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# Current exposure to environmental pollutants in the general adult population of Kinshasa, Democratic Republic of Congo (DRC): A cross-sectional study

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A R T I C L E I N F O

*Keywords:*
Biomonitoring
Toxic metals
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A B S T R A C T

*Background:* Environmental pollution is a serious public health problem because of its adverse effects on both human health and biodiversity. In Western countries, many human biomonitoring (HBM) studies are conducted to assess population exposure to pollutants. In contrast, the number of HBM studies in Africa is very low.
*Objective:* To measure contamination by arsenic, lead, 4,4′-dichlorodiphenyldichloroethylene (4,4′-DDE) and polychlorobiphenyls (PCBs) in the adult population of Kinshasa and to identify the susceptible population.
*Methods:* In the present work, we measured the contamination by arsenic in urine and lead in blood and by 4,4′-DDE and polychlorobiphenyls (PCBs) in serum in samples collected from 151 volunteers recruited in Kinshasa, the capital of the Democratic Republic of Congo (DRC).
*Results:* The PCBs 180, -153 and −138 were detected in most samples with median concentrations of 0.04, 0.05 and 0.04 ng/ml, respectively. The median concentration of 4,4′-DDE was 0.83 ng/ml and 12.7% of our population showed contamination above the threshold of 3.675 ng/ml, which is associated with a significantly higher risk of cancer. Arsenic concentrations were also high (median: 48.1 μg/L in urine). Finally, exposure to lead is problematic: the median blood concentration was 54.9 μg/L, which is above the thresholds proposed by the WHO and the US CDC (50 μg/L and 35 μg/L respectively) to initiate clinical intervention, and 12.6% of the population had a lead level above 100 μg/L, which is associated with several health outcomes.
*Conclusions:* Our results highlight the need for further HBM studies in Africa and should encourage the authorities of the DRC to implement laws and regulations to reduce pollution and population exposure.

## 1. Introduction

For decades, mankind has been developing and producing an ever-increasing number of synthetic chemicals, which have contributed greatly to the development of human society and our well-being (increased agricultural yields, improved health, e.g.). However, many of these compounds are released into the environment and contaminate all the environmental compartments (air, water, sediment, soil, e.g.) and the living organisms. In wildlife and in Human, pollutants can impair health and cause many problems such as respiratory, cardiovascular or renal pathologies, cancers or endocrine disrupting effects, e.g. (Akesson et al., 2005; Cox et al., 2007; Mbelambela et al., 2017; Paydar et al., 2019; Rauh et al., 2012). One of the best-known examples of this antagonism is the dichlorodiphenyltrichloroethane (DDT). This pesticide was so successful in vector control, both in preventive medicine and in agriculture that it won the Nobel Prize for Medicine, but was then gradually banned worldwide because of the numerous damages it caused to both human health and the ecosystem (Charlier, 2009).

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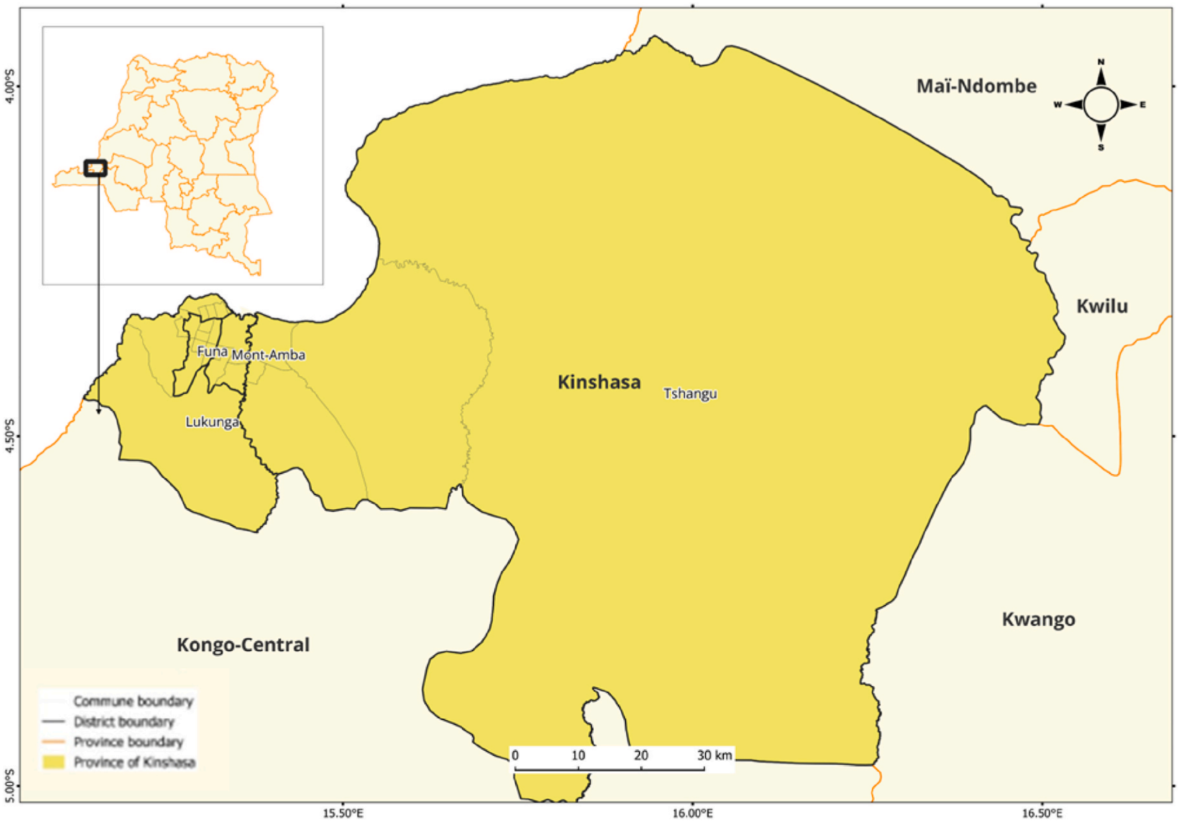


**Fig. 1.** Mapping the place of study.

To measure the risk posed by pollutants to a population, one of the possibilities is to assess the pollutants exposure through human biomonitoring (HBM) studies. In developed countries, there is a relatively high number of HBM studies concerning harmful pollutants. In contrast, there is a severe lack of HBM studies in sub-Saharan African countries. For instance, Kabamba et al., (2021) reported only 12 HBM studies conducted in the Democratic Republic of Congo (DRC), of which 9 focused on metals (Kabamba et al., 2021). Data on organic pollutants are therefore very limited. However, many facts suggest that the exposure of African populations to pollutants could be similar or even worse than those observed in developed countries (Luzardo et al., 2014). Developing countries are slow to legislate against harmful pollution. While most of the Western countries banned the organochlorine pesticides and polychlorinated biphenyls (PCBs) in the 70's or 80's and the use of leaded fuel in 2000, the Democratic Republic of Congo (DRC), which ratified the Stockholm Convention in 2005, banned the import and use of persistent organic pollutants (POPs), among which organochlorine pesticides and PCBs, in 2011 and leaded gasoline in 2009 (Tuakuila et al., 2013). Moreover, despite these interesting decisions, the application of the laws is still problematic. Another important issue in developing countries such as RDC, is the large amount of e-waste generated in developed countries and exported to developing countries. Poor management of e-waste exposes people in developing countries to many harmful compounds such as metals, PCBs and flame retardants (Luzardo et al., 2014). Thereby, in absence of HBM investigation, in DRC, various studies have been carried out on environmental samples (vegetables, water, fish, river sediment, etc.) and have shown high levels of chemical contamination (Kilunga et al., 2017; Ngweme et al., 2021; Tshibanda et al., 2021).

In 2019, we conducted a pilot study to assess contamination by numerous pollutants in a small population of 15 people living in Kinshasa (Bayebila Menanzambi et al., 2021). This pilot study showed, among others, an important contamination of the recruited participants with DDT and metals (As and Pb) but also a significant exposure to PCBs. PCBs and DDT are organochlorine compounds that persist in the environment. They accumulate preferentially in animal fat and can produce more toxic metabolites, such as 4,4′-dichlorodiphenyldichloroethylene (4,4′-DDE) for DDT or hydroxy-PCBs in the case of PCBs (Dufour et al., 2017). Several studies have highlighted the toxic effects of these compounds in living organisms. In particular, they are suspected of being involved in the increased incidence of certain endocrine pathologies such as metabolic syndrome, type 2 diabetes, hormone-related cancers, reduced semen quality, infertility, e.g. However, the toxicity of these compounds, in particular their endocrine disrupting properties, is not fully defined and further studies are still needed (Abou Ghayda et al., 2020; Cano-Sancho et al., 2019; Darbre, 2022; Dufour et al., 2018, 2020; Salimi et al., 2021; Zhang et al., 2023). Some metals such as arsenic (As) and lead (Pb) are known to have neurotoxic effects, are also suspected of interfering with some hormonal pathways (reproductive, thyroid, e.g.) and are causing damage to organs. Metals are also implicated in certain idiopathic and chronic diseases (Balderas-Vasquez et al., 2016; Iavicoli et al., 2009; Malamba-Lez et al., 2021).

According to our 2019 pilot study, exposure to Pb, As, DDT and PCBs is probably high in the population of Kinshasa. Since the number of individuals in our first study was low, we recruited a larger cohort and the aim of the present study was therefore to assess the Kinshasa population exposure to these pollutants by measuring the levels of these compounds in biological samples collected from 151 individuals recruited in Kinshasa.

## 2. Material and methods

### 2.1. Ethics

The current study was approved by the National Health Ethics Committee of the Democratic Republic of Congo under number 401/

CNES/BN/PMMF/2022.

### 2.2. Location and study population

The study was conducted in the provincial city of Kinshasa, the capital of the DRC, among the adult population (over 18 years). The study population was stratified into five age groups (18–29; 30–39; 40–49; 50–59 and ≥ 60 years). We used the same age stratification than in one of our previous work carried out in Belgium (Pirard et al., 2018) in order to easily compare the results.

Kinshasa is divided into 24 communes, grouped into 4 districts (Tshangu, Mont Amba, Funa and Lukunga) (Fig. 1). Twelve communes were randomly selected by choosing 3 from each district, and, based on the lists of associations and churches provided by each communal administration, a second random selection was made of six associations and six churches per commune to form our volunteer awareness and recruitment sites. In each recruitment site, we recruited one or two volunteers. The choice of the volunteers was made in order to have a similar age and gender repartition in each commune. Adult residents of Kinshasa who had not lived outside the city for more than 6 months in the last decade were eligible for the study. Between November 2022 and January 2023, 151 volunteers aged between 18 and 80 years provided their biological samples after completing a consent form and a questionnaire recording their anthropometric characteristics, dietary habits, smoking status, history of diabetes, occupation, frequentation of high-traffic areas, handling of fuels, e.g., with the help of the principal investigator. Covariates such as smoking and eating habits were dichotomized as consuming or not.

**Table 1**
Socio-demographic characteristics of the studied population.

| | | Total N (%) | Men N (%) | Women N (%) |
|---|---|---|---|---|
| **All** | | 151 (100) | 95 (62.9) | 56 (37.1) |
| **Age** | | | | |
| | Mean | 37.8 | 36.6 | 39.7 |
| | SD | 16.1 | 15.6 | 16.8 |
| | Median | 34.0 | 32.0 | 34.5 |
| | Range | 18–80 | 18–74 | 18–80 |
| | 18–29 years | 62 (41.1) | 41 (27.2) | 21 (13.9) |
| | 30–39 years | 29 (19.2) | 20 (13.2) | 9 (5.9) |
| | 40–49 years | 24 (15.9) | 14 (9.3) | 10 (6.6) |
| | 50–59 years | 15 (9.9) | 7 (4.6) | 8 (5.3) |
| | ≥60 years | 21 (13.9) | 13 (8.6) | 8 (5.3) |
| **BMI (kg/m$^2$)** | | | | |
| | Mean | 25.6 | 25.0 | 26.6 |
| | SD | 4.9 | 4.5 | 5.3 |
| | Median | 25.3 | 25.0 | 25.7 |
| | Range | 15.6–43.0 | 15.6–39.6 | 16.0–43.0 |
| | <18.5 | 7 (4.6) | 6 (4.0) | 1 (0.7) |
| | 18.5–24.9 | 66 (43.7) | 42 (27.8) | 24 (15.9) |
| | 25.0–29.9 | 54 (35.8) | 35 (23.2) | 19 (12.6) |
| | ≥30 | 24 (15.9) | 12 (7.9) | 12 (7.9) |
| **Smoking** | | | | |
| | Smokers | 29 (19.2) | 29 (19.2) | 0 (0.0) |
| | Non smokers | 122 (80.8) | 66 (43.7) | 56 (37.1) |
| **Diabetes history** | | | | |
| | No disease | 137 (90.7) | 87 (57.6) | 50 (33.1) |
| | Diabetic subjects | 14 (9.3) | 08 (5.3) | 06 (4.0) |
| **Occupation** | | | | |
| | Drivers | 20 (13.2) | 20 (13.2) | 0 (0.0) |
| | Teachers | 20 (13.2) | 15 (9.9) | 05 (3.3) |
| | Traders | 19 (12.6) | 10 (6.6) | 09 (6.0) |
| | Students | 16 (10.6) | 11 (7.3) | 05 (3.3) |
| | Nurses | 10 (6.6) | 04 (2.6) | 06 (4.0) |
| | Others | 66 (43.7) | 36 (23.8) | 30 (19.9) |
| **High traffic areas** | | | | |
| | Yes | 95 (62.9) | 71 (47.0) | 24 (15.9) |
| | No | 56 (37.1) | 24 (15.9) | 32 (21.2) |
| **Handling fuel** | | | | |
| | Yes | 30 (19.9) | 29 (19.2) | 01 (0.7) |
| | No | 121 (80.1) | 66 (43.7) | 55 (36.4) |
| **Fish consumption** | | | | |
| | Yes | 147 (97.4) | 92 (60.9) | 55 (36.4) |
| | No | 4 (2.6) | 03 (1.9) | 01 (0.7) |
| **Vegetable consumption** | | | | |
| | Yes | 147 (97.4) | 93 (61.6) | 54 (35.8) |
| | No | 4 (2.6) | 02 (1.3) | 02 (1.3) |
| **Area of residence** | | | | |
| | Tshangu | 30 (19.9) | 20 (13.2) | 10 (6.6) |
| | Mont Amba | 48 (31.8) | 37 (24.5) | 11 (7.3) |
| | Funa | 50 (33.1) | 25 (16.6) | 25 (16.6) |
| | Lukunga | 23 (15.2) | 13 (8.6) | 10 (6.6) |

### 2.3. Samples collection

Fasting samples were collected in the morning by technicians at selected centers near the selected recruitment sites. Each volunteer was asked to provide approximately 10 mL of whole blood collected in a heparinized plastic tube for Pb testing, 10 mL of blood collected in a clot activated plastic tube centrifuged at 2500 rpm for 10 min to collect the serum for organochlorine pesticide and PCB analysis, and approximately 50 mL of random urine spot collected in a polypropylene vial for As analysis. Six women were unable to provide urine due to menstruation and one volunteer had some difficulty in obtaining blood for serum collection. Therefore, 145, 150 and 151 samples were collected for urine, serum and whole blood analysis respectively.

The collected biological samples were directly placed in an isothermal box and transported to the Clinical Biology Laboratory of the Faculty of Pharmaceutical Sciences at the University of Kinshasa for centrifugation to obtain serum, and then to the Physical Chemistry Laboratory (Kinshasa) for storage at 4 °C for whole blood and −20 °C for urine and serum.

The samples were packed in a hermetically sealed container with icepack and transported for analysis to the Laboratory of Clinical, Forensic and Environmental Toxicology at the University of Liège in Belgium.

## 3. Laboratory analysis

### 3.1. Blood analysis of lead

Pb was determined in whole blood. Briefly, 500 μL of samples, quality control samples or standard calibration samples were mixed with internal standard (containing Rh, Sc and Ge) and diluted with 4500 μL of a mixture of nitric acid (0.5%), n-butanol (0.2%) and Triton (0.1%) in water. The Pb content was then determined using an Inductively Coupled Plasma Mass Spectrometry (ICP-MS) 7700 series from Agilent Technologies.

### 3.2. Urinary analysis of arsenic

Total As in urine was analysed by ICP-MS. Briefly, 100 μL of internal standard solution (containing Rh, Sc and Ge) were added to 400 μL of samples, quality control samples and standard calibration samples. This mixture was then diluted with 4500 μL of a 0.5% aqueous solution of nitric acid before being injected into an Agilent Technologies ICP-MS 7700 series. The analytical procedure has been detailed in the 2019 pilot study (Bayebila Menanzambi et al., 2021).

### 3.3. Serum analysis of organochlorine pesticides and polychlorinated biphenyls

Organochlorine pollutants, namely 4,4′-DDE, PCB 28, -52, −101, −118, −138, −153 and −180) were quantified in serum. Pirard et al., (2018) have extensively detailed the analytical procedure (Pirard et al., 2018). Briefly, after addition of the internal standard mixture (20 μL), 1 mL of sample or quality control was stirred for 1 h. The samples were denatured with 1 mL of a mixture of water, glacial acetic acid and isopropanol (70/30/5, v/v). The mixture was then extracted twice with 4

**Table 2**
Descriptive statistics of environmental contaminants in serum, whole blood and urine.

| Matrix | Pollutant | LOQ | DF (%) | Mean | SD | GM | P25 | P50 | P75 | P95 | Range |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Serum (pg/mL)* | | | | | | | | | | | |
| | **4,4′DDE** | 15 | **100** | 2235.9 | 4814.6 | 867.0 | 342.4 | 828.2 | 2113.7 | 7649.0 | 34.7–40279.1 |
| | **PCB 28** | 18 | **34** | 22.7 | 35.8 | <LOQ | <LOQ | <LOQ | 32.1 | 81.7 | <LOQ – 330.3 |
| | **PCB 52** | 15 | **25** | <LOQ | 22.1 | <LOQ | <LOQ | <LOQ | <LOQ | 51.6 | <LOQ – 146.2 |
| | **PCB 101** | 15 | **21** | <LOQ | 18.2 | <LOQ | <LOQ | <LOQ | <LOQ | 39.7 | <LOQ – 118.0 |
| | **PCB 118** | 5 | **56** | 14.3 | 23.6 | 7.41 | <LOQ | 6.79 | 13.5 | 47.4 | <LOQ – 160.2 |
| | **PCB 138** | 6 | **98** | 55.4 | 57.5 | 39.8 | 24.9 | 37.3 | 62.1 | 167.9 | <LOQ – 411.3 |
| | **PCB 153** | 7 | **98** | 71.9 | 68.4 | 53.0 | 34.9 | 50.6 | 82.1 | 226.5 | <LOQ – 465.0 |
| | **PCB 180** | 5 | **99** | 60.9 | 54.0 | 44.0 | 25.2 | 41.7 | 72.8 | 187.8 | <LOQ – 299.4 |
| *Whole blood (μg/L)* | | | | | | | | | | | |
| | **Lead (Pb)** | 0.5 | **100** | 64.8 | 34.6 | 57.5 | 40.2 | 54.9 | 80.4 | 124.9 | 21.7–231.9 |
| *Urine (μg/L)* | | | | | | | | | | | |
| | **Arsenic (As)** | 4.4 | **99** | 67.7 | 62.0 | 47.6 | 27.5 | 48.1 | 76.9 | 185.6 | <LOQ – 372.9 |

LOQ: Limit of Quantification.
DF: Detection Frequency.
GM: Geometric Mean.
SD: Standard Deviation.

mL of hexane-acetone mixture (95/5, v/v). The organic phase was cleaned on a PHREE phospholipid removal cartridge (Phenomenex) filled with approximately 1 cm of sodium sulphate, then evaporated until 500 μL and reconstituted into nonane. The extracts were analysed on an Agilent 8890A GC system coupled to a 7000D Triple Quad mass spectrometer (Agilent Technologies) operating in multiple reaction monitoring mode in electronic impact ionisation mode and equipped with a Restek Rxi-XLB 30 m column (0.25 mm ID, 0.25 μm df). The injection volume was 2 μL. Calibration curve was obtained with 8 standard calibration samples not extracted (ranges: 1–1000 ng/mL for PCBs and 10-10,000 ng/mL for 4,4′-DDE).

### 3.4. Quality assurance

The analytical methods used for this study were previously validated according to the total error approach (Dubois et al., 2012; Hubert et al., 2004). The limits of quantification (LOQ) for each pollutant are gathered in Table 2 and were defined as the smallest concentrations measurable in samples with a total error not exceeding 30%. External quality controls were included in each batch of samples (QC QM from the “Institut national de santé publique Québec” for metals and AMAP from the same institute for organochlorine pollutants). Each sequence also contained a procedural blank and a matrix blank. For organochlorine compounds, the blank concentration was withdrawn to obtain a true exposure value.

### 3.5. Statistical analysis

Statistical analyses were performed to identify parameters associated with higher or lower levels of contamination. Prior to statistical analysis, contaminant levels below the LOQ were replaced by the LOQ multiplied by the detection frequency (DF) of the compounds. Contaminants with a DF below 70% were dichotomized (detected vs not detected). Pollutant concentrations were not normally distributed (Shapiro-Wilk test $<0.05$), therefore non-parametric tests (Kruskal-Wallis, Mann-Whitney) and Spearman correlation were used for quantitative variables. For categorical variables and pollutants with DF $<$ 70%, chi-squared test was used. P value $\leq$ 0.05 was considered significant. RStudio, Rcmdr software (version 3.6.3., CRAN) and Excel 2013 (Microsoft, Redmond, WA) were used for statistical processing of data.

## 4. Results and discussion

### 4.1. Socio-demographic characteristics

A summary of the socio-demographic characteristics of the participants is shown in Table 1. Briefly, the proportion of males (63%) in our population is high compared to females (37%), the mean age was 37.8 years ($\pm$16.1 standard deviation (SD)). The mean BMI was 25.6 kg/m$^2$ $\pm$ 4.9 (SD), with 43.7% of the participants having a normal BMI, followed by individuals with overweight (35.8%). Overall, most participants were high consumers of fish and vegetables (97.4%), non-smokers (78.8%), without a history of diabetes (91.4%), and living in high traffic areas

(62.9%). We observed a high proportion of drivers and teachers (both 13.2%). According to their place of residence, most volunteers came from the districts of Funa (33.1%) and Mont Amba (31.8%).

## 5. Metals

Pb and As concentrations are gathered in Table 2, both are expressed in μg/L. Pb was detected in all blood samples from the adult population of Kinshasa with a median concentration of 54.9 μg/L. Total As was <LOQ in only 1% of urine samples and the median concentration was 48.1 μg/L.

The median Pb exposure observed in this study (54.9 μg/L) are consistent with the blood Pb levels found in the 2019 pilot study (53.6 μg/L) (Bayebila Menanzambi et al., 2021). In Table 3, we reported the blood Pb level measured in some recent studies. Compared to other populations around the world, the Pb levels determined in our population are relatively high. Thereby, our results are far higher than those measured in 1811 adults living in New York (USA) (11.3 μg/L) (Feinberg et al., 2018), in 3033 individuals from the German general population (25.3 μg/L) (Rooney et al., 2022) or in 401 inhabitants of Cape Verde (22.6 μg/L) (Henríquez-Hernández et al., 2023). Pb levels in our study are also higher than those reported in 207 Zimbabwean miners (19.7 μg/L) (Rakete et al., 2022) or in 88 urban gardeners exposed to lead-contaminated soil in the Wallonia region of Belgium (23.1 μg/L) (Petit et al., 2022). On the other hand, Pb levels in Kinshasa are similar than those measured in a study of 29 volunteers in Katanga (the mining area of the DRC), with a mean concentration of 58.3 μg/L or in 70 inhabitants of Cotonou (Benin) (47.7 μg/L) (Yedomon et al., 2017) i.e. two other African populations (16).

From a health point of view, the Pb contamination observed in the population of Kinshasa is problematic. Indeed, due to the Pb’s toxicity, the WHO and US CDC have proposed a blood Pb level of 50 μg/L and 35 μg/L respectively as the threshold to initiate clinical intervention (“Guideline for clinical management of exposure to Pb,” n.d.; “Lead - Understand Blood Lead Levels | NIOSH | CDC,” 2023) and more than half of the people in our study have blood Pb level above these limits. Pb exposure is associated with several health adverse outcomes (gastrointestinal effects, effects on hepatic, renal or cardiovascular systems, haematological impairments, e.g.) but the WHO limit of 50 μg/L was chosen because this level was associated with decreased IQ and

**Table 3**
Median levels (µg/L) of pollutants measured in the blood, serum and urine of different populations around the world.

| Pollutant | Matrix | Year of collection | Population | Median | Reference |
|---|---|---|---|---|---|
| **Lead** | *Blood* | | | | |
| | | 2013–2014 | New York City (USA), adult population, N = 1811 | 11.3[b] | Feinberg et al. (2018) |
| | | 2015 | Benin, Inhabitants of Cotonou, N = 70 | 47.7 | Yedomon et al. (2017) |
| | | 2018–2019 | Bavarian city of Augsburg (Germany), German population, N = 3033 | 25.3 | Rooney et al. (2022) |
| | | 2017–2019 | Katanga (DRC), population, N = 29 | 58.3 | Malamba-Lez et al. (2021) |
| | | 2018 | Wallonia (Belgium), exposed urban gardeners, N = 88 | 23.1 | Petit et al. (2022) |
| | | 2019 | Cape Verde, general population, N = 401 | 22.6 | Henríquez-Hernández et al. (2023) |
| | | 2019 | Zimbabwe, miners in two artisanal and small-scale gold mining, N = 207 | 19.7 | Rakete et al. (2022) |
| | | 2019 | Kinshasa (DRC), adult population, N = 15 | 53.6 | Bayebila Menanzambi et al. (2021) |
| | | **2022–2023** | **Kinshasa (DRC), adult population, N= 151** | **54.9** | **This study** |
| **Arsenic** | *Urine* | | | | |
| | | 2012–2013 | Lubumbashi (DRC), pregnant women, N = 39 | 23.6[b] | Musa Obadia et al. (2018) |
| | | 2015–2016 | Ethiopia, population living in the volcanic and rift valley of the central Ethiopian | 18.9 | Godebo et al. (2019) |
| | | 2016 | Berlin (Germany), museum staff, N = 28 | 6.40 | Deering et al. (2020) |
| | | 2017–2018 | general Korean population, N = 2025 | 62.3 | (Choi, Weon et al., 2022) |
| | | 2019 | Zimbabwe, miners in two artisanal and small-scale gold mining, N = 207 | 9.70 | Rakete et al. (2022) |
| | | 2019 | Kinshasa (DRC), adult population, N = 15 | 70.9 | Bayebila Menanzambi et al. (2021) |
| | | **2022–2023** | **Kinshasa (DRC), adult population, N= 145** | **48.1** | **This study** |
| **4,4′DDE** | *Serum* | | | | |
| | | 2010–2011 | Bolivian, women farmers, N = 24 | 9.34 | Mercado et al. (2013) |
| | | 2011–2012 | Bizerte (Tunisia), general population, N = 113 | 0.89[a] | Ben Hassine et al. (2014) |
| | | 2012–2013 | South-Africa, pregnant women, N = 733 | 1.75[a] | Murray et al. (2018) |
| | | 2013–2015 | Lebanon, population, N = 314 | 0.13[a] | Harmouche-Karaki et al. (2018) |
| | | 2015 | Belgium, adult population (women), N = 124 | 0.41 | Pirard et al. (2018) |
| | | 2016 | Berlin (Germany), museum staff (46–56 years old), N = 10 | 0.66 | Deering et al. (2020) |
| | | 2016 | Saudi Arabia, adult population, N = 302 | 0.12[a] | Al-Daghri et al. (2019) |
| | | 2017 | Algiers (Algeria), general population, N = 207 | **1.19**[a] | Mansouri and Reggabi (2021) |
| | | 2017 | Beijing (China), adult population, N = 1268 | 0.10 | Han et al. (2023) |
| | | 2019 | Kinshasa (DRC), adult population, N = 15 | 1.46 | Bayebila Menanzambi et al. (2021) |
| | | 2019 | Cape Verde, general population, N = 403 | 1.87 | Henríquez-Hernández et al. (2022) |
| | | **2022–2023** | **Kinshasa (DRC), adult population, N= 150** | **0.83** | **This study** |
| **PCB 138** | *Serum* | | | | |
| | | 2010 | Spain, men adult population, N = 963 | 0.26[a] | Huetos et al. (2014) |
| | | 2010 | Santa Cruz de la Sierra (Bolivia), adult population, N = 112 | 0.20[b] | Arrebola et al. (2012) |
| | | 2011–2012 | Bizerte (Tunisia), general population, N = 113 | 0.18[a] | Ben Hassine et al. (2014) |
| | | 2013 | South Germany, rural population, N = 70 | 0.08 | Fromme et al. (2015) |
| | | 2012–2015 | Michigan (USA), general population, N = 861 | 0.21 | Chang et al. (2020) |
| | | 2013–2015 | Lebanon, population, N = 316 | 0.06[a] | Harmouche-Karaki et al. (2017) |
| | | 2017 | Algiers (Algeria), general population, N = 207 | 0.03[a] | Mansouri and Reggabi (2021) |
| | | **2022–2023** | **Kinshasa (DRC), adult population, N= 150** | **0.04** | **This study** |
| **PCB 153** | *Serum* | | | | |
| | | 2010 | Spain, men adult population, N = 963 | 0.35[a] | Huetos et al. (2014) |
| | | 2011–2012 | Bizerte (Tunisia), general population, N = 113 | 0.36[a] | Ben Hassine et al. (2014) |
| | | 2013 | South Germany, rural population, N = 70 | 0.15 | Fromme et al. (2015) |
| | | 2012–2015 | Michigan (USA), general population, N = 861 | 0.25 | Chang et al. (2020) |
| | | 2013–2015 | Lebanon, population, N = 316 | 0.12[a] | Harmouche-Karaki et al. (2017) |
| | | 2015 | Belgium, adult population, N = 251 | 0.36 | Pirard et al. (2018) |
| | | 2017 | Algiers (Algeria), general population, N = 207 | 0.04[a] | Mansouri and Reggabi (2021) |
| | | 2019 | China, adult population, N = 1996 | 1.89[a] | Zhang et al. (2023) |
| | | 2019 | Kinshasa (DRC), adult population, N = 15 | 0.08 | Bayebila Menanzambi et al. (2021) |
| | | **2022–2023** | **Kinshasa (DRC), adult population, N= 150** | **0.05** | **This study** |
| **PCB 180** | *Serum* | | | | |
| | | 2010 | Spain, men adult population, N = 963 | 0.46[a] | Huetos et al. (2014) |
| | | 2011–2012 | Bizerte (Tunisia), general population, N = 113 | 0.24[a] | Ben Hassine et al. (2014) |
| | | 2013 | South Germany, rural population, N = 70 | 0.77 | Fromme et al. (2015) |
| | | 2012–2015 | Michigan (USA), general population, N = 861 | 0.19 | Chang et al. (2020) |
| | | 2013–2015 | Lebanon, population, N = 316 | 0.18[a] | Harmouche-Karaki et al. (2017) |
| | | 2015 | Belgium, adult population, N = 251 | 0.28 | Pirard et al. (2018) |
| | | 2017 | Algiers (Algeria), general population, N = 207 | 0.04[a] | Mansouri and Reggabi (2021) |
| | | 2019 | China, adult population, N = 1996 | 1.21[a] | Zhang et al. (2023) |
| | | **2022–2023** | **Kinshasa (DRC), adult population, N= 150** | **0.04** | **This study** |

[a] ng/lipid weight concentrations converted to µg/L after multiplication by mean body lipid concentration (0.00735).
[b] Geometric mean.

cognitive alterations in children and with reduced fetal weight in pregnant women. Moreover, in our population, 12.6% of the individuals presented blood Pb level above 100 µg/L, at these levels, there is a risk of anemia, decreased cognitive function in children and adults, increased cardiovascular disease in particular hypertension and spontaneous abortion or preterm birth in pregnant women.

Our results showed that Pb contamination was linked to some demographic parameters. Pb concentrations were significantly higher in males than in females (p-value <0.001) (Table 4a). Smokers were relatively more exposed to Pb than non-smokers (p-value <0.001), and blood Pb levels differed significantly by occupation, with drivers being the most exposed, followed by traders. Fuel handlers were significantly more exposed than non-handlers (p-value <0.001) (Tables 4a and 4b). Finally, residents of Tshangu had higher Pb levels than the inhabitants of the other districts (p-value <0.05) (Table 4b).

Due to its interesting physico-chemical properties, Pb has been widely used for centuries in many applications: additive in fuel, component of some paints or some traditional cosmetics, Pb is used for

**Table 4a**
the contamination of the Kinshasa population according to demographic and lifestyle variables.

| Variables | Pollutants | Median (pg/mL) | | p-value |
|---|---|---|---|---|
| *Sex* | | **Males** | **Females** | |
| | 4,4′DDE | 700.9 | 1136.7 | **0.026** |
| | PCB 138 | 39.8 | 36.0 | 0.294 |
| | PCB 153 | 56.7 | 44.3 | 0.058 |
| | PCB 180 | 48.7 | 29.8 | **< 0.001** |
| | Lead | 63.7[a] | 46.8[a] | **< 0.001** |
| | As | 56.5[a] | 39.7[a] | **0.023** |
| *Diabetes history* | | **Yes** | **No** | |
| | 4,4′DDE | 1477.5 | 795.2 | 0.125 |
| | PCB 138 | 65.7 | 36.2 | **0.013** |
| | PCB 153 | 92.9 | 49.8 | **0.009** |
| | PCB 180 | 83.7 | 39.6 | **0.002** |
| | Lead | 42.6[a] | 59.8[a] | **0.001** |
| | As | 44.5[a] | 51.7[a] | 0.277 |
| *Smoking* | | | | |
| | 4,4′DDE | 712.2 | 909.7 | 0.098 |
| | PCB 138 | 36.0 | 37.5 | 0.958 |
| | PCB 153 | 55.2 | 50.1 | 0.830 |
| | PCB 180 | 41.9 | 41.5 | 0.703 |
| | Lead | 82.3 | 50.0 | **< 0.001** |
| | As | 56.8 | 46.7 | 0.487 |
| *High traffic areas* | | | | |
| | 4,4′DDE | 712.2 | 1248.6 | 0.062 |
| | PCB 138 | 38.5 | 34.8 | 0.767 |
| | PCB 153 | 51.3 | 50.5 | 0.746 |
| | PCB 180 | 41.2 | 45.6 | 0.870 |
| | Lead | 62.1[a] | 50.0[a] | 0.081 |
| | As | 57.3[a] | 37.5[a] | **0.012** |
| *Handling fuel* | | | | |
| | 4,4′DDE | 444.0 | 867.1 | 0.131 |
| | PCB 138 | 45.2 | 36.1 | 0.116 |
| | PCB 153 | 63.3 | 48.5 | 0.030 |
| | PCB 180 | 50.3 | 39.9 | 0.101 |
| | Lead | 81.2[a] | 50.8[a] | **< 0.001** |
| | As | 58.6[a] | 46.6[a] | 0.186 |
| *Fish consumption* | | | | |
| | 4,4′DDE | 812.6 | 2031.8 | 0.398 |
| | PCB 138 | 37.3 | 37.5 | 0.903 |
| | PCB 153 | 50.6 | 61.1 | 0.564 |
| | PCB 180 | 41.4 | 98.8 | 0.065 |
| | Lead | 54.2[a] | 68.5[a] | 0.427 |
| | As | 49.2[a] | 27.1[a] | 0.124 |
| *Vegetable consumption* | | | | |
| | 4,4′DDE | 828.2 | 1217.4 | 0.847 |
| | PCB 138 | 37.7 | 23.6 | 0.270 |
| | PCB 153 | 50.9 | 36.6 | 0.398 |
| | PCB 180 | 41.7 | 65.1 | 0.875 |
| | Lead | 54.9[a] | 57.0[a] | 0.949 |
| | As | 47.1[a] | 52.2[a] | 0.713 |

[a] Concentration in μg/L.

the manufactures of water pipes or cooking utensils, e.g. There is thus many potential sources of exposure. We hypothesized that several factors could explain the high levels of Pb found in this study. First, the quality of fuel and tobacco sold in the capital is probably low, despite the enactment of environmental legislation. Indeed, atmospheric Pb is one of the main sources of contamination for living organisms. These hypotheses were supported by the fact that fuel handlers, drivers, traders, smokers and Tshangu residents (an area with heavy road traffic and high use of Pb utensils) were more contaminated than other social groups studied. Oral contamination is also likely to be significant, as Pb cooking utensils are still used in most of the makeshift restaurants frequented by many people in the city. Human contamination with these toxic metals can also be linked to the uncovered cooking style that is common in the city, burning wood and releasing all the toxic elements that have been trapped for years (Fig. 2).

As highlighted by the comparison of our results with the recent literature, the blood Pb levels in Africa are significantly higher than those observed in Western countries. In these countries, a large number of Pb containing products have long been banned and restrictive legislations are strictly enforced. Consequently, the DRC authorities should promote individual preventive measures against Pb contamination, such as avoiding illegal fuels, utensils and materials containing Pb, e.g., Moreover, the DRC authorities must ensure strict compliance with the laws in force and step up environmental and biological monitoring, which is the key to drastically reducing this toxic metal.

Mainly found in seafood, drinking water, e.g., As is a non-essential metalloid for living organisms. Both organic and inorganic forms of As are found in the environment, the latter being the most toxic. Such as Pb, As could be associated with several adverse health effects: skin, lung, liver and bladder cancer, miscarriages, premature births, effects on the central nervous and metabolic systems, e.g., are reported in the literature as target for the As toxicity (Agusa et al., 2014; Rahman et al., 2020). Compared to our 2019 pilot study, the median concentration of As in urine is lower (48.1 μg/L vs 70.9 μg/L). Nevertheless, the current median concentration is higher than the one found in 39 pregnant women in Lubumbashi (RDC) (23.6 μg/L) (Musa Obadia et al., 2018), in 386 inhabitants from central Ethiopia (18.9 μg/L) (Godebo et al., 2019), in 28 member of the Berlin museum staff (Germany) (6.4 μg/L) (Deering et al., 2020) or in 207 Zimbabwean miners (9.7 μg/L) (Rakete et al., 2022). On the other hand, our result are lower than the As contamination observed in the Korean general population (62.3 μg/L) (Choi, Weon et al., 2022) (Table 3). In our study, we highlighted two parameters associated with higher As contamination in our population: males were more contaminated than females (p-value = 0.023) and we observed higher As levels in overweight individuals compared to volunteers with normal BMI (p-value = 0.039).

We did not perform the speciation of As in the present study, which is a major limitation. Given the high consumption of fish in Kinshasa, we cannot exclude that the high contamination observed in our population is mainly related to organic As, which is less toxic than inorganic form. Nevertheless, some studies have measured high concentrations of this metalloid (above the WHO standard) in vegetables and other foods sold in the city, as well as in the various rivers that cross the city (Kilunga et al., 2017; Nuapia et al., 2018). It is therefore essential to carry out urinary As speciation in a nearly future, to determine the average concentration of the inorganic form in the population, as it is more toxic than its organic form.

### 5.1. Organochlorine compounds

DDT and PCBs were among the first group of pollutants included in the Stockholm Convention, and their production and use has been banned for decades in some parties to the Stockholm Convention [Stockholm Convention 2009, accessed June 2023], but in sub-Saharan Africa, DDT is still used in some countries with high malaria prevalence ("L'OMS relance l'utilisation du DDT pour lutter contre le paludisme," 2006). These lipophilic and persistent compounds accumulate in both environmental and biological matrices and have been implicated in numerous pathologies, including cancers and endocrine related diseases (Abou Ghayda et al., 2020; Rylander et al., 2015; Salimi et al., 2021; Zeng et al., 2022).

Among PCBs, three were detected in more than 70% of the samples, namely, PCB 138, 153 and 180 with median concentration of 39.8 pg/mL, 53.0 pg/mL and 44.0 pg/mL, respectively. As illustrated in Table 3, these concentrations were lower than those observed in most recent studies (populations were recruited after 2010) (Arrebola et al., 2012; Bayebila Menanzambi et al., 2021; Ben Hassine et al., 2014; Chang et al., 2020; Fromme et al., 2015; Harmouche-Karaki et al., 2017; Huetos et al., 2014; Mansouri and Reggabi, 2021; Pirard et al., 2018; Zhang et al., 2023). Moreover, the contamination level measured in our population is one or two orders of magnitude lower than the HBM value established by the German Environment Agency above which there is a risk for the human health (Apel et al., 2017). This HBM value was set at 7 μg/L for the sum of PCB 138, 153 and 180, multiplied by two. The low exposure

**Table 4b**
the contamination of the Kinshasa population according to demographic and lifestyle variables.

| Variables | Pollutants | Median concentrations (pg/mL) | | | | | | p-value |
|---|---|---|---|---|---|---|---|---|
| *Age* | | **18–29 years** | **30–39 years** | **40–49 years** | **50–59 years** | **≥ 60 years** | | |
| | *4,4'DDE* | 644.4 | 677.6 | 762.7 | 2012.4 | 3757.4 | | **< 0.001** |
| | *PCB 138* | 33.6 | 30.6 | 35.8 | 43.2 | 84.7 | | **< 0.001** |
| | *PCB 153* | 44.4 | 42.1 | 51.9 | 64.5 | 115.0 | | **< 0.001** |
| | *PCB 180* | 30.1 | 41.1 | 43.4 | 49.9 | 101.1 | | **< 0.001** |
| | Lead | 52.5[a] | 65.6[a] | 52.1[a] | 53.6[a] | 54.9[a] | | 0.583 |
| | As | 47.9[a] | 63.2[a] | 50.7[a] | 52.3[a] | 41.9[a] | | 0.459 |
| *BMI (Kg/m2)* | | **<18.5** | **18.5–24.9** | **25.0–29.9** | **≥ 30** | | | |
| | *4,4'DDE* | 852.0 | 660.5 | 824.4 | 1121.3 | | | 0.390 |
| | *PCB 138* | 26.3 | 38.7 | 37.5 | 41.5 | | | 0.421 |
| | *PCB 153* | 34.8 | 52.6 | 50.4 | 57.5 | | | 0.417 |
| | *PCB 180* | 33.3 | 46.0 | 40.0 | 51.3 | | | 0.718 |
| | Lead | 79.9[a] | 53.2[a] | 56.3[a] | 55.8[a] | | | 0.766 |
| | As | 25.9[a] | 48.9[a] | 56.7[a] | 45.0[a] | | | **0.039** |
| *Alimentation 24 H before* | | **No** | **Vegetables** | **Meat** | **Vegetables-meat** | **Others** | | |
| | *4,4'DDE* | 287.4 | 755.3 | 1248.6 | 802.0 | 1806.5 | | 0.015 |
| | *PCB 138* | 34.9 | 37.7 | 43.9 | 36.0 | 37.7 | | 0.846 |
| | *PCB 153* | 46.2 | 49.3 | 56.7 | 50.7 | 50.8 | | 0.869 |
| | *PCB 180* | 27.8 | 38.6 | 47.3 | 39.5 | 51.1 | | 0.734 |
| | Lead | 77.7[a] | 55.3[a] | 56.7[a] | 53.9[a] | 46.8[a] | | 0.678 |
| | As | 65.5[a] | 32.3[a] | 51.7[a] | 60.1[a] | 33.7[a] | | 0.013 |
| *Activities* | | **Drivers** | **Teachers** | **Traders** | **Students** | **Nurses** | **Others** | |
| | *4,4'DDE* | 371.1 | 1043.1 | 846.6 | 591.7 | 833.2 | 1038.4 | 0.063 |
| | *PCB 138* | 37.9 | 62.4 | 41.8 | 36.9 | 33.9 | 33.1 | **0.045** |
| | *PCB 153* | 59.1 | 84.3 | 65.4 | 49.7 | 49.4 | 43.7 | **0.019** |
| | *PCB 180* | 40.7 | 76.5 | 48.9 | 37.3 | 36.7 | 40.0 | **0.022** |
| | Lead | 87.0[a] | 49.3[a] | 71.8[a] | 36.8[a] | 49.9[a] | 60.9[a] | **< 0.001** |
| | As | 58.8[a] | 37.5[a] | 60.3[a] | 55.2[a] | 37.7[a] | 46.7[a] | 0.318 |
| *Area of residence* | | **Tshangu** | **Mont Amba** | **Funa** | **Lukunga** | | | |
| | *4,4'DDE* | 1373.8 | 422.5 | 969.1 | 521.1 | | | **0.013** |
| | *PCB 138* | 37.1 | 37.8 | 38.7 | 36.0 | | | 0.776 |
| | *PCB 153* | 45.0 | 50.1 | 57.3 | 50.5 | | | 0.650 |
| | *PCB 180* | 45.0 | 40.1 | 47.3 | 30.4 | | | 0.380 |
| | Lead | 79.9[a] | 51.7[a] | 50.2[a] | 51.2[a] | | | **0.004** |
| | As | 48.1[a] | 49.2[a] | 46.7[a] | 44.7[a] | | | 0.764 |

[a] Concentration in µg/L.

of the adult population of Kinshasa to PCB congeners is probably related to the low level of industrialization of the city and therefore could be a minor health concern in the general population. Nevertheless, we must keep in mind that PCBs are endocrine disruptors and classified as carcinogenic to humans by the International Agency for Research on Cancer ("IARC Monographs Volume 107," n.d.), two no-threshold effect toxicities, therefore even a low exposure could be associated to health risk. In addition, some specific populations, such as those involved in the management of electronic and electrical waste, may be at risk of higher exposure.

On the other hand, the exposure to DDT in Kinshasa is more important. The DDT metabolite (4,4′-DDE) was detected in all the samples and the median concentration found in this study was 830 pg/mL which is comparable to that found in 113 volunteers from the general population of Bizerte (Tunisia) (890 pg/mL) (Ben Hassine et al., 2014). Nevertheless, the contamination measured in our study is lower than that reported in the 2019 pilot study (1460 pg/mL) (Bayebila Menanzambi et al., 2021) and lower than those observed in some highly exposed populations: in 24 Bolivian farmers (9340 pg/mL) (Mercado et al., 2013), in 403 individuals from Cape Verde general population (1870 pg/mL) (Henríquez-Hernández et al., 2022), in 733 South-African pregnant women (1750 pg/mL) (Murray et al., 2018) or in 207 individuals from Algiers (Algeria) general population (1190 pg/mL) (Mansouri and Reggabi, 2021). On the other hand, the contamination in the adult population of Kinshasa is higher than the exposure reported in countries where DDT has been banned for decades: in 10 members of the Berlin (Germany) museum staff (660 pg/mL) (Deering et al., 2020), in 124 Belgium women (410 pg/mL) (Pirard et al., 2018), in 1268 adults from Beijing (China) (100 pg/mL) (Han et al., 2023), in 302 Saudi Arabian adults from the general population (120 pg/mL) (Al-Daghri et al., 2019) and in 314 individuals in Lebanon (130 pg/mL) (Harmouche-Karaki et al., 2018). To allow comparisons, all the above populations were recruited and sampled after 2010.

The DDE levels highlighted in the Kinese population were associated with significant health concerns. Using the RfCs of the US EPA, Kirman et al. computed HBM values for DDT and DDE above which there is a risk for Human health. First, they established that serum concentration for the sum of DDT/DDE/DDD above 5000 ng/g of lipid is associated with a risk to present hepatic lesions. By converting this concentration into ng/mL (by considering a mean lipid serum level of 7.35 g/L), we obtained a threshold of 36.8 ng/mL and we observed that one individual (0.7% of the population) in our cohort is above this limit. They also computed that the level of 500 ng/g of lipid for DDE is associated with a cancer risk specific of $1 \times 10^{-5}$. We have converted this limit into ng/mL (=3.675 ng/mL) and we highlighted than 12.7% of our population exceed this threshold. A significant proportion of the population of Kinshasa could thus present health issues because of the exposure to DDT (Kirman et al., 2011). Unfortunately, because the analytical performances of our method was not sufficient to quantify 4,4-DDT, 2,4-DDE or 2,4-DDT in our population, we didn't measure these compounds in our population. Therefore, some information concerning DDT exposure are missing and the sum of DDT/DDE/DDD couldn't be computed.

As expected, for PCBs 138, 153, 180 and 4,4′-DDE, contamination differed significantly between age groups, with higher contamination in older age groups (p-value <0.001) (Table 4b), and a significant correlation between contamination by these POPs and age was also found (p-value <0.001) (Table 5). On the other hand, it is surprising to see that PCB 118 was detected more frequently in females than in males (p-value


**Fig. 2.** Habitual cooking style in the city of Kinshasa (photo taken by the corresponding author, October 2023).

**Table 5**
Correlation of environmental pollutants with age and BMI.

| Variables | Pollutants | Spearman Correlation | p-value |
|---|---|---|---|
| *Age* | | | |
| | 4,4′DDE | 0.35 | **< 0.001** |
| | PCB 138 | 0.34 | **< 0.001** |
| | PCB 153 | 0.38 | **< 0.001** |
| | PCB 180 | 0.46 | **< 0.001** |
| | Lead | 0.01 | 0.913 |
| | As | −0.004 | 0.962 |
| *BMI* | | | |
| | 4,4′DDE | 0.16 | 0.055 |
| | PCB 138 | 0.06 | 0.471 |
| | PCB 153 | 0.08 | 0.350 |
| | PCB 180 | 0.07 | 0.392 |
| | Lead | −0.02 | 0.785 |
| | As | 0.08 | 0.336 |

= 0.01) and that for 4,4′-DDE, females were relatively more contaminated than males (p-value = 0.026) (Table 4a). PCB 180 contamination was significantly higher in males than in females (p-value <0.001), which is more consistent with the fact that organochlorine pollutants concentrations are usually lower in women because they eliminate a part of their contamination during lactation and when they give birth. We found no explanation to the higher levels reported in women compare to men in our population. Thanks to our results, we highlighted some additional parameters associated with a higher contamination by organochlorine pollutants in Kinshasa (Table 3). First, based on the type of food consumed 24 h prior to sampling, we observed that 4,4′-DDE contamination was higher in meat eaters (p-value = 0.015). Teachers recruited in this study (most of whom were diabetic) showed higher exposure to PCBs 138, 153 and 180 compared to other activities (p-value <0.05) (Table 4b). Tshangu residents also had higher levels of 4,4′-DDE (p-value <0.05) (Table 4b) which could be linked to the intensive agricultural activities in the Tshangu district. In addition, fuel handlers had higher PCB 153 contamination (p-value <0.001) (Table 4a).

The results of the present study should be considered with caution. As mentioned above, we did not perform As speciation nor the quantification of several DDT congeners, information concerning these compounds are thus incomplete. In addition, although we multiplied the number of participants by ten compared to our previous study, this number is still relatively small compared to the total population of Kinshasa (more than 17 million inhabitants). Therefore, our cohort is probably not perfectly representative of the population of Kinshasa, and certainly not of the DRC as a whole. Finally, we did not assess the exposure in individuals with identified important source of contamination such as e-waste workers. Nevertheless, our work is important because we highlighted high levels of some pollutants in Kinshasa inhabitants. The pollutants studied in this study are persistent both in the environment and in living organisms. Preventing exposure to these compounds is therefore the first line of defense against their harmful effects. As animal, plant, environmental and human health are closely interrelated, it is essential that the DRC authorities take joint action as part of a "one health" approach to ensure the well-being of its people and biodiversity.

## 6. Conclusion

This study is one of the first large scale biomonitoring study in Africa and particularly in the DRC. The study involved 151 volunteers aged 18 years and older living in Kinshasa. Pb, total As, 4,4′-DDE and PCB congeners were tested in the biological matrices provided. Compared to certain exposed populations around the world, the recruited participants had much higher HBM levels for Pb, As and 4,4′-DDE, with a significant proportion of participants above the thresholds associated with an increased risk of adverse human health effects.

The current levels of exposure observed in the adult population of Kinshasa are similar to those highlighted in the 2019 pilot study. Thus, as expected, the city of Kinshasa is not spared from environmental pollution. Moreover, despite the decision to phase out Pb in 2009 and the publication of the law on environmental protection in 2011, the contamination by Pb and to a lesser extent by DDT is still highly problematic in the health point of view. The efforts needed to protect the environment in the DRC are still important. Measures must be taken to reduce sources of exposure to pollutants, e.g. promoting good practices in e-waste management, finding and eliminating Pb water pipes, controlling the use of DDT or leaded fuel in the City. In addition, the authorities need to promote and strengthen continuous monitoring of exposure of the population and the ecosystem. This could be achieved by establishing a national HBM program and improving cooperation between researchers. Finally, this study concerned only a little number of pollutants and efforts should be made to extend research to other families of pollutants such as non-persistent organic pollutants (parabens, phthalates, triclosan, bisphenols, pyrethroids, e.g.).

## CRediT authorship contribution statement

**Trésor Bayebila Menanzambi:** Writing – original draft, Software, Investigation, Formal analysis, Data curation. **Catherine Pirard:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization. **Cédric Ilunga wa Kabuaya:** Software, Formal analysis. **Lievin's-Corneille Mputu Malolo:** Writing – review & editing, Investigation. **Manix Mayangi Makola:** Writing – review & editing, Investigation. **Fridolin Kodondi Kule-Koto:** Writing – review & editing, Resources. **Jean Nsangu Mpasi:** Writing – review & editing, Resources. **Roland Marini Djang'eing'a:** Writing – review & editing, Funding acquisition. **Jérémie Mbinze Kindenge:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Corinne Charlier:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Patrice Dufour:** Writing – review & editing, Validation, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization.

## Ethics approval and consent to participate

Ethics approval was obtained from the national health ethics committee in the Democratic Republic of Congo. Firstly, participants were informed about the study interest and then, written informed consent was obtained from each participant during data collection. Participants were free to refuse to take part in the study as well as to withdraw any time along the study. Study results were strictly confident according to the declaration of Helsinki.

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## Declaration of competing interest

The authors declare that there is no competing interest regarding the publication of this paper.

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## Abbreviations

| | |
|---|---|
| DRC | Democratic Republic of Congo |
| EP | Environmental Pollutants |
| POPs | Persistent organic pollutants |
| OCP | Organochlorine pesticides |
| PCB | Polychlorinated biphenyls |
| BFR | Brominated flame retardants |
| PFAS | Perfluoroalkyl substances |
| LOQ | Limit of Quantification |
| DF | Detection Frequency |
| GM | Geometric Mean |
| SD | Standard Deviation |
| PCA | Principal Component Analysis |
| SPE | Solid Phase Extraction |
| GC-MS | Gas Chromatography coupled to Mass Spectrometry |
| ICP-MS | Inductively Coupled Plasma-Mass Spectrometry |
| WHO | World Health Organization |
| BMI | Body Mass Index |
| 4,4′-DDE | 4,4′-dichlorodiphenyl-dichloroethylene |
| DDT | dichlorodiphenyl-trichloroethane |
| HBM | Human Biomonitoring |
| RfCs | reference concentrations. |

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