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☆

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ABSTRACT

International Public Health authorities recommend biomonitoring studies to assess the exposure to chemicals in the general population. The aim of the present study was to analyze the blood concentrations of a total 360 pollutants, including 230 pesticides in current or recent use, 59 persistent organochlorine pollutants (POPs), 11 anticoagulant rodenticides and 60 pharmaceutical active compounds (PhACs), in a cohort of 403 subjects from Cape Verde. The study was performed in the frame of the Pesticide Residues in Vegetables of the Macaronesia project (PERVEMAC-II). A total of 60 out of 360 toxic compounds (16.7%) were detected, at least, in one participant. The three most frequently detected substances were p,p'-DDE (100%), phenanthrene (94.0%) and hexachlobenzene (35.9%). 2-Phenylphenol and imidacloprid were detected in 29.0 and 14.4% of the population. The three substances with the highest serum concentrations were PhACs: naproxen (249.1 ng/mL), metroni-dazole (115.6 ng/mL) and acetaminophen (25.2 ng/mL). Median blood concentration of p,p'-DDE, HCB and phenanthrene were 1.87, 0.08 and 0.36 ng/mL. Blood concentrations of POPs were influenced by age, although both gender and body mass index may exert an influence in the presence of these substances. Lifestyle has an effect on the concentration of these substances, especially in terms of dietary habits. Both the frequency of detection and the concentration of the studied substances are similar to those of other biomonitored populations. This is the first biomonitoring study carried out in Cape Verde. Our results may be useful for the implementation of public health measures by the competent authorities.

1. Introduction

Over the last 70 years, the development of new - and abusive - pro-duction methods has brought with it the increased use of chemicals to improve production levels and economic benefits. Nowadays, it is esti-mated that more than 3.5 million tons of pesticides are consumed worldwide (Zhang, 2018). Although developed countries have legisla-tion regulating the use of these substances, globalization and economic growth in developing countries means that more and more chemicals are being used each year to control crop pests and minimize the impact of food shortages (Sharma and Kumar, 2019). China, USA, Argentina, Thailand, Brazil, Italy, France, Canada, Japan and India are the top ten

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pesticide consuming countries in the world (De and Bose, 2014). How-ever, given the lack of official and reliable data in many developing countries, the influence of these countries in the overall picture may have a greater specific weight than expected (De and Bose, 2014).

Historically, the availability of dichlorodiphenyltrichloroethane (DDT) in 1945 opened a new era of pest control. Following this, different substances came onto the market, all of them effective, inexpensive and enormously popular. These include cyclodienes (endrin, aldrin and dieldrin), hexachlorobencene (HCB) or hexachlorocyclohexane (α-, β-, δ- and γ-isomers), among others (O¨ zkara et al., 2016). All these substances form part of what are known as persistent organic pollutants (POPs), which are currently banned or restricted because of the damage they cause to the environment and to the health of living beings (Ritter and Solomon, 1995). By definition, they are persistent substances that do not degrade in the environment, are lipophilic - so they remain stored in the fatty tissue of living organisms for years - and many of them have es-trogenic activity (Ritter and Solomon, 1995), which makes them asso-ciated with numerous complex diseases such as diabetes, cancer or obesity. As a consequence of its chemical nature, POP residues were observed to be present in unexpected places; they bioaccumulate in the food chain and have a grasshopper effect – tha capacity to move across vast distances from the southern hemisphere to the northern hemisphere through volatilization and deposition -, so residues of these substances can be found in places on the planet where they have never been used before (Simonich and Hites, 1995). Among POPs are other substances apart of pesticides. This is the case of polychlorinated biphenyls (PCBs) and other industrial by-products. All of them were included in the Stockholm Convention for elimination (annex A), restriction (annex B) or reduction of their unintentional releases (annex C), decades ago (UNEP, 2004; UNEP, 2008). However, even today these substances are detected and quantified in human beings and other species (Sonne and Letcher, 2017; Porta and Pumarega, 2021), and are often found in soil or plants (Acosta-Dacal and Rial-Berriel, 2021).

Non-persistent pesticides are currently used, although even some of these are banned, and their use is limited to specific types of crops and indicated for the control of specific pests. Although they are less harmful to the environment, a non-persistent compound may be acutely toxic rather than exhibiting the chronic toxicity reported for many persistent compounds. Despite its apparent safety to the environment, there is an abusive use of this type of chemical compounds, which leads to the presence of residues of phytosanitary products – both in variety and quantity - that are incorporated into the food chain and have conse-quences for living beings (Silva and Mol, 2019). This is the case of the Canary Islands, considered the region in Spain with the highest con-sumption of phytosanitary products per hectare of crop, and one of the regions with the highest consumption at European level (Alonso--Gonza´lez and Parga-Dans, 2021). Among the group of pesticides currently or recently used are herbicides, fungicides, insecticides, acaricides, anthelmintics, molluscicides, and rodenticides; whose pres-ence is detected in the environment on a continuous basis, with the resulting consequences (Acosta-Dacal and Rial-Berriel, 2021; Rial-Ber-riel and Acosta-Dacal, 2021).

The problem of environmental pollution and the consequences on living beings goes far beyond the use and abuse of pesticides. Large amounts of industrially derived chemicals have been released into the environment since the beginning of the 20th century. Thus, potentially harmful pharmaceuticals - for human or veterinary prescription use -, or UV filters form a group of substances called emerging pollutants (Kan-wischer et al., 2021). Although they are not persistent, the daily use of these substances means that they are constantly present in the envi-ronment; they are not subject to environmental legislation and are responsible for polluting the

environment, food, fauna and the different human populations (Henriquez-Hernandez and Montero, 2017; Cama-cho and Herrera, 2019; Luzardo and Badea, 2019; Acosta-Dacal and Rial-Berriel, 2021).

As a consequence of the above, people are daily and inadvertently exposed to several types of pollutants. Biomonitoring of human pop-ulations is a key point to evaluate the effectiveness of policies aimed to diminish the impact of pollutants in human health. Various public ini-tiatives attest to the importance of this public health issue. This is the case of the European Human Biomonitoring Initiative (HMB4EU), a project that joints the effort of 30 countries, the European Environment Agency, and the European Commission (HMB4EU, 2017). In that sense, the present study was carried out in the frame of the PERVEMAC II study, a European project aimed to promote food safety and a more responsible agriculture in the archipelagos of the Macaronesian Region – Azores, Canary Islands, Madeira and Cape Verde -, in order to ensure the safety and health of farmers and consumers and to minimize the risk of environmental pollution (PERVEMAC-II, 2017). In all of these regions there is an important agricultural and livestock sector dedicated to do-mestic consumption and export (Corral and Serruto-Díaz, 2017). The drought and arid climate make farming in Cape Verde particularly difficult. Even so, 11.2% of the territory is utilized for agricultural purposes, mainly gardening and extensive cultivation of sugar cane, bananas and mango (Monteiro and Fortes, 2020). The orographic and climatic similarities of the Macaronesian regions presuppose a signifi-cant use of chemicals for pest control (Alonso-Gonz´alez and Parga-Dans, 2021). However, only the population from Canary Islands has been biomonitored about environmental pollutants, and it is considered one of the best-studied regions on the planet in this respect (Zumbado and Goethals, 2005; Luzardo and Goethals, 2006; Henriquez-Hernandez and Luzardo, 2011; Henriquez-Hernandez and Ortiz-Andrelluchi, 2021).

The aim of the present study was to analyze the blood levels of 230 pesticides in current or recent use (210 parental compounds and 20 metabolites), 59 POPs (18 PCBs, 17 organochlorine pesticies (OCPs), 16 PAHs and 8 BDEs), 11 anticoagulant rodenticides (ARs) and 60 phar-maceutical active compounds (PhACs), in a cohort of subjects from Cape Verde. A total of 360 toxic chemicals were analyzed in a validated multi-residue method (Rial-Berriel and Acosta-Dacal, 2020a; Rial-Berriel and Acosta-Dacal, 2020b; Rial-Berriel and Acosta-Dacal, 2021). This is the first

biomonitoring study in the Cape Verde archipielago.

2. Material and methods

2.1. *Study population*

The PERVEMAC study developed a residue monitoring program in vegetables with the aim of identifying health hazards and conducting an intake risk assessment. Based on its results and conclusions, the PER-VEMAC II study has emerged. It is a Research and Development Coop-eration 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 geographical area of Macaronesia (PERVEMAC-II, 2017). Among its primary objectives was to conduct a dietary habits survey, an intake risk assessment and the promotion of a healthy diet. Within this framework, a specific blood sample collection program was designed to carry out a biomonitoring study, restricted to the territory of Cape Verde.

A total of 403 subjects were included in this part of the study. Due to the complexity of the archipelago, made up of ten large islands and five smaller islands, all participants came from Santiago Island, which is the most inhabited, which means that the sample is representative of the total population of the island. Blood for chemical analysis was available in 403 participants (Table 1), which make up the total number of sub-jects analyzed in the present report. Sampling was done between August 09, 2019 and September 11, 2019. A total of 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.

The average age of participants was 28.7 years and 58.6% of all

Table 1
Sociodemographic characteristics of study participants.

Total N (%)	Males N (%)	Females N (%)	*P-value*
All participants	403 (100)	167 (41.4)	236 (58.6)
Age (years)			
Mean ± SD	28.7 ± 17.7	26.2 ± 17.2	30.6 ± 17.8	0.013[a]
Mean	25.0	19.0	29.0	0.012[b]
<18	154 (38.2)	74 (44.3)	80 (33.9)	0.029[c]
18–30	86 (21.3)	40 (24.0)	46 (19.5)	
31–45	75 (18.6)	24 (14.4)	51 (21.6)	
>45	88 (21.8)	29 (17.4)	59 (25.0)	
BMI (kg/m^2)				
Mean ± SD	22.2 ± 5.5	20.3 ± 4.3	23.5 ± 5.9	<0.001[a]
Mean	21.2	20.3	22.9	<0.001[b]
<18.5	118 (29.5)	63 (38.2)	55 (23.4)	<0.001[c]
18.5–24.9	166 (41.5)	78 (47.3)	88 (37.4)	
25–29.9	73 (18.3)	20 (12.1)	53 (22.6)	
>29.9	43 (10.8)	4 (2.4)	39 (16.6)	
Habitat				
Urban	266 (66.0)	110 (65.9)	156 (66.1)	0.522[c]
Rural	137 (34.0)	57 (34.1)	80 (33.9)	
Civil status[d]				
Single	195 (59.6)	83 (63.4)	112 (57.1)	0.260[c]
Married	99 (30.3)	40 (30.5)	59 (30.1)	
Divorced	22 (6.7)	5 (3.8)	17 (8.7)	
Widowed	11 (3.4)	3 (2.3)	8 (4.1)	
Educational level[e]				
Primary schooling	166 (46.1)	80 (51.6)	86 (42.0)	0.114[c]
Secondary schooling	153 (42.5)	62 (40.0)	91 (44.4)	
Higher education	41 (11.4)	13 (8.4)	28 (13.7)	
Employment status[f]				
Employed	120 (42.7)	55 (48.2)	65 (38.9)	0.321[c]
Unemployed	89 (31.7)	30 (26.3)	59 (35.3)	
Retired	57 (20.3)	24 (21.1)	33 (19.8)	

participants were women. Mean BMI of the total series was 22.2 kg/m^2. About 11% were obese (BMI >29.9 kg/m^2), 66.0% lived in an urban habitat, 42.5% had completed at least secondary schooling (2nd. stage), and 20.3% were retired. Occupation for 16.4% of the participants was related with the primary sector. Age and BMI were significantly higher among women (P = 0.012 and P < 0.001, respectively; Table 1).

2.2. *Sample preparation*

The extraction protocol is based on a QuEChERS method previously published (Anastassiades and Lehotay, 2003) and subsequently modified and validated for the simultaneous extraction of 360 chemicals (Rial-Berriel and Acosta-Dacal, 2020b). Whole blood samples (250 μL) were placed into a 2 mL Eppendorf tube. The fortification of blank matrix samples was done using different volumes of intermediate fortification solutions for each calibration point (12-point calibration curve). The mixture of procedural internal standards (P-ISs) included compounds used for Gas Chromatography (acenaphthene-d10, chlorpyrifos-d10, chrysene-d12, diazinon-d10, PCB 200, and phenanthrene-d10) and Liquid Chromatography (atrazine-d5, carbendazim-d3, cyromazine-d4, diazinon-d10, linuron-d3, and pirimicarb-d6). Ten microliters of the mixture of P-ISs were added to all samples and calibration points to yield a final concentration of 1 ng/mL.

The samples were vortex for 30 s (s) and placed in an orbital shaker for 1 h. After that, 500 μL of acidified acetonitrile (1% formic acid (FA)) were added, and the tubes were well mixed for 30 s. Then, the tubes were placed in an ultrasonic bath (Selecta, Barcelona, Spain) at room temperature for 20 min. Anhydrous magnesium sulfate (150 mg) and sodium acetate (37.5 mg) were then added, mixed using vortex for 30 s, and vigorous-manually shaken for 1 min. Finally, the samples were centrifuged at 4200 rpm during 5 min in an ALC 4214 microcentrifuge (A.L.C. International SRL, Cologno Monzese, Italy). The supernatant (approximately 400 μl) was collected with a 1-mL syringe, passed through a 0.2 μm Chromafil PET-20/15 MS syringe filter (polyester, HPLC certified, Macherey-Nagel, Düren, Germany), and placed in an inserted chromatographic amber vial. This methology allows the detection and quantification of 360 analytes using two complementary chromatographic analyses: a liquid chromatography analysis coupled to triple quadrupole mass spectrometry (LC-MS/MS) and a gas chroma-

Others (housewife and student)	15 (5.3)	5 (4.4)	10 (6.0)	
Occupation[g]				
Primary sector	48 (16.4)	18 (15.5)	30 (16.9)	<0.001[c]
Secondary sector	73 (24.9)	14 (12.1)	59 (33.3)	
Tertiary sector	172 (58.7)	84 (72.4)	88 (49.7)	
Income[h]				
Low (<13,000 CVE)	84 (23.8)	28 (18.9)	56 (27.3)	0.117[c]
Medium (13,000–33,000 CVE)	150 (42.5)	73 (49.3)	87 (42.4)	
High (>33,000 CVE)	119 (33.7)	57 (38.5)	62 (30.2)	

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.
[e] Missing data = 43. Percentage calculated with the total valid data.
[f] Missing data = 122. Percentage calculated with the total valid data.
[g] Missing data = 43. Percentage calculated with the total valid data.
[h] Missing data = 50. Percentage calculated with the total valid data. Data for segmentation were obtained from the Ministry of Foreign Affairs, European Union and Cooperation (Gobierno de Espan˜a). Available at: http://www.exteriores.gob.es/Embajadas/PRAIA/es/VivirEnCaboVerde/Paginas/Trabajar.aspx.

tography coupled to triple quadrupole mass spectrometry (GC–MS/MS). The vial obtained after the centrifugation was used directly in this two consecutive analyses without the need for further clean-up, dilution or solvent change steps (Rial-Berriel and Acosta-Dacal, 2020a; Rial-Berriel and Acosta-Dacal, 2020b).

2.3. Instrumental analysis

A total of 126 out of 360 analytes were detected and quantified using this methodology. For that, an Agilent 7890 B gas chromatographer

2.3.1. GC–MS/MS

equipped with an Agilent 7693 automatic sampler and tandem coupled to an Agilent 7010 mass spectrometer (Agilent Technologies, Palo Alto, USA) was used. The injection volume was 1.5 μL. The chromatographic separations were performed using two fused silica ultra-inert capillary columns Agilent J&W HP-5MS (crosslinked 5% phenyl-methyl-polysiloxane, Agilent Technologies), each with a length of 15 m, 0.25 mm i. d, and a film thickness of 0.25 μm. Helium (99.999%) was set in constant flow mode as carrier gas, and nitrogen 6.0 (99,9999% purity, Linde, Dublin, Ireland) was used as collision gas. The oven temperature program was programmed as follows: (a) 80 °C held for 1.8 min; (b) increase to 170 °C at a rate of 40 °C/min; (c) increase to 310 °C at a rate of 10 °C/min to 310 °C; (d) 3 min hold time at 310 °C. The final run time was 21.05 min. The mass spectrometer was operated in the multiple reaction monitoring (MRM) mode, using 24-time segments. The opti-mized operating conditions of the mass spectrometer analyses were previously detailed (Rial-Berriel and Acosta-Dacal, 2020b).

2.3.2. LC–MS/MS

A total of 234 out of 360 analytes were detected and quantified using this methodology. An Agilent 1290 UHPLC tandem coupled to an Agilent 6460 mass spectrometer (Agilent Technologies, Palo Alto, USA) was used. The chromatographic separations were performed using an InfinityLab Poroshell 120 (2.1 mm × 100 mm, 2.7 µm). The mobile phase A consisted on 2 mM ammonium acetate and 0.1% FA in ultrapure water. The mobile phase B consisted on 2 mM ammonium acetate in MeOH. The flow rate was set at 0.4 mL/min. The injection volume was 8 µL. The column oven temperature was set at 50 °C. Total run time was 18 min. The mass spectrometer was operated in the dynamic multiple reaction monitoring (dMRM) mode. Nitrogen provided by Zefiro 40 nitrogen generator (F-DGSi, Evry, France) was used as drying and des-olvation gas. Nitrogen 6.0 (99.9999% purity, Linde, Dublin, Ireland) was used as collision gas. The optimized operating conditions of the mass spectrometer analyses were previously detailed (Rial-Berriel and Acosta-Dacal, 2020b).

2.4. *Quality of analyses and quality control (QA/QC)*

The limits of detection (LOD) were determined as three times the standard deviation of the concentrations of ten blanks of blood matrix. The limits of quantification (LOQ) were determined as the lowest con-centration tested in recovery experiments that meets satisfactory accu-racy (recoveries in the range 70–120%) and precision (RSD <20%), according to the SANTE/12682/2019 guidance definition (EC, 2019). QA/QC were made according to previous publications (Henri-quez-Hernandez and Ortiz-Andrelluchi, 2021). All determinations were performed in triplicate. Additionally, a reagent blank containing cyclohexane and an internal laboratory QC sample - consisting of blank serum (Fetal Bovine Serum, Lonza, Verviers, Belgium) spiked at 2.5 ng/mL of each of the analytes - were included every 30 vials. The QC was processed using the same method as the whole blood samples. The re-sults were considered to be acceptable when the percentages of re-coveries were in the range 70–120% and the precision was RSD <20%, according to the recommendations of the European Union SANTE 12682/2019 (EC, 2019).

2.5. *Statistical analysis*

Analyses were conducted using PASW Statistics v 19.0 (SPSS Inc, Chicago, IL, USA). Given that many substances were detected in a low percentage of the population, the main statistical analyses were made using the sum of compounds according to chemical groups.

Kruskal–Wallis' test and Mann–Whitney's *U* test were used to assess differences in concentrations of pollutants by sociodemographic char-acteristics of participants. The Kolmogorov–Smirnov test for normality was used to check the distributions of sociodemographic variables and chemicals. Student's t-test was used to examine the relationships be-tween normally distributed variables; chi-square test was used to examine the relationships between categorical variables. The results were reported as medians and interquartile ranges. Concentrations below the LOQ but above the LOD were assigned a random value be-tween these two limits (Acosta-Dacal and Hernandez-Marrero, 2022). The level of statistical significance was set at 0.05 and all tests were two tailed.

3. Results and discusion

A total of 360 toxic substances were determined in whole blood from 403 subjects from Cape Verde, in the context of the PERVEMAC-II study. Mean age of the whole series was 28.7 ± 17.7 years old, and mean BMI was 22.2 ± 5.5 kg/m^2, which means a young population with normal weight (Table 1). Age and BMI are classic variables positive associated to body burden of POPs (Henriquez-Hernandez and Ortiz-Andrelluchi, 2021; Porta and Pumarega, 2021); thus, the influence of these

variables on POP concentrations can be better studied given the char-acteristics of the sample itself. The majority of the participants were female (58.6 vs. 41.4%), significantly older and with higher BMI than males (Table 1). No significant differences were observed by gender in relation to the habitat, civil status, educational level, employment status and income. Most of the subjects included in the study are engaged in the tertiary sector, although this proportion is significantly lower among women. In absolute numbers, the study has a higher number of subjects than other studies of similar design (Porta and Lopez, 2012; Chovancova and Drobna, 2014; Luzardo and Badea, 2019; Henriquez-Hernandez and Ortiz-Andrelluchi, 2021). Since all subjects came from the same geographical area, the present study can be considered as representative of the entire population.

To our knowledge, there is no other biomonitoring study that in-cludes such a large number of substances (n = 360), including POPs (PCBs, OCPs, PAHs and BDEs), anticoagulant rodenticides and phar-maceutical active compounds. A total of 60 out of 360 toxiccompounds (16.7%) were detected, at least, in one participant (Additional File 1). By groups, 7 out of 16 PAHs (43.7%), 4 out of 17 OCs (23.5%), 12 out of 60

PhACs (20%), 3 out of 18 PCBs (16.7%) and 34 out of 230 pesticides (14.8%) were detected. The three most frequently detected substances were p,p'-DDE (100%), phenanthrene (94.0%) and hexachlobenzene (35.9%), which are all considered POPs. These percentages are similar to those reported in other population-based studies of similar design. In that sense, p,p'-DDE and hexachlobenzene (HCB) were detected and quantified in ≥95% of a series of 175 elderly subjects (Henri-quez-Hernandez and Ortiz-Andrelluchi, 2021); p,p'-DDE, HCB and phenanthrene were detected in 100, 53.7 and 98.3% of 121 Romanian subjects (mean age = 27.8 years) (Luzardo and Badea, 2019); p,p'-DDE and HCB were detected in ≥95% of a series of 231 and 240 subjects from Catalonia studied in 2006 and 2016 (mean age ≈ 50 years). Percentage of detection for phenanthrene was ≥75% (Porta and Pumarega, 2021). Despite the similarities, the comparison between studies cannot be straightforward, mainly due to differences in the distribution of vari-ables directly associated with POP burden, such as age and BMI (apart from others such as gender).

Since we did not have total lipids to correct the POPs values, com-parison with other studies is more difficult. Moreover, since different formulas can be used to calculate total lipids, the comparison becomes even more difficult (Akins and Waldrep, 1989; Phillips and Pirkle, 1989; Grimvall and Rylander, 1997; Covaci and Voorspoels, 2006; Rylander and Nilsson-Ehle, 2006). Lipophilic compounds are often analyzed in serum or plasma, while whole blood was used in the present study. Thus, the results may have been impacted because of the choice of whole blood for analysis (Batterman and Chernyak, 2016), and the comparison with other studies must be taken with caution. As shown in Additional File 1, median blood concentration of p,p'-DDE, HCB and phenanthrene were 1.87, 0.08 and 0.36 ng/mL in the present series. To compare our results with those reported in other populations, we focused on studies that shared the same units of measurement. Thus, these concentrations were 2.1, 0.2 and 0.9 ng/mL among Romanian subjects (Luzardo and Badea, 2019). Covaci et al. reported, twenty years ago, a concentration of 0.17 μg/L of HCB in a series of 20 subjects (1–68 years) from Romania (Covaci and Hura, 2001); and Hura reported mean levels of 0.5 and 0.2 μg/L of p,p'-DDE in the serum obtained from young girls and boys (Hura and Leanca, 1999). Median value of p,p'-DDE in a representative series of 428 subjects from Canary Islands (Spain) was 1.02 ng/mL (Henri-quez-Hernandez and Luzardo, 2014). Taken together, these results show the inherent persistence of this type of compounds. While it is true that concentrations have decreased over time, detection frequencies remain similar (Luzardo and Badea, 2019; Henriquez-Hernandez and Ortiz-Andrelluchi, 2021; Porta and Pumarega, 2021).

2-Phenylphenol and imidacloprid were detected in 29.0 and 14.4% of the population (Additional File 1). Neonicotinoid insecticides are extensively applied in global agricultural production for pest control, and have been detected in greater proportion than that observed in our

study. Thus, imidacloprid was detected in 95% of a series of 80 elderly subjects from South China (Zhang and Zhu, 2022), and it was detected in 70.7% of a series of 75 subjects from Kumasi, a cosmopolitan city in Ghana (Nimako and Ikenaka, 2021). Nonetheless, frequency of detection was 4.3% in a representative sample of the U.S. general population (Ospina and Wong, 2019). These differences are probably associated with different agricultural production patterns and trends in the use of different pesticides depending on the geographical region under study. Mean blood concentration of imidacloprid was 0.18 ng/mL; a lower or similar amount than those reported in other studies: 0.76 ng/mL in South China (Zhang and Zhu, 2022), 0.15 ng/mL in Ghana (Nimako and Ikenaka, 2021) and was < LOD in the U.S. general population (Ospina and Wong, 2019). About 2-Phenylphenol (a fungicide approved in the European Union), studies are scarce and conducted on urine. Frequency of detection among German population is 1% (Tschersich et al., 2021). Production patterns in Germany and Cape Verde may explain these differences, together with the fact that we are comparing results ob-tained in two different matrices (whole blood vs. urine).

Finally, it has drawn our attention that the three substances with the highest blood concentrations were PhACs (Additional File 1): naproxen

Table 2

Plasma concentration of chemicals considered a sum of groups, in the study population and by sociodemographic characteristics. Frequency of detection (N, (%)) was included. The concentrations are expressed in median (percentile 25—percentile75) ng/mL.

	Σ pesticides		Σ pharmaceuticals		Σ OCPs		Σ PAHs		Σ PCBs	
All participants	189	0.25 (0.2–0.6)	57 (14.1)	9.48 (0.9–57.2)	403 (100)	1.90 (0.8–4.8)	379 (94.0)	0.43 (0.2–0.9)	42 (10.4)	0.05 (0.02–0.1)
(46.9)										
Gender										
Male	84	0.24 (0.2–0.6)	19 (11.4)	6.76 (0.4–22.7)	167 (100)	2.11 (0.9–4.7)	157 (94.0)	0.35 (0.2–0.8)*	24 (14.4)	0.05 (0.02–0.1)
(50.3)										
Female	105	0.25 (0.2–0.6)	38 (16.1)	23.0 (0.9–123.5)	236 (100)	1.72 (0.8–5.1)	222 (94.1)	0.46 (0.2–0.9)	18 (7.6)	0.03 (0.01–0.1)
(44.5)										
Age (years)										
<18	80	0.30 (0.2–0.6)*	10 (6.5)	35.4 (17.6–210.8)	154 (100)	1.60 (0.7–2.9)***	144 (93.5)	0.40 (0.2–0.9)	1 (0.6)	0.01
(51.9)										
18–30	33	0.17 (0.1–0.3)	13 (15.1)	7.26 (0.4–24.0)	86 (100)	1.17 (0.7–3.0)	79 (91.9)	0.52 (0.2–1.1)	1 (1.2)	0.003
(38.4)										
31–45	28	0.28 (0.2–0.5)	12 (16.0)	2.31 (0.5–18.9)	75 (100)	1.74 (0.8–5.1)	69 (92.0)	0.35 (0.2–0.9)	9 (12.0)	0.02 (0.01–0.05)
(37.3)										
>45	48	0.35 (0.2–0.8)	22 (25.0)	25.7 (0.9–213.6)	88 (100)	5.91 (2.6–10.2)	87 (98.9)	0.46 (0.2–0.8)	31 (35.2)	0.05 (0.02–0.1)
(54.5)										
BMI (kg/m^2)[a]										
<24.9	57	0.21 (0.1–0.6)	28 (20.6)	8.37 (0.5–61.6)	136 (100)	1.90 (0.8–5.9)*	127 (93.4)	0.47 (0.2–1.0)	20 (14.7)	0.05 (0.01–0.1)
(41.9)										
≥30	52	0.28 (0.2–0.6)	19 (17.3)	3.27 (0.8–44.8)	110 (100)	3.12 (1.1–6.8)	106 (96.4)	0.40 (0.2–0.8)	21 (19.1)	0.02 (0.02–0.07)
(47.3)										
Habitat										
Urban	139	0.25	36	13.41	266	1.76	254	0.42	29	0.05

(52.3)		(0.2–0.6)	(13.5)	(0.9–38.4)	(100)	(0.8–4.1)*	(95.5)	(0.2–0.9)	(10.9)	(0.02–0.1)
Rural	50	0.25	21	6.76	137	2.30	125	0.45	13	0.05
(36.5)		(0.2–0.5)	(15.3)	(0.8–160.5)	(100)	(1.0–5.8)	(91.2)	(0.2–1.0)	(9.5)	(0.01–0.1)
Educational level										
Primary	84	0.28	22	6.19	166	2.17	159	0.41	21	0.05
schooling		(0.2–0.7)	(13.3)	(0.6–26.7)	(100)	(0.9–5.2)***	(95.8)	(0.2–0.9)	(12.7)	(0.02–0.1)
(50.6)										
Secundary	68	0.21	19	7.26	153	1.26	140	0.44	5 (3.3)	0.02
schooling		(0.1–0.5)	(12.4)	(0.8–93.2)	(100)	(0.6–2.6)	(91.5)	(0.2–1.0)		(0.01–0.03)
(44.4)										
Higher schoolig		0.20	8	2.98	41	3.06	38	0.44	5	0.05
18										
(43.9)		(0.1–1.0)	(19.5)	(0.2–89.0)	(100)	(1.2–4.7)	(92.7)	(0.2–0.7)	(12.2)	(0.01–0.1)
Employment status[a]										
Employed	60	0.23	23	4.94	120	2.80	111	0.42	24	0.04
(50.0)		(0.2–0.6)	(19.2)	(0.4–69.5)	(100)	(1.0–6.1)*	(92.5)	(0.2–0.8)	(20.0)	(0.01–0.07)
Unemployed	16	0.45	13	4.78	63	1.28	59	0.55	2 (3.2)	0.29
(25.4)		(0.2–1.1)	(20.6)	(0.4–35.2)	(100)	(0.8–3.8)	(93.7)	(0.2–1.1)		(0.2–0.3)
Others[b]	4	0.34	1 (7.7)	6.76	13	4.53	13	0.35	6	0.04
(30.8)										
		(0.1–2.0)			(100)	(1.6–15.3)	(100)	(0.2–0.6)	(46.2)	(0.01–0.05)
Retired	24	0.20	7	22.7	41	1.81	40	0.51	5	0.07
(58.5)		(0.2–0.5)	(17.1)	(3.1–195.1)	(100)	(0.7–5.4)	(97.6)	(0.3–1.0)	(12.2)	(0.01–0.1)

*p < 0.05 (Mann Whitney *U* test or Kruskal-Wallis test), **p < 0.01 (Mann Whitney *U* test or Kruskal-Wallis test), ***p < 0.001 (Mann Whitney *U* test or Kruskal-Wallis test).

Σ pesticides = Acrinathrin + Atrazine + Azoxystrobin + Benalaxyl + Carbofuran + Cyflufenamid + Dimethoate + Dodine + Fenpropidin + Fenpropimorph +
Imidacloprid + Iprovalicarb + Mepiquat + Phosmet + Pirimiphos.
Methyl + Propamocarb + Propoxur + Tebufenpyrad + Thiabendazole + Thiacloprid + 2-Phenylphenol + Bifenthrin + Boscalid + Bromopropylate + Bromuconazole
(I) + Fenarimol + Fenitrothion + Fludioxonil +.
Fluquinconazole + Flutriafol + Nuarimol + Penconazol + Prothioconazol + Tetraconazole (34 substances).

Σ pharmace
Romatic hydrocarbons (PAHs) = acenaphthene + anthracene + fluoranthene + fluorene + naphthalene + phenanthrene + pyrene (7 substances).

Σ polychlorinuticals = acetaminophen + albendazole + cloxacillin + diclofenac + difloxacin + levamisole + metronidazole + naproxen + phenylbutazone + sul-fametoxazole + sulfaquinoxaline + trimethoprim (12 substances).

Σ organochlorine pesticides (OCP) = hexachlorobenzene + p,p'-DDE + p,p'-DDD + p,p'-DDT (4 substances).

Σ polycyclic aated biphenyls (PCBs) = PCB-138 + PCB-153 + PCB-180 (3 substances).

[a] Analysis made in the group of subjects older than 18 years.

[b] This group included houesewifes and students together due to the low number of subjects in these groups (n = 8 and 7, respectively).

(median = 249.1 ng/mL, detected in 1% of participants), metronidazole (median = 115.6 ng/mL, detected in 2% of participants) and acetaminophen (median = 25.2 ng/mL, detected in 5% of participants). By their nature, this PhACs are widely used and can be purchased without a prescription, which makes it expected to find high levels of these sub-stances: 2 anti-inflammatory (naproxen and acetaminophen) and 1 antibiotic (metronidazole). In any case, the concentrations detected are below the doses prescribed for therapeutic use (Oladosu and Tu, 2020) and the reported concentrations have low detection frequencies in the population, so these results should be taken with great caution.

3.1. *Influence of sociodemographic variables on the concentration of analytes*

In order to provide as much information with as much support as possible, we work with the sum of the concentration of groups of com-pounds rather than individual analytes. Thus, five different groups of substance were analyzed separately: Σ pesticides (34 substances), Σ PhACs (12 substances), Σ OCPs (4 substances), Σ PAHs (7 substances) and Σ PCBs (3 substances). The influence of gender, age, BMI, habitat, education level and employment status in relation to the concentration of the different groups of substances in the blood of the series was analyzed (Table 2).

None of the demographic variables taken into account seemed to influence blood levels of PhACs or PCBs, although in the latter case, there is a clear - and expected - trend towards higher levels of these compounds with increasing age. PCBs are POPs and there is sufficient scientific evidence to support the hypothesis that the older the age, the higher the levels of PCBs (Henriquez-Hernandez and Luzardo, 2011). We did not observe this association in the present series. Even more, when age was included in the analysis as a continuous variable, no significant association was observed in relation with the concentration of PCBs. This result is probably due to the low frequency of detection of PCBs in the sample, a result that is directly related to the level of industrialization (Henriquez-Hernandez and Luzardo, 2016). We observed that age was a variable associated with the concentration of pesticides in the blood of the analyzed individuals (Table 2). Apparently, the older the age, the higher the residue levels ($p = 0.045$), with the exception of the youngest age group, whose values were similar to the subgroup of individuals older than 45 years. When age was analyzed as a continuous variable, no significant relationship with blood pesticide concentration was observed (Data not shown), so the result should be taken with caution. However, 42.4% of the individuals under 18 years of age had no PCB residues. This percentage was 15.8% among individuals over 45 years of age. In contrast, no minors had 2 or more PCB residues in their blood while 81% of individuals over 45 years of age had >1 detectable and quantifiable PCB residue in their blood ($P < 0.0001$; Table 3). This trend supports the general idea regarding the role of age in relation to PCB levels: the older the age, the higher the concentration levels and the higher the number of different residues.

The concentration of OCPs was modified by age (older age, higher
levels), BMI (higher BMI, higher levels), as well as by habitat, education level and employment status (Table 2). The role of age and BMI is well described in the literature (Zumbado and Goethals, 2005;

Table 3
Number of compounds detected by group, according to gender, age and body mass index (BMI).

Number and percentage were included. Chi-square test (two-tailed) was used.

Gender					Age (years)					BMI (kg/m^2)[a]			
	Male	Female	Total	*P-value*	<18	18–30	31–45	>45	Total	*P-value*	<24.9	≥30	Total	*P-value*
Pesticides				0.673						0.169				0.794

0	83 (38.8)	131 (61.2)	214		74 (34.6)	53 (24.8)	47 (22.0)	40 (18.7)	214		79 (57.7)	58 (42.3)	137	
1	57 (44.2)	72 (55.8)	129		59 (45.7)	24 (18.6)	16 (12.4)	30 (23.3)	129		38 (54.3)	32 (45.7)	70	
2	21 (46.7)	24 (53.3)	45		16 (35.6)	6 (13.3)	9 (20.0)	14 (31.1)	45		14 (48.3)	15 (51.7)	29	
>2	6 (40.0)	9 (60.0)	15		5 (33.3)	3 (20.0)	3 (20.0)	4 (26.7)	15		5 (50.0)	5 (50.0)	10	
Pharmaceuticals				0.224						0.003				0.751
0	148 (42.8)	198 (57.2)	346		144 (41.6)	73 (21.1)	63 (18.2)	66 (19.1)	346		108 (54.3)	91 (45.7)	199	
1	18 (36.0)	32 (64.0)	50		9 (18.0)	13 (26.0)	10 (20.0)	18 (36.6)	50		24 (58.5)	17 (41.5)	41	
>1	1 (14.3)	6 (85.7)	7		1 (14.3)	0 (0)	2 (28.6)	4 (57.1)	7		4 (66.6)	2 (33.4)	6	
OCPs				0.001						<0.0001				0.328
1	115 (46.7)	131 (53.3)	246		102 (41.5)	55 (22.4)	48 (19.5)	41 (16.7)	246		81 (57.0)	61 (43.0)	142	
2	51 (36.4)	89 (63.6)	140		51 (36.4)	31 (22.1)	21 (15.0)	37 (26.4)	140		49 (55.7)	39 (44.3)	88	
>2	1 (5.9)	16 (94.1)	17		1 (5.9)	0 (0)	6 (35.3)	10 (58.8)	17		6 (37.5)	10 (62.5)	16	
PAHs				0.986						0.230				0.381
0	10 (41.7)	14 (58.3)	24		10 (41.7)	7 (29.2)	6 (25.0)	1 (4.2)	24		9 (69.2)	4 (30.8)	13	
1	136 (41.6)	191 (58.4)	327		126 (38.5)	65 (19.9)	63 (19.3)	73 (22.3)	327		106 (53.3)	93 (46.7)	199	
>1	21 (40.4)	31 (59.6)	52		18 (34.6)	14 (26.9)	6 (11.5)	14 (26.9)	52		21 (61.8)	13 (38.2)	34	
PCBs				0.076						<0.0001				0.484
0	143 (39.6)	218 (60.4)	361		153 (42.4)	85 (23.5)	66 (18.3)	57 (15.8)	361		116 (56.6)	89 (43.4)	205	
1	11 (52.4)	10 (47.6)	21		1 (4.8)	1 (4.8)	5 (23.8)	14 (66.7)	21		11 (55.0)	9 (45.0)	20	
>1	13 (61.9)	8 (38.1)	21		0 (0)	0 (0)	4 (19.0)	17 (81.0)	21		9 (42.9)	12 (57.1)	21	

[a] Analysis made in the group of subjects older than 18 years (n = 246).

Henriquez-Hernandez and Luzardo, 2011; Henriquez-Hernandez and Ortiz-Andrelluchi, 2021; Porta and Pumarega, 2021), although it is striking to observe these differences in such a young, non-obese popu-lation. As POPs, OCPs are resistant to degradation and liposoluble compounds; this fact makes easy to explain the role of age and BMI on the blood levels of these substances. Age not only affects the residue levels but also the total number of chemicals detected and quantified. Thus, only 5.9% of individuals under 18 had >2 different OCPs in their blood, while this percentage was 58.8% among individuals over 45 years of age ($P < 0.0001$; Table 3). In the present series, age not only influ-enced the number of different PCBs and OCPs detected, but also the number of pharmaceuticals (Fig. 1). In that sense, age is so important that it can be a bias in the interpretation of other results. This is the case for educational level: median age of individuals with primary education was significantly lower than that of those with higher education (23.5 vs. 32 years, $p < 0.0001$; Data not shown), which implies that the hy-pothesis that educational level is related to blood concentrations of POPs should be taken with great caution. Other authors have reported that certain socio-economic variables may influence POPs levels (Porta and Lopez, 2012; Porta and Pumarega, 2021). Among them, gender appears to be a determining factor, with women being more likely to accumulate higher levels of POPs and to have a greater number of different com-pounds (Zumbado and Goethals, 2005; Porta and Lopez, 2012). In the present series, blood levels of OCPs were similar between men and women (Table 2). However, only 5.9% of men had >2 different OCPs residues compared to 94.1% of women ($P = 0.001$; Table 3). The asso-ciation of gender and BMI should always be taken into account, as women tend to have a higher BMI and therefore both variables are a confounding factor. This is the case of the present series, where median BMI was significantly higher among women than men (Table 1).

The scenario becomes more complicated if we introduce other var-
iables such as diet, which is the main route of entry of pollutants into living organisms and which varies in quantity and quality according to the economic level of the individual, something that is also related to the level of education and even the habitat (Zumbado and Goethals, 2005). In our series, OCPs levels were significantly higher among individuals living in an urban habitat (2.30 vs. 1.76 ng/mL), a result that is not conditioned by age or BMI, since the median age and median BMI be-tween the two groups – rural vs. urban - was not significantly different (Data not shown). Similarly, median concentration of OCPs was different according to the type of work performed. A total of 9 different professions were recorded and grouped according to the production sector to which they belonged. Thus, median concentration of OCP were 1.25, 5.92, and 2.16 ng/mL among people working in the primary, secondary and tertiary sectors, respectively ($P < 0.0001$, Data not shown). Differences in concentration must be explained by other factors, and diet may be one of the most important (Almeida-Gonzalez and Luzardo, 2012; Luzardo and Almeida-Gonzalez, 2012; Luzardo and

Rodriguez-Hernandez, 2013; Boada and Sangil, 2014; Hernandez and Boada, 2017; Rodriguez-Hernandez and Camacho, 2017). The PERVE-MAC II project included, among its objectives, a nutritional survey whose data will be analyzed in the near future, with the intention of finding out the role of diet in this specific population.

3.2. *Influence of lifestyle habits on the concentration of analytes*

In the present study, some variables related to lifestyle habits were collected in order to explore the relationship these might have with blood levels of the chemicals under study (Table 4). We observed that people who bought their food in the local market had higher concen-trations of OCPs than those who bought their food in supermarkets (2.82 vs. 1.60 ng/mL, $P < 0.001$). This is a result that is directly related to the habitat in which individuals live. Thus, 81 out of 266 (30.4%) people living in urban habitats acquired foodstuffs in local markets, while 57 out of 136 (41.9%) people living in rural habitats acquired foodstuffs with the same origin ($P = 0.043$, Data not shown). This result indirectly shows the influence of diet, which is more exposed to OCPs in rural areas, as observed in other studies. In that sense, we have shown a different pattern of contamination in two populations from the same geographical area but with completely different lifestyles (Henri-quez-Hernandez and Luzardo, 2016). People living in Morocco – a rural area – had higher median values of OCPs than the residents in the Canaries. The two populations are only 100 km apart, but lifestyle habits condition the pollutant profile of the individuals. The fact that in-dividuals purchasing food in supermarkets have a lower concentration of OCPs may have to do with the presence of food from other regions in the supermarkets, which will therefore have different levels of acquired contaminants. The role of food of animal origin as a variable associated with POPs levels in consumers is well studied (Boada and Sangil, 2014). As these substances are fat-soluble and remain in the soil for a long time, they have been detected and quantified in olive oil (Romanic and Saric, 2011). To our knowledge, there is no study comparing the levels of POPs in different types of oil, so our result should be considered only as in-direct evidence of food contamination, as there are multiple variables that may condition the interpretation of the present result, including the type of food being cooked and the way in which the food is cooked (Perello and Marti-Cid, 2009). While olive oil is usually consumed raw, corn oil is mainly used for frying. It has been published that the highest PAH concentrations were found after frying various foodstuffs (Perello and Marti-Cid, 2009), an observation which is consistent with our re-sults, where we observed that the blood concentration of PAHs was higher among those people using corn oil (0.43 vs. 0.22 ng/mL, $P < 0.05$, Table 4).

Finally, we observed significant differences in blood concentration of pharmaceutical active compounds (PhACs) depending on the source of water. Although the number of individuals is low ($n = 12$), a median of

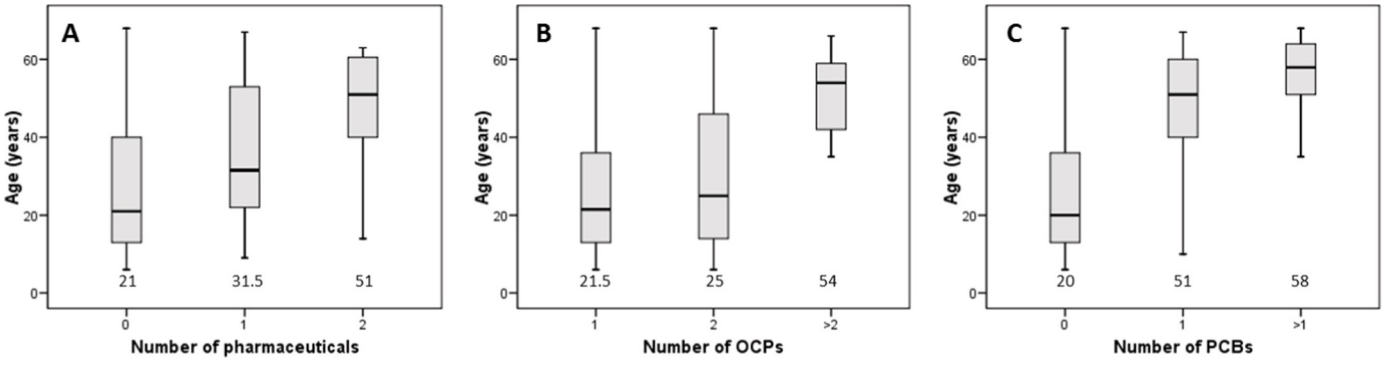

Fig. 1. Box plot showing the effect of age on the number of pharmaceuticals (panel A), organochlorine pestices (panel B) and polychlorinated biphenyls (panel C) detected in the Cape Verdean population.

Median ages were included in each plot. The lines connect the medians, the boxes cover the 25th to 75th percentiles, and the minimal and maximal values are shown by the ends of the bars.

Table 4
Plasma concentration of chemicals considered a sum of groups by lifestyle habits. Frequency of detection (N, (%)) was included. The concentrations are expressed in median (percentile 25—percentile75) ng/mL.

	Σ pesticides		Σ pharmaceuticals		Σ OCPs	Σ PAHs		Σ PCBs		
Origin of foodstuffs										
Supermarket	114 (51.6)	0.23 (0.2–0.5)	30 (13.6)	4.97 (0.9–43.4)	221 (100)	1.60 (0.8–3.6) ***	211 (95.5)	0.38 (0.2–0.8)	27 (12.2)	0.03 (0.01–0.1)
Local market	51 (37.0)	0.30 (0.2–1.1)	18 (13.0)	30.9 (1.2–131.9)	138 (100)	2.82 (1.1–6.3)	124 (89.9)	0.46 (0.2–1.1)	11 (8.0)	0.06 (0.02–0.2)
Others[a]	24 (55.8)	0.24 (0.1–0.4)	8 (18.6)	12.3 (0.6–127.0)	43 (100)	1.36 (0.7–3.7)	43 (100)	0.50 (0.2–1.4)	4 (9.3)	0.10 (0.03–0.6)
Food preparation										
Wood/Charcoal	50 (43.9)	0.29 (0.2–0.8)	18 (15.8)	5.19 (0.4–101.4)	114 (100)	1.81 (0.9–5.2)	107 (93.9)	0.46 (0.2–0.9)	11 (9.6)	0.03 (0.01–0.1)
Electricity/Gas	139 (48.1)	0.24 (0.2–0.5)	39 (13.5)	17.3 (1.4–43.0)	289 (100)	1.94 (0.8–4.7)	272 (94.1)	0.41 (0.2–0.9)	31 (10.7)	0.05 (0.02–0.1)
Coocking oil										
Corn oil	68 (48.5)	0.26 (0.1–0.8)	22 (13.1)	34.6 (0.8–238.6)	168 (100)	2.09 (0.9–5.6)*	155 (92.3)	0.43 (0.2–0.9)*	19 (11.3)	0.05 (0.02–0.1)
Olive oil	9 (32.1)	0.71 (0.2–1.6)	5 (17.9)	4.78 (0.3–20.9)	28 (100)	2.57 (1.3–5.8)	26 (92.9)	0.22 (0.1–0.4)	4 (14.3)	0.03 (0.01–0.2)
Both	108 (54.3)	0.24 (0.2–0.5)	28 (14.1)	4.97 (0.9–38.5)	199 (100)	1.67 (0.8–3.7)	190 (95.5)	0.47 (0.2–1.0)	18 (9.0)	0.05 (0.01–0.1)
School canteen[b]										
No	19 (59.4)	0.30 (0.2–0.8)	5 (15.6)	40.3 (11.7–2405.3)	32 (100)	1.76 (0.8–2.8)	31 (96.9)	0.33 (0.2–0.7)	0 (0.0)	–
Yes	36 (46.2)	0.21 (0.1–0.4)	3 (3.8)	21.7 (5.6–93.2)	78 (100)	1.57 (0.7–3.8)	71 (91.0)	0.43 (0.2–1.0)	0 (0.0)	–
Source of water										
Running water	111 (43.5)	0.24 (0.2–0.6)	42 (16.5)	5.30 (0.5–27.0)**	255 (100)	1.74 (0.8–4.2)	244 (95.7)	0.44 (0.2–0.9)	23 (9.0)	0.05 (0.02–0.2)

Pond	14 (43.8)	0.19 (0.1–0.3)	3 (9.4)	3.27 (0.8–93.2)	32 (100)	2.13 (1.0–4.5)	29 (90.6)	0.37 (0.1–1.2)	3 (9.4)	0.05 (0.02–0.2)
Drum/Cistern	64 (55.2)	0.27 (0.2–0.7)	12 (10.3)	160.5 (30.7–2629.3)	116 (100)	2.12 (1.0–6.0)	106 (91.4)	0.42 (0.2–0.9)	16 (13.8)	0.05 (0.01–0.1)
Water disposal										
Sewer	16 (36.4)	0.20 (0.1–0.4)	5 (11.4)	17.3 (6.1–23.4)	44 (100)	1.34 (0.8–3.7)	41 (93.2)	0.51 (0.2–1.0)	4 (9.1)	0.17 (0.03–0.4)
Cesspool	27 (56.3)	0.19 (0.1–0.3)	5 (10.4)	0.72 (0.3–1.0)	48 (100)	1.83 (0.6–5.1)	47 (97.9)	0.42 (0.2–1.0)	1 (2.1)	0.07 (0.06–0.1)
Outside	138 (46.5)	0.27 (0.2–0.6)	45 (15.2)	20.1 (0.9–81.3)	297 (100)	1.97 (0.9–5.1)	277 (93.3)	0.41 (0.2–0.8)	35 (11.8)	0.05 (0.01–0.1)

*p < 0.05 (Mann Whitney *U* test or Kruskal-Wallis test), **p < 0.01 (Mann Whitney *U* test or Kruskal-Wallis test), ***p < 0.001 (Mann Whitney *U* test or Kruskal-Wallis test).

Σ pesticides = Acrinathrin + Atrazine + Azoxystrobin + Benalaxyl + Carbofuran + Cyflufenamid + Dimethoate + Dodine + Fenpropidin + Fenpropimorph + Imidacloprid + Iprovalicarb + Mepiquat + Phosmet + Pirimiphos methyl + Propamocarb + Propoxur + Tebufenpyrad + Thiabendazole + Thiacloprid + 2-Phe-nylphenol + Bifenthrin + Boscalid + Bromopropylate + Bromuconazole (I) + Fenarimol + Fenitrothion + Fludioxonil + Fluquinconazole + Flutriafol + Nuarimol + Penconazol + Prothioconazol + Tetraconazole (34 substances).

Σ pharmaceuticals = acetaminophen + albendazole + cloxacillin + diclofenac + difloxacin + levamisole + metronidazole + naproxen + phenylbutazone + sulfa-metoxazole + sulfaquinoxaline + trimethoprim (12 substances).

Σ organochlorine pesticides (OCP) = hexachlorobenzene + p,p'-DDE + p,p'-DDD + p,p'-DDT (4 substances).

Σ polycyclic aromatic hydrocarbons (PAHs) = acenaphthene + anthracene + fluoranthene + fluorene + naphthalene + phenanthrene + pyrene (7 substances).

Σ polychlorinated biphenyls (PCBs) = PCB-138 + PCB-153 + PCB-180 (3 substances).

[a] In-house production, barter and other non-monetized acquisition systems.

[b] Analisys made in the subgroup of population under 18 years old.

160.5 ng/mL of PhACs was quantified in the blood of those individuals who consumed water from drum/cisterns (Table 4). This amount was much higher than that reported for other water sources. Storing water in this way can contribute to a concentrating effect that can even be dangerous to people's health. This effect is less evident when water is stored in larger volumes (pond; median value = 3.27 ng/mL) or simply flows free (running water; median value = 5.30 ng/mL). The importance of the water source as a conditioning factor for the levels of pharmaceuticals has been reported in the literature. In a large-scale study across de United State, Bexfield et al. reported that detections of hormone and PhACs were most common in shallow wells with a component of recent recharge (Bexfield and Toccalino, 2019). Water treatment systems are a determining factor in eliminating this type of substances (Kleywegt and Pileggi, 2011), and this is a variable to be studied in the specific case of our study population. In addition, population density affects water pollution levels, especially in regions where water treatment systems are

less efficient or even non-existent (Standley and Rudel, 2008). In any case, it should be borne in mind that our results are referred the sum of compounds and that, in general, the literature indicates that levels that could pose a risk to the health of the population are not reached (Wen and Chen, 2014; Bexfield and Toccalino, 2019; Dehkordi and Paknejad, 2021).

4. Conclusions

To our knowledge, this is one of the largest biomonitoring studies ever published. In addition to a representative sample of individuals, a total of 360 toxic substances were analyzed. In any case, it is the first biomonitoring study carried out in Cape Verde. Blood concentrations of POPs are influenced by age, although both gender and BMI should be considered as conditioning factors for the presence of these substances in individuals. As in most of the populations studied worldwide, p,p'-DDE

is detected in 100% of the population. Lifestyle has an effect on the concentration of these substances, especially in terms of dietary habits: where food is purchased, how food is cooked, or the type of water consumed. Both the frequency of detection and the concentration of the studied pharmaceuticals and other emerging contaminants are low. This is an interesting finding given the limitations that developing countries may have in terms of water treatment. Our results may be useful for the implementation of public health measures by the competent authorities in Cape Verde.

Author statement

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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.

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Appendix A. Supplementary data

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