azores and Madeira, it belongs to the Macaronesia eco-region. The largest island, Santiago, is home to the present-day capital, Praia. Cape Verde has a population of just over half a million. The present study is part of the PERVEMAC-II project, with European funding and whose purpose is the monitoring of chemical residues in plants, with the aim of identifying health hazards and carrying out an assessment of the risk of ingestion (PERVEMAC-, 2017). In this context, a representative blood sample was taken from the Cape Verdean population and monitored for contaminants. Results have recently been published for organic pollutants: pesticides and persistent organic pollutants (Henriquez-Hernandez et al., 2022).

The aim of the present study was to analyze the blood levels of 49 inorganic elements, including heavy metals, rare earth elements and other minor elements used in high-tech devices, in a cohort of subjects from Cape Verde, and to discern the socio-demographic factors that condition the distribution of these chemicals in the study population.

2. Material and methods

2.1. Study population

The PERVEMAC-II study is a Research and Development Cooperation Project in the field of Agriculture and Food Safety, which studies the impact on consumer health of the presence of pesticide residues, mycotoxins and heavy metals in the Vegetable Products consumed in the

Table 1
Sociodemographic characteristics of study participants in the whole series and according to gender.

	Whole series N (%)	Males N (%)	Females N (%)	P-value
	401 (100)	167 (41.6)	234 (58.4)	
Age (years)				
Mean ± SD	28.6 ± 17.6	26.1 ± 17.2	30.3 ± 17.7	0.019[a]
Median	24.0	19.0	28.5	0.016[b]
<18	154 (38.4)	74 (44.3)	80 (34.2)	0.036[c]
18–30	86 (21.4)	40 (24.0)	46 (19.7)	
31–45	75 (18.7)	24 (14.4)	51 (21.8)	
>45	86 (21.4)	29 (17.4)	57 (24.4)	
BMI (kg/m^2)				
Mean ± SD	22.1 ± 5.5	20.3 ± 4.3	23.4 ± 5.9	<0.001[a]
Median	21.2	20.3	22.8	<0.001[b]
<18.5	118 (29.6)	63 (38.2)	55 (23.6)	<0.001[c]
18.5–24.9	166 (41.7)	78 (47.3)	88 (37.8)	
25–29.9	72 (18.1)	20 (12.1)	52 (22.3)	
>29.9	43 (10.6)	4 (2.4)	38 (16.3)	
Habitat				
Urban	264 (65.8)	110 (65.9)	154 (65.8)	0.539[c]
Rural	137 (34.2)	57 (34.1)	80 (34.2)	
Civil status[d]				
Single	195 (60.0)	83 (63.4)	112 (57.7)	0.311[c]
Married	98 (30.2)	40 (30.5)	58 (29.9)	
Divorced	21 (6.5)	5 (3.8)	16 (8.2)	
Widowed	11 (3.4)	3 (2.3)	8 (4.1)	
Educational level[e]				
Primary schooling	165 (46.0)	80 (51.6)	85 (41.7)	0.104[c]
Secondary schooling	153 (42.6)	62 (40.0)	91 (44.6)	
Higher education	41 (11.4)	13 (8.4)	28 (13.7)	
Employment status[f]				
Employed	119 (42.7)	55 (48.2)	64 (38.8)	0.322[c]
Unemployed	89 (31.9)	30 (26.3)	59 (35.8)	
Retired	57 (20.4)	24 (21.1)	33 (20.0)	
Others (housewife and student)	14 (5.0)	5 (4.4)	9 (5.5)	
Occupation[g]				
Primary sector	48 (16.5)	18 (15.5)	30 (17.1)	<0.001[c]
Secondary sector	72 (24.7)	14 (12.1)	58 (33.1)	
Tertiary sector	171 (58.8)	84 (72.4)	87 (49.8)	
Income[h]				
Low (<13,000 C VE)	84 (23.9)	28 (18.9)	56 (27.6)	0.105[c]
Medium (13,001–33,000 C VE)	149 (42.5)	63 (42.6)	86 (42.4)	
High (>33,000 C VE)	118 (33.6)	57 (38.5)	61 (30.0)	

SD: standard deviation; BMI: body mass index; CVE: Cape Verdean escudo.
[a] Student's t-test (two tail).
[b] Mann-Whitney *U* test (two tail).
[c] Chi-square test (two tail).
[d] Missing data = 76. Percentage calculated with the total valid data (36 males and 40 females).
[e] Missing data = 42. Percentage calculated with the total valid data (12 males and 30 females).
[f] Missing data = 122. Percentage calculated with the total valid data (53 males and 69 females).
[g] Missing data = 110. Percentage calculated with the total valid data (51 males and 59 females).
[h] Missing data = 50. Percentage calculated with the total valid data (19 males and 31 females). Data for segmentation were obtained from the Ministry of Foreign Affairs, European Union and Cooperation (Spanish Government). Available at: http://www.exteriores.gob.es/Embajadas/PRAIA/es/VivirEnCaboVerde/Paginas/Trabajar.aspx.

geographical area of Macaronesia (PERVEMAC-, 2017). One of its specific objectives was to carry out a survey of eating habits. Within this framework, a blood sample was taken to monitor contaminants. For logistical reasons, mainly due to the fragmentation of the Cape Verde archipelago and the complexity of transporting samples, all subjects participating in this study belong to the island of Santiago. Sampling was done between August 09, 2019 and September 11, 2019.

A total of 403 subjects were included in this part of the study, which means that the sample is representative of the total population of the Santiago Island (Henriquez-Hernandez et al., 2022). Blood for chemical analysis was available in 401 participants (Table 1). 5 mL of whole blood were collected in a vacuum system tube and stored at −80 °C until it was sent to the Toxicology Unit (Universidad de Las Palmas de Gran Canaria, Canary Islands, Spain). The shipment was made on dry ice to avoid breaking the cold chain. Once the samples arrived, blood was stored at −80 °C until analysis. Mean age of participants was 28.6 years, 41.6% of all participants were men and mean Body Mass Index (BMI) of the total series was 22.1 kg/m^2. About 11% were obese (BMI >29.9 kg/m^2), 65.8% lived in an urban habitat, 30.2% were married, 42.5% had completed at least secondary schooling (2nd. stage), and 20.4% were retired. Age and BMI were significantly higher among women ($P = 0.012$ and $P < 0.001$, respectively; Table 1). Most of the subjects who were of working age were in the tertiary sector, with a higher proportion of males than females (72.4 vs. 49.8%, respectively; $P < 0.001$).

2.2. Selection of elements and sample preparation

The 49 elements analyzed included 21 elements from ATSDR's Substance Priority List of 2022 (ATSDR's, 2022) and 28 rare earth elements (REEs) and other minority elements (Additional file 1). The list of elements included 4 essential trace elements and 14 lanthanides (Tansel, 2017; Gonzalez-Antuna et al., 2017).

Analytical chemical method has been previously described in detail (Henriquez-Hernandez et al., 2017b, 2020; Gonzalez-Antuna et al., 2017). Briefly, two replicates 100 mL of whole blood samples were weighed into quartz digestion tubes and then digested with the use of 200 μL of acid nitric (65% HNO3 distilled by sub-boiling) and 800 μL of ultra-pure water obtained from a Milli-Q system using a Milestone Ethos Up equipment (Milestone, Bologna, Italy). The digestion conditions were programmed as follows (power (W)–temperature (C)–time (min): step 1: 1800–100–5; step 2: 1800–150–5; step 3: 1800–200–8; and step 4: 1800–200–7. After the complete microwave assisted extraction finished, which includes cooling, the digested samples were transferred and diluted to obtain a final concentration of 4% (v/v). An aliquot of 2 mL of each sample was taken and the internal standard (ISTD) was manually added for the analysis.

The ISTD solution included scandium, germanium, rhodium and iridium (20 mg/mL each) and was introduced in the ICP-MS at an approximate concentration of 38 ppb to assess the reproducibility of the counts per second of ions (CPS) and RSD values, in addition to the recovery values of the four isotopes (^{45}Sc, ^{72}Ge, ^{103}Rh, ^{193}Ir) between 70 and 130% expressed in a stability graph. After each sequence is completed, Ge is removed as internal standard with rare earth elements calibration curve to avoid the interferences of doubly charge ions of Nd and Sm (double charge ions with an *m/z* ratio from 71 to 75). Elements of standard purity (5% HNO3, 100 mg/L) were purchased from CPA Chem (Stara Zagora, Bulgaria). Two standard curves (range = 0–300 ng/mL) were made in order to avoid the interferences of doubly charge ions from some rare earth elements an reach the highest accuracy: (a) one used a commercial multi-element mixture (CPA Chem Catalog number E5B8·K1.5 N.L1, 21 elements) containing the essential trace elements, the main heavy metals and elements stabilized in hydrochloric acid (Os, Pt, Au, Pd and Ru); (b) one containing the other multi-element mixture included individual elements (CPA Chem) that contained the REEs and other elements used in electronic devices. To avoid the memory effect of elements, especially with Hg, a cleaning solution consisting of 2.0% HNO3 and 1% HCl was introduced between samples.

2.3. Analytical method

An Agilent 7900 ICP-MS (Agilent Technologies, Tokyo, Japan) with standard nickel cones, MicroMist glass concentric nebulizer, and Ultra High Matrix Introduction (UHMI) system was used for all measurements. The Integrated Sample Introduction System (ISIS) was configured for discrete sampling. To avoid isobaric interferences, the isotopes included are totally different from each other, preventing that the mass of each element (generally the one of the highest abundance) would interfere in the determination. The 4th generation Octopole Reaction System (ORS4) was operated in helium (He) for all elements since the lack of the interferences of low-mass elements measured in no gas mode. Helium mode is adequate to reduce polyatomic interferences and improving detection limits for most elements, and totally ruling out the need for mathematical correction of interferences. Each replicate of sample was introduced in the ICP in two individual vials and three complete readings are made automatically in triplicate from each vial. Therefore, a total of 12 individual measurements were carried out for each sample. A tuning solution consisting in a mix of cesium, cobalt, lithium, magnesium, thallium, and yttrium was used before the analysis for optimization of instrumentation, including the verification for working conditions of the sensibility of the six isotopes (CPS), the RSD values and the recommended values of the oxide ratio and the double ion charges. Quantification of the elements was made in the MassHunter v.4.2. ICP-MS Data Analysis software (Agilent Technologies).

The complete procedure was in-house validated prior to its use with the employment of a reference certified material (RCM, Seronorm™ Trace Elements Whole Blood, Billingstad, Norway) at three levels of concentration (L-1, L-2, L-3). RCM included three clinically relevant levels for all the elements included in the present study except for palladium, indium, osmium, ruthenium, and titanium (catalog reference: 210,105, 210,205 and 210,305), which were assessed by our fortified matrix. Validation parameters such as estimated expanded uncertainty have not been determined. After the reconstitution with MilliQ Water and sonication of the RCM, five replicates of five independent vials of each level were previously digested as the procedure considered for the samples and analyzed in routine analysis conditions by ICP-MS. Linear calibration curves were found for all trace and toxic elements (regression coefficients ≥0.996) and recoveries obtained ranged from 79 to 121% for REE and other elements used in high tech devices, and from 86 to 122% for ATSDR's toxic elements. During the in-house validation, at least 10 blanks reagents previously included in the microwave digester in the same conditions as samples were added in the work sequence. Instrumental limit of detection (LOD) and quantification (LOQ) were calculated as the concentration of the element produced a signal that was three and ten times higher than of the averaged blanks solution measured in the same day of the analysis of the samples, respectively. This is the most accurate way to estimate such limits since the analytical values are calculated according to the instrumental conditions of the equipment on a daily basis. The accuracy and precision of this methodology was assessed performing recovery studies using acid nitric solution at 4% (v/v) fortified at three different levels (0.5, 5 and 50) using the mixtures A and B. Then, the recovery values were calculated dividing the obtained concentration by the theoretical concentration calculated from the added amount of the solution standard A and B.

Finally, to obtain the RCM and samples concentration, LOQs were calculated by multiplying the instrumental LOQ by the dilution factor suffered by the sample during the methodology procedure (1:40 v:v) and corrected for the exact mass of each sample weighed on a precision analytical balance (Additional file 1). The calculated relative standard deviations (RSD) were generally lower than 5%, except for few elements (Cu, Ni, Se, As, Ba, Zn, Sm), as the RSD raised to 10–12% at the lowest level of fortification. The precision improved at the medium and the highest level of concentration, as it was lower than 5% for all elements. RSD values higher than 5% have been eliminated for the subsequent calculation of the concentrations of the elements in the samples (12 measurements per sample as previously mentioned). Thus, all the analytical values taken for quantification come from measurements of RSD lower than 5%, which is recommended and suitable for the determination of the levels of elements in our ICP-MS.

As quality control of the analysis of whole blood samples, a reagent blank digested in the same conditions and two tailor-made mix to obtain a final concentration of 50 μg/L for the essential, toxic, and rare earth elements (A and B) were included each 21 vials of the sequence. The reagent blanks were employed to verify the possible contamination and obtain the instrumental limit of detection of each element as recently explained and the vials named as quality control A and B were performed to monitor an accurate determination of the elements through the sequence. Results were acceptable when the concentration of the analytes determined in the QCs was within 20% of the deviation of the theoretical value. Furthermore, every 30 vials one vial of each level (L-1, L-2 and L-3) of the RCM was included in the autosampler to test the sensibility and precision reached. ISTD was added to each vial (calibration, blanks, quality controls) prior to its introduction in the ICP-MS.

2.4. Statistical analysis

Descriptive analyses were conducted for all variables. Means, standard deviation (SD), medians, ranges and percentiles 5th, and 95th of the distribution were calculated for continuous variables. Proportions were calculated for categorical variables. Values below the LOQ were assigned a random number between 0 and the LOQ. Probability levels of <0.05 (two tailed) were considered statistically significant.

The normality of the data was tested using the Kolmogorov-Smirnov test. Those elements with frequencies of detection >20% conducted

Table 2
Blood concentration of inorganic elements according to gender and age. The concentrations are expressed in ng/mL and refer only to individuals with values > LOQ.

	Gender					Age (years)								
	Male n, (%)	Median (p5th-p95th)	Female n, (%)	Median (p5th-p95th)	P-value	<18 n, (%)	Median (p5th-p95th)	18–30 n, (%)	Median (p5th-p95th)	31–45 n, (%)	Median (p5th-p95th)	>45 n, (%)	Median (p5th-p95th)	P-value
As (arsenic)	167 (100)	3.17 (1.1–14.5)	234 (100)	3.03 (1.2–11.1)	0.910[a]	154 (100)	2.49 (0.1–8.1)	86 (100)	3.17 (1.1–13.1)	75 (100)	3.65 (1.2–13.5)	86 (100)	4.13 (1.5–18.6)	**<0.001**[c]
Be (beryllium)	49 (29.3)	0.22 (0.1–0.6)	58 (24.8)	0.23 (0.1–0.6)	0.538 [a]	38 (24.7)	0.21 (0.1–0.6)	22 (24.6)	0.22 (0.1–0.6)	20 (26.7)	0.36 (0.1–0.6)	27 (31.4)	0.21 (0.1–0.5)	0.381[c]
Cd (cadmium)	139 (83.2)	0.26 (0.1–1.4)	196 (83.8)	0.25 (0.1–1.9)	0.626 [a]	118 (76.6)	0.21 (0.1–1.1)	72 (83.7)	0.25 (0.1–0.7)	65 (86.7)	0.32 (0.1–2.3)	80 (93.0)	0.34 (0.1–1.9)	**<0.001**[c]
Co (cobalt)	100 (59.9)	0.29 (0.1–0.6)	150 (64.1)	0.30 (0.1–0.8)	0.204 [a]	104 (67.5)	0.33 (0.1–1.0)	58 (67.4)	0.30 (0.1–0.7)	47 (62.7)	0.30 (0.1–0.9)	41 (47.7)	0.30 (0.1–0.6)	0.002 [c]
Cu (copper)[e],[f]	167 (100)	0.80 (0.6–1.1)	234 (100)	0.87 (0.7–1.2)	**<0.001**[b]	154 (100)	0.85 (0.6–1.1)	86 (100)	0.78 (0.6–1.2)	75 (100)	0.87 (0.6–1.4)	86 (100)	0.87 (0.6–1.2)	**0.006**[d]
Hg (mercury)	167 (100)	10.09 (3.7–33.1)	234 (100)	10.01 (4.0–35.4)	0.906 [a]	154 (100)	7.84 (3.3–23.9)	86 (100)	10.60 (4.4–30.9)	75 (100)	13.08 (4.3–38.6)	86 (100)	13.29 (5.0–43.9)	**<0.001**[c]
Mn (manganese)[e]	109 (65.3)	10.91 (4.7–23.2)	173 (73.9)	10.83 (4.8–22.3)	0.723[b]	108 (70.1)	10.83 (4.5–19.3)	62 (72.1)	11.83 (5.3–27.4)	54 (72.0)	10.85 (4.6–25.5)	58 (67.4)	10.71 (4.7–19.1)	0.132[d]
Ni (nickel)	35 (21.0)	12.59 (1.7–140.1)	57 (24.4)	17.90 (0.9–137.3)	0.816 [a]	33 (21.4)	17.49 (0.9–220.5)	14 (16.3)	10.79 (0.8–110.8)	20 (26.7)	20.96 (2.1–191.5)	25 (29.1)	14.27 (2.2–118.3)	0.557 [c]
Pb (lead)	167 (100)	30.03 (9.7–249.4)	233 (99.6)	18.87 (7.0–125.5)	**<0.001** [a]	153 (99.4)	23.72 (8.9–218.9)	86 (100)	20.61 (7.6–109.7)	75 (100)	20.39 (6.4–193.7)	86 (100)	26.81 (8.9–409.5)	0.138 [c]
Se (selenium)[e]	167 (100)	209.13 (144.1–370.5)	234 (100)	224.03 (152.2–338.8)	0.967[b]	154 (100)	185.64 (138.9–264.3)	86 (100)	212.80 (163.5–289.5)	75 (100)	244.65 (177.4–387.8)	86 (100)	252.26 (189.1–448.1)	**<0.001**[d]
Sb (antimony)	156 (93.4)	4.91 (3.7–7.3)	221 (94.4)	4.92 (3.7–7.4)	0.888 [a]	143 (92.9)	4.83 (3.7–7.3)	80 (93.0)	4.79 (3.7–7.3)	70 (93.3)	4.98 (3.8–7.1)	84 (97.7)	5.24 (3.6–11.1)	0.131 [c]
Sr (strontium)	167 (100)	26.25 (15.7–52.5)	234 (100)	28.52 (15.9–48.3)	0.096 [a]	154 (100)	31.06 (17.6–51.3)	86 (100)	23.71 (14.2–44.1)	75 (100)	25.36 (14.1–52.8)	86 (100)	28.34 (18.2–60.9)	**<0.001**[c]
Zn (zinc)[e],[f]	167 (100)	6.10 (4.1–8.3)	234 (100)	5.55 (3.5–7.6)	**<0.001** [a]	154 (100)	5.35 (3.1–7.1)	86 (100)	5.89 (4.0–8.2)	75 (100)	5.91 (4.1–8.5)	86 (100)	6.08 (4.2–8.6)	**<0.001**[c]
Ga (gallium)	68 (40.7)	0.35 (0.1–0.6)	104 (44.4)	0.29 (0.1–0.5)	0.995 [a]	64 (41.6)	0.30 (0.1–0.4)	37 (43.0)	0.34 (0.1–0.8)	34 (45.3)	0.29 (0.1–0.6)	37 (43.0)	0.35 (0.1–0.5)	0.457 [c]
La (lanthanum)	36 (21.6)	0.36 (0.1–28.2)	43 (18.4)	0.39 (0.1–5.7)	0.915 [a]	24 (15.6)	0.36 (0.2–12.7)	16 (18.6)	0.46 (0.1–162.3)	16 (21.3)	0.38 (0.1–6.7)	23 (26.7)	0.35 (0.1–1.1)	0.344 [c]
Mo (molybdenum)	105 (62.9)	1.90 (0.8–5.1)	146 (62.4)	1.71 (0.7–6.9)	0.557 [a]	103 (66.9)	1.78 (0.9–3.8)	51 (59.3)	1.67 (0.7–8.6)	42 (56.0)	1.72 (0.8–15.1)	55 (64.0)	1.68 (0.8–11.6)	0.499 [c]
Nb (niobium)	101 (60.5)	2.81 (0.7–9.8)	152 (65.0)	2.20 (0.7–8.5)	0.758 [a]	103 (66.9)	2.28 (0.6–9.1)	59 (68.6)	2.21 (0.8–10.2)	43 (57.3)	2.47 (0.7–1.0)	48 (55.8)	2.49 (0.5–7.9)	0.304 [c]
Ta (tantalum)	151 (90.4)	1.59 (0.3–6.5)	210 (89.7)	1.55 (0.4–6.3)	0.804 [a]	142 (92.2)	1.61 (0.3–4.6)	78 (90.7)	1.62 (0.6–5.9)	65 (86.7)	1.47 (0.4–7.3)	76 (88.4)	1.34 (0.3–6.2)	0.465 [c]
Ti (titanium)	68 (40.7)	12.63 (1.9–91.3)	88 (37.6)	11.58 (1.9–24.1)	0.674 [a]	56 (36.4)	8.47 (1.8–21.1)	35 (40.7)	11.90 (2.6–248.4)	23 (30.7)	12.75 (3.4–29.9)	42 (48.8)	13.89 (1.9–46.0)	0.066 [c]
Tl (thallium)	53 (31.7)	0.61 (0.1–1.1)	45 (19.2)	0.52 (0.2–1.5)	**0.024**[a]	40 (26.0)	0.59 (0.3–1.2)	20 (23.3)	0.61 (0.2–1.3)	17 (22.7)	0.62 (0.1–1.6)	21 (24.4)	0.41 (0.1–0.9)	0.750 [c]

Abbreviations: LOQ, limit of quantification; p5th-p95th, percentiles 5 and 95 of the distribution.
#Complete list available at https://www.atsdr.cdc.gov/spl/index.html.
##Complete list available from B. Tansel et al. Enviroment International 98 (2017) 35–45.
[a] Mann-Whitney *U* test (two tails). Significant differences were highlighted in bold.
[b] Student T test (two tails). Significant differences were highlighted in bold. Concentrations of Cu, Mn and Se followed a normal distribution (Kolmogorov-Smirnof test).
[c] Kruskal-Wallis test (two tails). Significant differences were highlighted in bold.
[d] ANOVA test (two tails). Significant differences were highlighted in bold.
[e] Also considered as trace elements.
[f] Data reported in ug/mL.

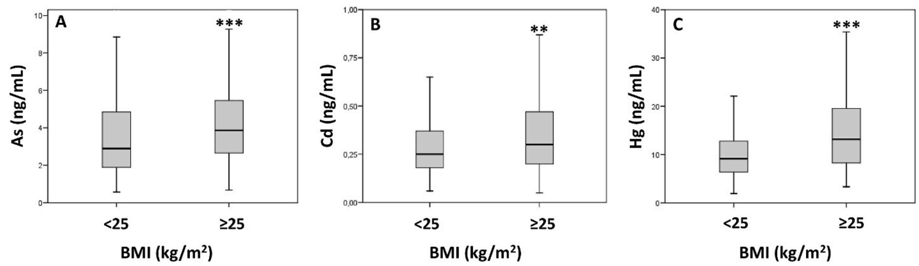


Fig. 1. Box plots illustrating the blood concentration of arsenic (As, panel A), cadmium (Cd, panel B) and mercury (Hg, panel C), according to body mass index (BMI) segmented as <25 kg/m2 and ≥0.25 kg/m2. P-values were calculated with Kruskal-Wallis test (two tails). The lines show the medians, the boxes cover the 25th to 75th percentiles, and the minimal and maximal values are shown by the ends of the bars. ***P < 0.001; **P < 0.01.

subsequent analyses. Comparisons between groups were performed using parametric (student t-test or ANOVA test) or non-parametric test (Kruskal-Wallis or Mann-Whitney *U* test). Differences in the categorical variables were tested by the chi-squared test. The correlation of inorganic elements with continuous variables was analyzed by the Spearman's correlation test or Pearson's correlation test. We used PASW Statistics v 19.0 (SPSS Inc., Chicago, IL, USA) to manage the database of the study and to perform statistical analyses. Probability levels of <0.05 (two tailed) were considered statistically significant.

3. Results and discussion

A total of 49 inorganic elements were measured in whole blood from 401 subjects from Cape Verde, in the context of the PERVEMAC-II study. This is the first time that a biomonitoring study of elements has been carried out in Cape Verde, complementing the previous biomonitoring study of organic pollutants (Henriquez-Hernandez et al., 2022). A similar number of subjects was recently published in plasma from Andalusian population (Spain) (Henriquez-Hernandez et al., 2020), whole blood from Catalonia (Spain) (Porta et al., 2023) and cord blood from newborns from Canary Islands, Spain (Cabrera-Rodriguez et al., 2018). Given the number of individuals studied and the population of the island of Santiago, the study can be considered representative of the population.

A total of 20 inorganic elements out of the 49 analyzed (40.8%) were detected in more than 20% of the population (Additional file 1). Of these, 6 were detected in 100% of individuals: arsenic, copper, mercury, selenium, strontium and zinc. If we consider copper, selenium and zinc as essential elements (which explains why they appear in all individuals), and we take into account that the detection frequency of lead was 99.8%, there are three elements (arsenic, mercury and lead), very harmful to people's health, present in the whole series. Among the 10 most dangerous substances in the ATSDR's substance priority list, arsenic, lead and mercury occupy positions 1, 2 and 3, respectively (ATSDR's, 2022). This profile is partially in line with other studies, where detection frequencies were >95% for arsenic and lead (Henriquez-Hernandez et al., 2020). The case of mercury draws our attention. In a series of 419 individuals from Andalusia, mercury was present in 65.9% of individuals (Henriquez-Hernandez et al., 2020); in 89 children and adolescents from Romania, the frequency of detection was 17.9% (Gaman et al., 2020), while in populations from Morocco and the Canary Islands it was less than 5% (Henriquez-Hernandez et al., 2018). The explanation for this result may be due to the dietary habits of the Cape Verdean population. In the frame of the PERVEMAC-II project, the first nutritional survey in Cape Verde (known as ENCAVE) was conducted, involving a total of 433 individuals. In it, 47.8% and 44.1% of the surveyed population consumed fresh or canned tuna, being - together with red meat and maize - the most consumed foods in the Cape Verdean population (PERVEMAC-II, 2022). The percentage of tuna consumers in the Canary Islands Nutritional Survey was less than 20% (Encuesta, 2000). Although the usual portion for consumers was similar in both nutritional surveys (≈150 g/day), the difference in the frequency of consumption could explain the differences in the frequency of mercury detection. In that sense, it is well known that large predatory fishes such as tuna, contain large amounts of mercury, which is why it is recommended to reduce the consumption of this type of food in at-risk populations (Recomendaciones, 2019).

Apart from the essential elements, lead, mercury and arsenic were the elements present in highest concentration (median values = 22.6, 10.1, and 3.09 ng/mL, respectively) surpassed only by strontium (median value = 27.8 ng/mL; Additional file 1). Median values of this elements were 5.9, 1.5 and 1.4 ng/mL, respectively among Andalusian subjects (Henriquez-Hernandez et al., 2020). Among Canarian subjects, median concentrations of lead, mercury and arsenic were 7.4, 17.0 and 1.92, respectively; but it has to be taken into account, as detailed above, that frequency of detection of mercury in this series was 3.3% (Henriquez-Hernandez et al., 2018). These differences would be explained by diet or environmental factors (Aguilera et al., 2008; Olmedo et al., 2013). Reference Values 95th (RV95s) - defined as the 95th percentile of the measured chemical concentration of a reference population - for arsenic, mercury, and lead among adults are 2.0, 2.3, and 33 ng/mL, respectively (Saravanabhavan et al., 2017). In the present series, 77.0% (n = 309), 99.2% (n = 398) and 33.4% (n = 134) of the participants showed values of arsenic, mercury and lead higher than RV95s. These percentages are much higher than those reported in similar studies (Henriquez-Hernandez et al., 2020).

Among the REEs and MEs, only 7 elements showed detection frequencies above 20%; of these, 4 (molybdenum, niobium, tantalum and titanium) had median concentrations above the LOQ, when considering the whole series (Additional file 1). In general, the exposure profile of this population is different to others, in terms of detection frequencies and median concentrations (Henriquez-Hernandez et al., 2018, 2020; Cirtiu et al., 2022). Since available biomonitoring data for REEs in non-mining environments remain limited, explaining the exposure profile of the populations is only hypothetical. The presence of some elements or others, considered individually, will depend on environmental factors and lifestyle habits as varied as the use of electronic cigarettes (Badea et al., 2018) or certain brands of tobacco (Zumbado et al., 2019). Niobium and tantalum showed the highest median concentrations: 1.35 and 1.34 ng/mL (Additional file 1). Both elements are considered as geochemical "identical twins" related with the evolution of the Earth and other planetary bodies (Green, 1995). This would explain why both elements are the most frequently detected and at the highest concentrations among subjects from an island of volcanic origin belonging to an oceanic rather than continental plate. Tantalum is a technology-critical element also identified as a "conflict mineral" for being linked to civil wars in some African countries (OECD. OECD, 2013). Studies on tantalum concentrations in the different environmental compartments are scarce. However, values exist for concentrations in natural waters, soils, bed sediments and atmospheric aerosols (Filella, 2017). Taken together, the present results suggest an environmental source of niobium and tantalum in Cape Verde. However, despite

Table 3
Distribution of the number of inorganic elements by sociodemographic and lifestyle variables.

Variable	Below median (≤15)[a]	Above median (>15)[a]	Total	P-value[b]
Gender				0.666
Male	90	77	167	
Female	121	113	234	
	211	190	401	
Age (years)				0.771
<18	86	68	154	
18–30	43	43	86	
31–45	39	36	75	
>45	43	43	86	
	211	190	401	
BMI (kg/m^2)				**0.033**
<18.5	63	55	118	
18.5–24.9	97	69	166	
25–29.9	36	36	72	
>29.9	14	28	42	
	210	188	398	
Habitat				**0.037**
Urban	129	135	264	
Rural	82	55	137	
	211	190	401	
Civil status				0.733
Single	98	97	195	
Married	52	46	98	
Divorced	13	8	21	
Widowed	5	6	11	
	168	157	325	
Educational level				0.884
Primary schooling	87	78	165	
Secondary schooling	77	76	153	
Higher education	22	19	41	
	186	173	359	
Employment status				**0.011**
Employed	68	51	119	
Unemployed	52	37	89	
Retired	19	38	57	
Housewife/student	6	8	14	
	145	134	279	
Income				0.465
Low	43	41	84	
Medium	72	77	149	
High	66	52	118	
	181	170	351	
Origin of foodstuffs				**<0.001**
Supermarket	97	124	221	
Local market	98	38	136	
Others	15	28	43	
	210	190	400	
Food preparation				0.504
Wood/Charcoal	63	51	114	
Electricity/Gas	148	139	287	
	211	190	401	
School canteen				0.895
No	43	33	76	
Yes	96	71	167	
	139	104	243	
Source of water				0.533
Running water	138	115	253	
Pond	17	15	32	
Drum/Cistern	56	60	116	
	211	190	401	
Water disposal				0.161
Sewer	27	17	44	
Cesspool	29	19	48	
Outside	146	149	295	
	202	185	387	

[a] Participants had a median of 15 different inorganic elements detected in their blood. The segmentation of the whole population was done according to this value.
[b] Chi-square test (two-tailed).

the high concentrations observed, tantalum is relatively innocuous and plays no biological role (Frausto da Silva and Williams, 2001).

3.1. *Influence of gender, age and BMI on blood levels of the inorganic elements*

Blood levels of copper, lead and zinc were influenced by gender (Table 2). Copper concentration was significantly higher among females while lead, zinc and thallium levels were higher among males. Regarding copper, it is well known that plasma copper is higher in females, especially in those women who use oral contraceptives (Milne and Johnson, 1993). Unfortunately, the variable "contraceptive use" is not available in the present study. Similar results for lead have been observed in other series, where men had higher blood levels than women (Bertram et al., 2022; Nisse et al., 2017). This finding is explained by the binding of lead to hemoglobin, which has a higher concentration in the blood of males than in females (Canada, 2013). Similarly, zinc and thallium levels have been found to be higher among men in other series (Nisse et al., 2017), although in the case of thallium, the finding is limited to the urine concentration uncorrected for creatinine. In other scenarios, women have higher levels (Nisse et al., 2017) or no significant differences were found (Cirtiu et al., 2022; Zeng et al., 2019). No other elements were found to be significantly associated with gender.

Blood concentration of inorganic elements were influenced by age. In general, the older the age, the higher the concentration levels of arsenic (Spearman Rho = 0.293), cadmium (Spearman Rho = 0.374), mercury (Spearman Rho = 0.380), selenium (Spearman Rho = 0.581) and zinc (Spearman Rho = 0.336); P value < 0.001 in all cases (Data not shown). On the contrary, the older the age, the lower the levels of cobalt (Spearman Rho = −0.201, P value < 0.001) and strontium (Spearman Rho = −0.114, P value = 0.022). When the age was segmented, a total of 8 elements showed significant different concentrations: the 7 named above and copper (Table 2). The deterioration of physiological functions and the cumulative nature of many of these elements, especially the heavy metals, explains the influence of age on the levels of many inorganic elements (Wang et al., 2023). Similar results to the present study have been reported in other series, where arsenic and cadmium blood levels increased with increasing age of the individuals (Simic et al., 2022). In general, the lower the elimination from the body, the greater the influence of age (Gil and Hernández, 2015). However, the role of body mass index (BMI) should be taken into account, as there is a positive correlation with age (Spearman Rho = 0.715, P value < 0.001).

A positive correlation was observed between BMI and blood levels of arsenic, cadmium and mercury: Spearman Rho = 0.101, P value = 0.044, for arsenic and cadmium; Spearman Rho = 0.198, P value < 0.001, for mercury (Data not shown). When BMI was segmented, blood levels of arsenic, cadmium and mercury were higher in individuals who were overweight or obese than in subjects who were under- or normal weight: 2.9 vs. 3.9 ng/mL (P < 0.001), 0.2 vs. 0.3 ng/mL (P = 0.002) and 9.2 vs. 13.2 ng/mL (P < 0.001), respectively (Fig. 1). This trend was also significant when BMI was segmented into underweight, normal weight, overweight and obese: P value = 0.002 (for arsenic) and P < 0.001 (for cadmium and mercury), respectively (Data not shown). Moreover, while 76.2% of individuals with a BMI<25 kg/m^2 had 15 or fewer different inorganic elements in their blood, this percentage was 65.9% among overweight or obese subjects (P value = 0.033; Table 3). Thus, the higher the BMI, the greater the number of different elements present in the individual's blood. For these analyses, the number of substances detected was dichotomized on the basis of the median of the distribution, which was 15. The role of BMI in relation to chemical contaminants is unclear; while some authors have not observed this association (Simic et al., 2022; Ashley-Martin et al., 2019), others have (Henriquez-Hernandez et al., 2020). These inorganic elements have no particular affinity for fat; thus, there must be different co-factors that explain this association. Among them, age and diet appear as the most relevant. Since there is a strong positive correlation between age and

Table 4
Distribution of blood concentration of arsenic, cadmium, mercury and lead in the study population by sociodemographic and lifestyle habits. The concentrations are expressed in ng/mL and refer only to individuals with values > LOQ.

	Arsenic (As)		Cadmium (Cd)		Mercury (Hg)		Lead (Pb)	
Characteristic	Median (p5th—95th)	*P-value*	Median (p5th—95th)	*P-value*	Median (p5th—95th)	*P-value*	Median (p5th—95th)	*P-value*
Habitat		0.195[a]		0.513[a]		0.931[a]		0.873[a]
Urban	3.03 (1.2–11.7)		0.26 (0.1–1.9)		10.11 (3.6–37.1)		22.82 (8.6–139.5)	
Rural	3.40 (1.2–15.4)		0.26 (0.1–0.7)		9.88 (4.1–30.8)		21.79 (7.4–222.6)	
Educational level		0.149[b]		0.632[b]		**<0.001**[b]		**<0.001**[b]
Primary schooling	3.01 (1.2–13.1)		0.26 (0.1–1.9)		9.68 (3.4–37.7)		26.78 (8.7–252.0)	
Secundary schooling	2.89 (1.0–10.6)		0.25 (0.1–1.2)		8.96 (4.0–23.3)		21.23 (8.0–134.5)	
Higher schoolig	3.37 (1.2–13.7)		0.25 (0.1–0.7)		16.18 (5.7–44.0)		14.42 (6.2–55.9)	
Employment status[c]		**0.003**[b]		0.160[b]		**<0.001**[b]		**0.027**[b]
Employed	4.08 (1.6–20.5)		0.32 (0.1–2.0)		14.67 (4.9–43.8)		24.49 (8.0–177.2)	
Unemployed	3.04 (1.0–11.8)		0.30 (0.1–0.7)		9.82 (3.5–21.4)		15.54 (5.7–150.5)	
Housewife/student	2.86 (1.2–5.3)		0.21 (0.2–0.7)		10.84 (3.9–22.4)		20.67 (8.7–738.9)	
Retired	4.13 (1.3–12.9)		0.25 (0.1–2.0)		10.83 (5.7–42.7)		26.29 (6.7–218.6)	
Civil status		**0.002**[b]		0.061[b]		**<0.001**[b]		**0.011**[b]
Single	2.99 (1.2–11.1)		0.26 (0.1–1.9)		9.81 (3.9–29.7)		20.94 (7.9–139.2)	
Married	4.46 (1.5–23.4)		0.30 (0.1–1.4)		13.59 (5.6–43.8)		20.96 (6.9–188.3)	
Divorced	4.07 (1.1–12.5)		0.32 (0.2–1.0)		10.41 (6.8–20.9)		28.08 (8.9–678.7)	
Widowed	2.90 (1.2–15.0)		0.26 (0.1–0.9)		14.96 (3.5–35.5)		81.49 (11.0–590.9)	
Income		0.950[b]		0.714[b]		**0.022**[b]		0.752[b]
Low (<13,000 C VE)	3.24 (1.3–11.5)		0.27 (0.1–0.8)		8.43 (3.4–23.6)		21.03 (8.1–201.7)	
Medium (13,001–33,000 C VE)	3.01 (1.2–13.1)		0.26 (0.1–2.1)		9.74 (3.4–27.0)		23.97 (7.8–131.9)	
High (>33,000 C VE)	3.25 (1.0–13.7)		0.26 (0.1–1.9)		10.76 (4.1–44.0)		22.07 (7.8–235.3)	
Origin of foodstuffs		0.884[b]		0.646[b]		0.120[b]		0.371[b]
Supermarket	3.08 (1.1–12.9)		0.25 (0.1–1.2)		10.44 (4.0–34.8)		24.34 (8.1–210.5)	
Local market	3.14 (1.3–12.1)		0.26 (0.1–1.2)		9.74 (3.6–35.8)		20.41 (8.2–229.4)	
Others[d]	2.83 (1.1–9.8)		0.28 (0.1–2.3)		8.42 (3.2–27.1)		23.72 (7.9–99.6)	
Food preparation		0.454[a]		0.165[a]		**<0.001**[a]		0.159[a]
Wood/Charcoal	3.08 (1.3–18.9)		0.25 (0.1–0.7)		8.45 (3.5–21.4)		20.80 (7.4–211.2)	
Electricity/Gas	3.09 (1.1–12.1)		0.27 (0.1–1.9)		11.08 (3.9–37.7)		23.48 (8.6–169.5)	
School canteen[e]		0.583[a]		0.680[a]		0.351[a]		0.495[a]
No	2.36 (0.7–13.2)		0.18 (0.1–0.8)		9.45 (3.5–22.9)		19.59 (10.3–313.3)	
Yes	2.58 (1.0–7.9)		0.22 (0.1–1.2)		8.01 (3.7–35.6)		22.58 (9.3–202.1)	
Source of water		**0.022**[b]		0.421[b]		0.193[b]		0.920[b]
Running water	2.94 (1.1–12.0)		0.26 (0.1–0.9)		10.40 (3.5–34.0)		22.33 (8.2–172.3)	
Pond	4.56 (1.3–14.9)		0.28 (0.1–0.8)		11.70 (4.5–30.1)		19.99 (10.9–147.8)	
Drum/Cistern	3.49 (1.4–11.9)		0.27 (0.1–2.4)		9.18 (4.0–37.7)		22.96 (7.5–235.7)	
Water disposal		**0.024**[b]		0.421[b]		0.903[b]		0.166[b]
Sewer	3.96 (0.9–21.5)		0.31 (0.1–1.5)		10.76 (3.4–20.6)		22.11 (7.1–253.3)	
Cesspool	2.54 (0.7–9.6)		0.27 (0.2–0.8)		10.40 (4.1–50.0)		18.76 (8.0–207.8)	
Outside	3.04 (1.2–12.2)		0.25 (0.1–1.7)		9.81 (4.0–33.9)		23.30 (8.0–189.3)	

Abbreviations: LOQ, limit of quantification; CVE, Cape Verdean escudo.
[a] Mann Whitney *U* test.
[b] Kruskal-Wallis test.
[c] Analisys made in the subgroup of population ≥18 years old.
[d] In-house production, barter and other non-monetized acquisition systems.
[e] Analisys made in the subgroup of population under 18 years old.

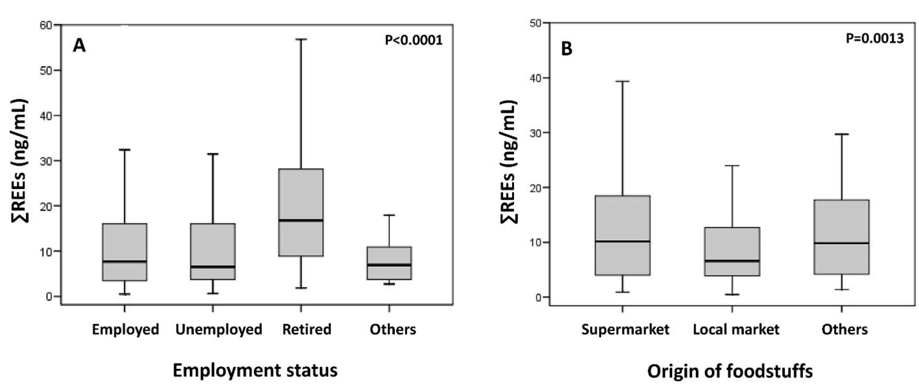


Fig. 2. Box plots illustrating the blood concentration of sum of rare earth elements (∑RREs) according to Employment status (A) and Origin of foodstuffs (B). P-values were calculated with Kruskal-Wallis test (two tails). The lines show the medians, the boxes cover the 25th to 75th percentiles, and the minimal and maximal values are shown by the ends of the bars.

BMI (Spearman Rho = 0.715, P value < 0.001), the role of body weight in different age segments was studied. In this model, only mercury was significantly associated with BMI, but only in individuals older than 45 years (P = 0.014), confirming a determinant influence of age rather than body mass index. Diet is a key factor in the correct interpretation of these results. It has to be highlighted that the study population is a high consumer of fish and seafood products, according to the nutritional survey. It is precisely these foods that have the highest concentrations of arsenic, cadmium and mercury (Rodriguez-Hernandez et al., 2019; Mehouel and Fowler, 2022).

Taken together, as with other pollutants (Henriquez-Hernandez et al., 2011, 2022), age appears to be the most important factor in relation to blood levels of inorganic elements, especially heavy metals.

3.2. Sociodemographic and lifestyle habits determining blood levels of inorganic elements

Following the strategy of the previous study in this population (Henriquez-Hernandez et al., 2022), other variables related to socio-demographic factors and lifestyle habits were collected in order to explore the relationship these might have with blood levels of the elements under study (Table 4). We observed that employment and civil status were the variables with the greatest influence on blood levels of arsenic, mercury and lead. Although an association between age and employment status was observed (P < 0.001, Kruskal-Wallis test), contrary to expectations, retired subjects did not always show the highest levels of contaminants. While this was true for lead, where blood levels were higher among the retired subjects, mercury, where levels were significantly higher among employed subjects, caught our attention (P < 0.001, Table 4). In fact, employed and married individuals, with higher educational and income levels, showed the highest blood levels of mercury. This suggests the presence of other environmental determinants, including diet, whose quality, quantity and frequency of food is conditioned by the economic level (directly related to the level of education and active employment) (Costa et al., 2023). 13% of the retired individuals had less than 15 different elements (19 out of 145), compared to 28% of the retired subjects who had more than 15 different inorganic elements in their blood (38 out of 134) (P value = 0.011, Table 4). This segment of the population showed the highest concentration of the sum of RREs and MEs, taken as a subgroup of analysis (P < 0.001, Fig. 2A). On the other hand, widowers showed the highest levels of mercury and lead (Table 4). These associations suggest that age appears as a confounding variable to be taken into account when analyzing the influence of socio-demographic variables in biomonitoring studies (Gilles et al., 2022).

Water is an established source of arsenic. However, the source of water determines the levels of contaminants. In the case of arsenic, it appears that pond water is associated with higher levels of arsenic in the food chain (Rahman et al., 2023). In the present study, we observed that those subjects whose water source was pond water had significantly higher arsenic levels (P = 0.022; Table 4). The association observed with the way water is disposed of is conditioned by other variables such as income level. Thus, 36.6% of individuals with sewerage had high incomes. This percentage dropped to 28% for individuals who disposed of their water outside (P < 0.001, Data not shown). In any case, these variables associated with water were not associated with any other element.

We have previously noted that the origin of the food is a factor conditioning the levels of contaminants in the blood of this population (Henriquez-Hernandez et al., 2022). Specifically, people who bought their food in the local market had higher concentrations of organochlorine pesticides than those who bought their food in supermarkets, a result related to the habitat in which the individual lives, as those living in rural environments, whose food is locally marketed, are more exposed to these types of pollutants (Henriquez-Hernandez et al., 2022). For the inorganic elements, the situation is just the opposite: individuals who buy their food in supermarkets have a significantly higher number of contaminants (46.2 vs. 65.3%, P < 0.001; Table 4). As previously published, this result is directly related to the habitat. Thus, 152 out of 221 (68.8%) people who acquired foodstuffs in supermarkets lived in an urban area, while 69 out of 221 (31.2%) who acquired foodstuffs in local markets lived in a rural area (P = 0.034, Data not shown). Moreover, 61.1% of subjects living in an urban habitat had ≤15 different elements, while the percentage of individuals with more than 15 different elements and living in an urban habitat was 71.1% (P = 0.037, Table 4). This pattern is also observed when considering the RREs and MEs as a group: the concentration of the sum of these elements is significantly higher among individuals who purchase their food in supermarkets (P = 0.013, Fig. 2B).

These results suggest that some socio-demographic factors and lifestyle habits influence the blood concentration of some inorganic elements, mainly heavy metals and metalloids, RREs and MEs. Special attention should be paid to the source of water and the origin of food, as these are variables that can be controlled by the individual to reduce exposure to these contaminants.

4. Conclusions

This biomonitoring study complements the previously published study on organic pollutants carried out in Cape Verde. A total of 49 inorganic elements have been determined in a total of 401 individuals, which is representative of the population of Santiago Island. 7 elements were detected in >99% of individuals: arsenic, copper, mercury, lead, selenium, strontium and zinc. In the present series, 77.0, 99.2 and 33.4% of the participants showed values of arsenic, mercury and lead higher than RV95s, respectively. Among RREs and MEs, niobium and tantalum were the most frequently detected elements and at the highest concentration. Blood concentrations of inorganic elements were mainly influenced by age, although gender and BMI should exert some effect. Lifestyle has an effect on the concentration of some of these substances, especially in terms of dietary habits: where food is purchased or the type of water consumed. Our results may be useful for the implementation of public health measures by the competent authorities in Cape Verde.

Author statement

Luis Alberto Henríquez-Hernández: Conceptualization, Formal analysis, and Writing – original draft, Manuel Zumbado and Ángel Rodríguez-Hernández: Data curation and Methodology, Edna Duarte-Lopes, Ailton Luis Lopes-Ribeiro, Patricia Miranda Alfama, Miriam Livramento and Adriana Ortiz-Andrelluchi: Data curation and Project administration, Octavio Pérez-Luzardo and Luis D. Boada: Methodology and Project administration, Ricardo Díaz-Díaz, María del Mar Bernal-Suárez and Lluis Serra-Majem: Funding acquisition and Project administration, Octavio Pérez-Luzardo: Investigation, writing – review & editing and project administration.

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

Data will be made available on request.

Acknowledgements

This research was supported by the PERVEMAC-II project (MAC/1.1 A/049).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chemosphere.2023.139594.

References

Aguilera, I., Daponte, A., Gil, F., Hernández, A.F., Godoy, P., Pla, A., et al., 2008. Biomonitoring of urinary metals in a population living in the vicinity of industrial sources: a comparison with the general population of Andalusia, Spain. Sci. Total Environ. 407, 669–678.

Ashley-Martin, J., Dodds, L., Arbuckle, T.E., Lanphear, B., Muckle, G., Bouchard, M.F., et al., 2019. Blood metal levels and early childhood anthropometric measures in a cohort of Canadian children. Environ. Res. 179, 108736.

Atsdr's, A.T.S.D.R., 2022. Substance Priority List: Agency for Toxic Substances and Disease Registry.

Badea, M., Luzardo, O.P., Gonzalez-Antuna, A., Zumbado, M., Rogozea, L., Floroian, L., et al., 2018. Body burden of toxic metals and rare earth elements in non-smokers, cigarette smokers and electronic cigarette users. Environ. Res. 166, 269–275.

Bertram, J., Ramolla, C., Esser, A., Schettgen, T., Fohn, N., Kraus, T., 2022. Blood lead monitoring in a former mining area in euskirchen, Germany-volunteers across the entire population. Int. J. Environ. Res. Publ. Health 19.

Buekers, J., David, M., Koppen, G., Bessems, J., Scheringer, M., Lebret, E., et al., 2018. Development of Policy Relevant Human Biomonitoring Indicators for Chemical Exposure in the European Population 15, 2085.

Cabrera-Rodriguez, R., Luzardo, O.P., Gonzalez-Antuna, A., Boada, L.D., Almeida-Gonzalez, M., Camacho, M., et al., 2018. Occurrence of 44 elements in human cord blood and their association with growth indicators in newborns. Environ. Int. 116, 43–51.

Canada, H., 2013. Risk Management Strategy for Lead. Health Canada, Ottawa, ON, Canada.

Cirtiu, C.M., Valcke, M., Gagne, M., Bourgault, M.H., Narame, C., Gadio, S., et al., 2022. Biological monitoring of exposure to rare earth elements and selected metals in the Inuit population of Nunavik, Canada. Chemosphere 289, 133142.

Cong, X., Xu, X., Xu, L., Li, M., Xu, C., Qin, Q., et al., 2018. Elevated biomarkers of sympatho-adrenomedullary activity linked to e-waste air pollutant exposure in preschool children. Environ. Int. 115, 117–126.

Costa, P.R., Carvalho, T., Pitangueira, J.C.D., Santana, M.L.P., Kinra, S., Potvin, L., 2023. Global, regional and national prevalence of copper, selenium and zinc deficiencies in women of childbearing age: protocol for systematic review and meta-analysis. BMJ Open 13, e066324.

Council, N.R., 2006. Human Biomonitoring for Environmental Chemicals. The National Academies Press, Washington, DC.

Davis, J.M., Garb, Y., 2019. A strong spatial association between e-waste burn sites and childhood lymphoma in the West Bank, Palestine. Int. J. Cancer 144, 470–475.

Encuesta, GobCan, 2000. Nutricional de Canarias (ENCA) - Hábitos alimentarios y consumo de alimentos (1997-1998), Canary Islands (Spain). Gobierno de Canarias - Servicio Canario de Salud (Islas Canarias, España), p. 204.

Filella, M., 2017. Tantalum in the environment. Earth Sci. Rev. 173, 122–140.

Frausto da Silva, J.J.R., Williams, R.J.P., 2001. The Biological Chemistry of the Elements. The Inorganic Chemistry of Life. Oxford University Press, New York (USA).

Gaman, L., Delia, C.E., Luzardo, O.P., Zumbado, M., Badea, M., Stoian, I., et al., 2020. Serum concentration of toxic metals and rare earth elements in children and adolescent. Int. J. Environ. Health Res. 30, 696–712.

Gaman, L., Radoi, M.P., Delia, C.E., Luzardo, O.P., Zumbado, M., Rodriguez-Hernandez, A., et al., 2021. Concentration of heavy metals and rare earth elements in patients with brain tumours: analysis in tumour tissue, non-tumour tissue, and blood. Int. J. Environ. Health Res. 31, 741–754.

Gil, F., Hernández, A.F., 2015. Toxicological importance of human biomonitoring of metallic and metalloid elements in different biological samples. Food Chem. Toxicol. 80, 287–297.

Gilles, L., Govarts, E., Rodriguez Martin, L., Andersson, A.M., Appenzeller, B.M.R., Barbone, F., et al., 2022. Harmonization of human biomonitoring studies in Europe: characteristics of the hbm4eu-aligned studies participants. Int. J. Environ. Res. Publ. Health 19.

Gonzalez-Antuna, A., Camacho, M., Henriquez-Hernandez, L.A., Boada, L.D., Almeida-Gonzalez, M., Zumbado, M., et al., 2017. Simultaneous quantification of 49 elements associated to e-waste in human blood by ICP-MS for routine analysis. MethodsX 4, 328–334.

Green, T.H., 1995. Significance of Nb/Ta as an indicator of geochemical processes in the crust-mantle system. Chem. Geol. 120, 347–359.

Hbm4Eu, 2016. The Human Biomonitoring for European Union Citizens Program. German Environment Agency.

Henriquez-Hernandez, L.A., Luzardo, O.P., Almeida-Gonzalez, M., Alvarez-Leon, E.E., Serra-Majem, L., Zumbado, M., et al., 2011. Background levels of polychlorinated biphenyls in the population of the Canary Islands (Spain). Environ. Res. 111, 10–16.

Henriquez-Hernandez, L.A., Luzardo, O.P., Boada, L.D., Carranza, C., Perez Arellano, J. L., Gonzalez-Antuna, A., et al., 2017a. Study of the influencing factors of the blood levels of toxic elements in Africans from 16 countries. Environ Pollut 230, 817–828.

Henriquez-Hernandez, L.A., Boada, L.D., Carranza, C., Perez-Arellano, J.L., Gonzalez-Antuna, A., Camacho, M., et al., 2017b. Blood levels of toxic metals and rare earth elements commonly found in e-waste may exert subtle effects on hemoglobin concentration in sub-Saharan immigrants. Environ. Int. 109, 20–28.

Henriquez-Hernandez, L.A., Gonzalez-Antuna, A., Boada, L.D., Carranza, C., Perez-Arellano, J.L., Almeida-Gonzalez, M., et al., 2018. Pattern of blood concentrations of 47 elements in two populations from the same geographical area but with different geological origin and lifestyles: Canary Islands (Spain) vs. Morocco. Sci. Total Environ. 636, 709–716.

Henriquez-Hernandez, L.A., Romero, D., Gonzalez-Antuna, A., Gonzalez-Alzaga, B., Zumbado, M., Boada, L.D., et al., 2020. Biomonitoring of 45 inorganic elements measured in plasma from Spanish subjects: a cross-sectional study in Andalusian population. Sci. Total Environ. 706, 135750.

Henriquez-Hernandez, L.A., Ortiz-Andrelluchi, A., Alvarez-Perez, J., Acosta-Dacal, A., Zumbado, M., Martinez-Gonzalez, M.A., et al., 2021. Human biomonitoring of persistent organic pollutants in elderly people from the Canary Islands (Spain): a temporal trend analysis from the PREDIMED and PREDIMED-Plus cohorts. Sci. Total Environ. 758, 143637.

Henriquez-Hernandez, L.A., Macias-Montes, A., Acosta-Dacal, A., Rial-Berriel, C., Duarte-Lopes, E., Lopes-Ribeiro, A.L., et al., 2022. Human biomonitoring of persistent and non-persistent pollutants in a representative sample of the general population from Cape Verde: results from the PERVEMAC-II study. Environ Pollut 306, 119331.

Huo, X., Wu, Y., Xu, L., Zeng, X., Qin, Q., Xu, X., 2019. Maternal urinary metabolites of PAHs and its association with adverse birth outcomes in an intensive e-waste recycling area. Environ Pollut 245, 453–461.

Medina-Estevez, F., Zumbado, M., Luzardo, O.P., Rodriguez-Hernandez, A., Boada, L.D., Fernandez-Fuertes, F., et al., 2020. Association between heavy metals and rare earth elements with acute ischemic stroke: a case-control study conducted in the canary islands (Spain). Toxics 8.

Mehouel, F., Fowler, S.W., 2022. Review of the toxic trace elements arsenic, cadmium, lead and mercury in seafood species from Algeria and contiguous waters in the Southwestern Mediterranean Sea. Environ. Sci. Pollut. Res. Int. 29, 3288–3301.

Milne, D.B., Johnson, P.E., 1993. Assessment of copper status: effect of age and gender on reference ranges in healthy adults. Clin. Chem. 39, 883–887.

Nisse, C., Tagne-Fotso, R., Howsam, M., 2017. Members of Health Examination Centres of the Nord - pas-de-Calais region n., Richeval C., Labat L. et al. Blood and urinary levels of metals and metalloids in the general adult population of Northern France: the IMEPOGE study, 2008-2010. Int. J. Hyg Environ. Health 220, 341–363.

OECD. OECD, 2013. Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas.

Olmedo, P., Pla, A., Hernández, A.F., Barbier, F., Ayouni, L., Gil, F., 2013. Determination of toxic elements (mercury, cadmium, lead, tin and arsenic) in fish and shellfish samples. Risk assessment for the consumers. Environ. Int. 59, 63–72.

Ougier, E., Ganzleben, C., Lecoq, P., Bessems, J., David, M., Schoeters, G., et al., 2021. Chemical prioritisation strategy in the European human biomonitoring initiative (HBM4EU) – development and results. Int. J. Hyg Environ. Health 236, 113778.

Pervemac, I.I., 2017. PERVEMAC: Agricultura Sostenible y Seguridad Alimentaria en la Macaronesia, 2014-2020.

PERVEMAC-II, 2022. Encuesta nutricional de Cabo Verde - Isla de Santiago (ENCAVE 2018-2019) - Preliminar version, Cape Verde and Spain. Instituto Nacional de Salud Pública de Cabo Verde y Universidad de Las Palmas de Gran Canaria, pp. 108–114.

Porta, M., Pumarega, J., Henríquez-Hernández, L.A., Gasull, M., Bartoll, X., Arrebola, J. P., et al., 2021. Reductions in blood concentrations of persistent organic pollutants in the general population of Barcelona from 2006 to 2016. Sci. Total Environ. 777, 146013.

Porta, M., Pumarega, J., Gasull, M., Aguilar, R., Henriquez-Hernandez, L.A., Basagana, X., et al., 2023. Individual blood concentrations of persistent organic pollutants and chemical elements, and COVID-19: a prospective cohort study in Barcelona. Environ. Res. 223, 115419.

Rahman, M., Abdullah-Al-Mamun, M., Khatun, M.S., Khan, A.S., Sarkar, O.S., Islam, O. K., et al., 2023. Contamination of selected toxic elements in integrated chicken-fish farm settings of Bangladesh and associated human health risk assessments. Biol. Trace Elem. Res. 201, 1465–1477.

Rare, E.P.A., 2012. Earth Elements: A Review of Production, Processing, Recycling, and Associated Environmental Issues. U.S. Environmental Protection Agency, Washington, D.C. (USA).

Recomendaciones, A.E.S.A.N., 2019. de consumo de pescado por presencia de mercurio. Agencia Española de Seguridad Alimentaria y Nutrición (AESAN).

Rodriguez-Hernandez, A., Zumbado, M., Henriquez-Hernandez, L.A., Boada, L.D., Luzardo, O.P., 2019. Dietary intake of essential, toxic, and potentially toxic elements from mussels (Mytilus spp.) in the Spanish population: a nutritional assessment. Nutrients 11.

Saravanabhavan, G., Werry, K., Walker, M., Haines, D., Malowany, M., Khoury, C., 2017. Human biomonitoring reference values for metals and trace elements in blood and urine derived from the Canadian Health Measures Survey 2007–2013. Int. J. Hyg Environ. Health 220, 189–200.

Simic, A., Hansen, A.F., Syversen, T., Lierhagen, S., Ciesielski, T.M., Romundstad, P.R., et al., 2022. Trace elements in whole blood in the general population in Trondelag County, Norway: the HUNT3 Survey. Sci. Total Environ. 806, 150875.

Soetrisno, F.N., Delgado-Saborit, J.M., 2020. Chronic exposure to heavy metals from informal e-waste recycling plants and children's attention, executive function and academic performance. Sci. Total Environ. 717, 137099.

Tansel, B., 2017. From electronic consumer products to e-wastes: global outlook, waste quantities, recycling challenges. Environ. Int. 98, 35–45.

UNITAR, 2020. The Global E-Waste Monitor 2020 – Quantities, Flows, and the Circular Economy Potential. United Nations Institute for Training and Research, Bonn, Germany.

Wada, O., 2004. What are trace elements? — their deficiency and excess states. J. Jpn. Med. Assoc. 47, 351–358.

Wang, C., Hong, S., Guan, X., Xiao, Y., Fu, M., Meng, H., et al., 2023. Associations between multiple metals exposure and biological aging: evidence from the Dongfeng-Tongji cohort. Sci. Total Environ. 861, 160596.
Zeng, H.L., Li, H., Lu, J., Guan, Q., Cheng, L., 2019. Assessment of 12 metals and metalloids in blood of general populations living in wuhan of China by ICP-ms. Biol. Trace Elem. Res. 189, 344–353.
Zhang, Y., Xu, X., Chen, A., Davuljigari, C.B., Zheng, X., Kim, S.S., et al., 2018. Maternal urinary cadmium levels during pregnancy associated with risk of sex-dependent birth outcomes from an e-waste pollution site in China. Reprod. Toxicol. 75, 49–55.
Zumbado, M., Luzardo, O.P., Rodriguez-Hernandez, A., Boada, L.D., Henriquez-Hernandez, L.A., 2019. Differential exposure to 33 toxic elements through cigarette smoking, based on the type of tobacco and rolling paper used. Environ. Res. 169, 368–376.