



Serum PFAS levels measured in the general population of Kinshasa, Democratic Republic of Congo, in 2022–2023

Patrice Dufour^{1,2} · Trésor Bayebila Menanzambi³ · Catherine Pirard^{1,2} · Corinne Charlier^{1,2}

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Abstract

Per- and polyfluoroalkyl substances (PFAS) are synthetic compounds widely used for their remarkable chemical properties, but they are raising growing health concerns. While biomonitoring data exist for North America, Europe, and the Asia-Pacific region, evidence from Sub-Saharan Africa was scarce. The objective of the present study is to measure PFAS contamination in volunteers recruited in Kinshasa, capital of the Democratic Republic of Congo. We assessed serum PFAS concentrations in 136 adults (63.2% men and 36.8% women, median age: 33.5 years) recruited in 2022 and 2023 in Kinshasa, Democratic Republic of Congo. Fourteen PFAS were measured using liquid chromatography-mass spectrometry (Agilent 1290 Infinity II LC/Agilent 6495 LC/TQ MS). Only five compounds were quantified in more than 10% of samples: perfluorononanoic acid (PFNA), perfluorohexane sulfonate (PFHxS), perfluorooctanoic acid (PFOA), linear perfluorooctane sulfonate (linPFOS), and total PFOS (totPFOS). Median serum levels were 0.166 ng/mL (PFNA), 0.270 ng/mL (PFHxS), 0.384 ng/mL (PFOA), 0.675 ng/mL (linPFOS), and 1.70 ng/mL (totPFOS). Compared with international data, PFAS levels in our population were among the lowest reported in the past decade. Only 0.7% of participants exceeded the German HBM-I value for PFOA while no volunteer exceeded this threshold for linPFOS. These HBM-I values are concentrations below which no health effect are. These findings suggest relatively low health risks related to PFAS in Kinshasa compared to Western and Asian countries. In the DRC context, where risk associated to other pollutants such as triclosan, lead or DDT metabolites is higher, resources may be better directed toward these more pressing threats.

Keywords PFAS · Democratic Republic of Congo · Biomonitoring · Health risk · Pollution

Introduction

Polyfluoroalkyl and perfluoroalkyl substances (PFAS) are a group of compounds that are characterized by the presence of at least one CF_3 - or $-\text{CF}_2$ - moiety within their chemical structure. These products boast a range of key properties,

including chemical resistance, water-, grease- and stain repellency, and surfactant effectiveness, making them highly suitable for a variety of applications. Therefore, in their review, Glüge et al. (2020) reported the use of 1400 individual PFAS in more than 200 types of application. However, alongside their widespread industrial use, a growing number of studies have highlighted the deleterious effects of certain PFAS on human health. Although the peer-reviewed literature on PFAS toxicity is continuously and rapidly growing, there is still significant debate on this issue and only a few outcomes are properly supported by scientific evidence (Fenton et al. 2021). Among the properly documented health effects, we can mention disruptions to the immune system. For instance, significant immunosuppressive effects were observed in mice exposed orally to perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) (Vetvicka and Vetvickova 2013). This effect on immunity has also been supported by two epidemiological studies which highlight negative associations between exposure to PFAS

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✉ Patrice Dufour
pdufour@chuliege.be

¹ Laboratory of Clinical, Forensic and Environmental Toxicology, CIRM, CHU Sart-Tilman, University of Liège, B-4000 Liège, Belgium

² Center for Interdisciplinary Research On Medicines (C.I.R.M.), University of Liege (ULiège), CHU (B35), 4000 Liege, Belgium

³ Faculty of Pharmaceutical Sciences, University of Kinshasa, Kinshasa, Democratic Republic of the Congo

during pregnancy and early childhood and vaccine response in children (Abraham et al. 2020; Grandjean et al. 2017). The literature also strongly suggests that PFAS affect the lipid profile: several epidemiological studies have reported a positive association between PFAS blood concentrations and total cholesterol levels (Rebholz et al. 2016; Steenland et al. 2009). These associations are notably highlighted in longitudinal studies (Olsen et al. 2012; Sakr et al. 2007). PFAS could also have deleterious effects on in utero development. Indeed, Verner et al. (2015) concluded in their meta-analysis that PFOA and PFOS are significantly and negatively associated with birth weight. However, these associations have not been confirmed by other meta-analyses using different methodologies (Negri et al. 2017; Steenland et al. 2018). Recently, the International Agency for Research on Cancer (IARC) classified PFOA (one of the most prevalent PFAS in the environment) as a human carcinogen (Group 1) (Zahm et al. 2024). However, this IARC decision has been criticized by some authors (Drury et al. 2024). In its human health toxicity assessment for PFOA, the US Environmental Protection Agency concluded that PFOA is ‘likely carcinogenic to humans’ and emphasized the relationship between this chemical and renal cancer (U.S. Environmental Protection Agency 2024). Therefore, there is still debate about the definitive classification of PFOA as a carcinogen.

In response to these health concerns, restrictions have been implemented on the production and utilization of certain PFAS. For instance, PFOA, perfluorooctane sulfonate (PFOS) and perfluorohexane sulfonate (PFHxS) have been included in the Stockholm Convention on Persistent Organic Pollutants, an international treaty restricting the production and the use of persistent organic pollutants (United Nations 2001). At the same time, biomonitoring studies are being conducted in numerous countries to assess the exposure of the local population to these pollutants. For example, PFAS concentrations were measured several times in the serum of participants of the National Health and Nutrition Examination Survey (NHANES) in the USA (Botelho et al. 2025). In Europe, several research teams from different countries, associated in the European Human Biomonitoring Initiative (HBM4EU) consortium assessed the levels of PFAS in the serum of teenagers (Richterová et al. 2023). PFAS exposure were also determined in many cohorts recruited in countries from the Asia-Pacific region (Kee et al. 2024). Unfortunately, while a significant amount of resources has been and is allocated to biomonitoring studies in North America, Europe and the Asia-Pacific region, this is not the case in other parts of the world. In Sub-Saharan Africa, studies on pollutant exposure are far fewer in number than in Western countries. For example, Kabamba et al. (2021) reported only 12 articles on biomonitoring studies conducted in the Democratic Republic of the Congo (DRC), 10 of which focused on trace elements. This scarcity of data is particularly evident

with regard to PFAS: a review of the literature revealed only five studies measuring PFAS contamination in African populations, including our own pilot study (Bayebila Menanzambi et al. 2021; Dartey et al. 2021; Hanssen et al. 2010; Müller et al. 2019; Sørensen et al. 2023). This lack of data is particularly regrettable because the exposure pattern to PFAS in African countries is probably very different to that observed in developed countries. PFAS are indeed associated with several applications and industrial processes that are unlikely to be common in developing countries, such as metal electroplating, firefighting foam and grease-resistant food packaging (Glüge et al. 2020).

We performed a pilot study on a population of 15 people recruited in Kinshasa in 2019, highlighting relatively low levels of PFAS in this small sample of volunteers (median PFOA and PFOS concentrations were 0.48 ng/mL and 0.50 ng/mL, respectively) (Bayebila Menanzambi et al. 2021). However, since then, no large-scale study has assessed the population’s exposure to these pollutants in the DRC to confirm our preliminary results. The aim of the present study is therefore to measure PFAS serum levels in a larger sample of volunteers recruited in Kinshasa. Recruitment took place between 2022 and 2023 and involved 151 volunteers. This work forms part of a larger project that aims to provide an indicator of the population of Kinshasa’s exposure to environmental pollutants. Several pollutant families (e.g. DDT, polychlorobiphenyls, parabens, bisphenols and lead) were or will be measured in these volunteers recruited in 2022–23. The concentrations measured in biological samples (urine, blood or serum) are compared to health-based thresholds, such as human biomonitoring guidance values, to determine the potential health impacts of chemical exposure in the Kinshasa population. The results of this project could help the DRC authorities to identify and address the most problematic pollutants in Kinshasa. Indeed, few resources are available to combat environmental pollution; identifying the most concerning pollutants could help the authorities to manage these resources more effectively.

Materials and methods

Study population

Our cohort was recruited between November 2022 and January 2023. Blood samples were obtained from 151 volunteers aged between 18 and 80. This study was performed in line with the principles of the Declaration of Helsinki and was approved by the National Health Ethics Committee of the Democratic Republic of Congo under the reference number 401/CNES/BN/PMMF/2022. The recruitment process was previously described in Bayebila Menanzambi et al. (2025). In brief, recruitment took place in 12 communes, which were

randomly selected from the 24 communes in the city (three communes were selected from each of the four districts: Tshangu, Mont-Amba, Funa, and Lukunga). Within each selected commune, volunteers were recruited from randomly selected churches or community associations. Volunteers were selected to ensure similar proportions of each gender and age group in each commune.

Blood samples were collected by venipuncture from volunteers in plastic (polyethylene terephthalate) BD Vacutainer 10-mL clot activator tubes (CATs) (reference no. 367896). The samples were placed directly in an isothermal box and transported to the Clinical Biology Laboratory at the Faculty of Pharmaceutical Sciences, University of Kinshasa, for centrifugation. The serum was collected and stored at -20°C until shipment to Belgium. Samples were shipped to Belgium for analysis in a hermetically sealed container with ice packs. All volunteers signed an informed consent form and completed a questionnaire recording their demographic characteristics and lifestyle habits. Height and weight of the volunteers were measured by the investigator in charge of the recruitment during the sample collection. BMI were categorized according to the standard cut-offs: < 18.5 : underweight; 18.5 to 24.9: normal weight; 25.0 to 29.9: overweight; 30 or greater: obese. Smoking status was defined as current smoker vs. never or former smoker.

PFAS measurement in serum

PFAS concentrations were measured in the Laboratory of Clinical, Forensic and Environmental Toxicology at the University Hospital of Liege (Belgium) using to the method described in Dufour et al. (2025). Fourteen PFAS (namely, perfluoropentanoic acid (PFPeA), perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), PFOA, perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnDA), perfluorobutanesulfonate (PFBS), PFHxS, and linear and total perfluorooctanesulfonate (linPFOS and totPFOS, totPFOS corresponds to sum of linPFOS and branched PFOS), N-Methylperfluorooctane sulfonamidoacetic acid (MeFOSAA) and N-Ethylperfluorooctane sulfonamidoacetic acid (EtFOSAA)) were measured. Briefly, 100 μL of serum were spiked with 20 μL of an internal standard containing a labelled isotope for each target at 0.01 ng/mL. Then, the serum proteins were precipitated by adding 300 μL of methanol. After ultracentrifugation, 50 μL of supernatant were collected and transferred to a liquid chromatography vial containing 50 μL of water. Chromatographic analysis was performed using an Agilent 1290 Infinity II liquid chromatography apparatus coupled to an Agilent 6495 LC/TQ mass spectrometer. Chromatographic separation took place on a Kinetex F5 Core-Shell column (2.1×100 mm, $1.7 \mu\text{m}$) from Phenomenex, with mobile phases consisting of ammonium

acetate 2 mM in water ($\text{pH} = 7$) (phase A) and methanol (phase B).

Total and linear PFOS were quantified with the same calibration curve. The calibration standards were spiked with the PFAS mixture PFAC-24PAR purchased from Wellington Laboratories Inc., Canada. This mixture contains both linear and branched PFOS, and the reported concentration takes all isomers into account. Therefore, the calibration curve was built and totPFOS was quantified by integrating the peaks corresponding to the linear and branched isomers of PFOS. Linear PFOS was quantified using the same calibration curve, but by integrating the peak corresponding to linPFOS. The branched isomers of PFOA and PFHxS were not quantified because they usually represent less than 10% of the total (Schulz et al. 2020).

The PFAS quantification method was validated using the total error approach (Dubois et al. 2012; Hubert et al. 2004). According to this approach, the limits of quantification (LOQ) were defined as the lowest measurable concentrations in samples with a total error of no more than 30%. Limit of detections (LOD) were not used in this study. During the validation process, we demonstrated that the method's coefficients of variation and bias do not exceed 15%. We also demonstrated the linearity of the method within the calibration curve range (0.1 ng/mL to 25 ng/mL). Matrix effects were tested during validation and were found to be between 85 and 115%. In addition of unknown samples, each batch of analyses consisted of a calibration curve (not extracted), one procedural blank, and several quality controls (QCs). The quality controls consisted of materials from the previous Arctic Monitoring and Assessment Program (AMAP), provided by the Institut National de Santé Publique du Québec. For batch validation, the concentrations of PFAS measured within these QCs must fall within the target concentration range of $\pm 20\%$. The laboratory regularly participates in AMAP (three times a year). Furthermore, as the laboratory has successfully participated in several Partnership for the Assessment of Risks from Chemicals (PARC) quality assurance/quality control (QA/QC) programs, the laboratory has been qualified as a 'PARC lab' for PFAS quantification.

Statistical analyses

Statistical analyses were performed using Microsoft Excel (Redmond, WA) and RStudio (version 2023.9.1, CRAN). Given the non-normal distribution of the pollutant concentrations in our population, non-parametric tests were used for the analyses (Spearman rank correlation, Mann-Whitney test, and Kruskal-Wallis test), inferential statistics were performed only with pollutants with detection frequency (DF) above 25%. Based on the recommendations of the National Academy of Sciences, Engineering, and Medicine, we computed for each volunteer the sum of PFOA, PFNA, PFDA,

PFUnDA, PFHxS, total PFOS, and MeFOSAA. These results were reported under the ‘NAS Sum’ appellation. When pollutants were measured below the LOQ, the concentration value was replaced by the LOQ multiplied by DF of the pollutant in our population (Ali et al. 2013; James et al. 2002).

Results and discussion

The characteristics of our study population are presented in Table 1. Serum samples collected during the recruitment were previously used for polychlorobiphenyls and 4,4'-DDE

determination in a previous study (Bayebila Menanzambi et al. 2025) and remaining serum volume was high enough for PFAS analysis for 136 samples out of the 151 collected. Most of the volunteers were male (63.2%) and nonsmokers (80.0%). The median age of our population was 33.5 years (range: 18–80 years), and the median BMI was 25.3 (range: 15.6–39.6). Most participants had a normal BMI (43.4%), but a substantial proportion were overweight (39.0%) or obese (13.2%). The recruitment protocols were designed to equitably represent the four Kinshasa districts; however, the Mont-Amba and Funa districts were overrepresented (34.6% and 31.6%, respectively), and the Lukunga district was underrepresented (12.5%).

Only five of the studied compounds were quantified in more than 10% of the samples: PFNA (81.6% of the samples), PFHxS (89.7%), PFOA (95.6%), linPFOS (97.1%), and totPFOS (100%). The LOQ, DF, and measured concentrations for the seven PFAS in the NAS sum are reported in Table 2. The results presented in Tables 3, 4, and 5 and Table S1 and S2 in the supplementary materials. With the exception of PFOA, all PFAS levels are positively correlated with age (Table 3). These correlations are consistent with those observed in most of recent studies and are probably due to longer exposure to compounds that accumulate in the organism (Jaus et al. 2025; Nilsson et al. 2025; Pirard et al. 2020). Concentrations of PFHxS (median concentrations: 0.290 ng/mL vs 0.180 ng/mL, p -value < 0.001) and PFOA (median concentrations: 0.438 ng/mL vs 0.278 ng/mL, p -value < 0.001) are significantly higher in men than in women (Table 4). This observation is also consistent with most of previous studies and the commonly accepted

Table 1 demographic characteristics of the studied population

Age (years)		
Median	33.5	
IQR	24–49	
Range	18–80	
District (<i>n</i> and %)		
Funa	43	31.6%
Lukunga	17	12.5%
Mont Amba	47	34.6%
Tshangu	29	21.3%
Sex (<i>n</i> and %)		
Male	86	63.2%
Female	50	36.8%
BMI (kg/m ²)		
Median	25.3	
IQR	22.2–27.6	
Range	15.6–39.9	
BMI categories (<i>n</i> and %)		
Underweight	7	5.1%
Normal	58	42.6%
Overweight	53	39.0%
Obese	18	13.2%
Smoking (<i>n</i> and %)		
Yes	26	20.0%
No	104	80.0%

Table 3 Correlations between PFAS concentrations and age

	<i>r</i>	<i>p</i> -value
PFHxS	0.301	< 0.001
PFOA	0.073	0.40
PFNA	0.409	< 0.001
totPFOS	0.418	< 0.001
linPFOS	0.330	< 0.001
NAS Sum	0.378	< 0.001

Table 2 limits of quantification (LOQ), detection frequencies (DF), median, mean, minimum, maximum and quartile concentrations (in ng/mL) for the PFAS included in the National Academies of Sciences, Engineering and Medicine sum (NAS Sum, consisting in the sum of PFOA, PFNA, PFDA, PFUnDA, PFHxS, total PFOS and MeFOSAA) and linear PFOS (linPFOS)

	LOQ	DF (%)	Median	Mean	Min	Max	P25	P75
PFOA	0.1	95.6	0.384	0.473	< LOQ	4.84	0.257	0.565
PFNA	0.1	81.6	0.166	0.190	< LOQ	0.685	0.110	0.223
PFDA	0.2	0.70	< LOQ	< LOQ	< LOQ	0.202	< LOQ	< LOQ
PFUnDA	0.2	0.00	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ
PFHxS	0.1	89.7	0.270	0.276	< LOQ	0.806	0.153	0.362
totPFOS	0.1	100	1.70	1.90	0.343	13.7	1.14	2.26
linPFOS	0.1	97.1	0.675	0.744	< LOQ	4.31	0.335	0.952
MeFOSAA	0.1	5.10	< LOQ	< LOQ	< LOQ	0.564	< LOQ	< LOQ
NAS Sum			2.39	2.88	0.614	15.4	1.85	3.46

Table 4 PFAS median concentrations (in ng/mL) according to sex

	Female	Male	<i>p</i> -value
PFHxS	0.180	0.290	< 0.001
PFOA	0.278	0.438	< 0.001
PFNA	0.184	0.148	0.23
totPFOS	1.58	1.57	0.68
linPFOS	0.611	0.494	0.20
NAS Sum	2.23	2.52	0.14

Table 5 PFAS median concentrations (in ng/mL) according to BMI category

	Underweight	Normal	Overweight	Obese	<i>p</i> -value
PFHxS	0.240	0.225	0.247	0.285	0.695
PFOA	0.463	0.357	0.406	0.401	0.298
PFNA	0.0788	0.141	0.184	0.230	< 0.001
totPFOS	1.43	1.32	1.56	2.26	< 0.001
linPFOS	0.222	0.454	0.595	1.09	< 0.001
NAS Sum	2.37	2.17	2.40	3.73	< 0.001

hypothesis that women have an increased rate of elimination due to menstruations, lactation, and childbirth (Jaus et al. 2025; Nilsson et al. 2025; Pirard et al. 2020). We also observed that levels of PFNA, linPFOS, and totPFOS gradually increased with BMI categories (Table 5). The literature does not consistently report associations between BMI and PFAS. It is unclear whether BMI could predict PFAS serum concentrations or whether PFAS exposure favors overweight and obesity (Fábelová et al. 2023; Pirard et al. 2020). We found no significant differences in PFAS concentration according to district (see Table S1), suggesting that contamination is similar across the whole city. Nevertheless, the limited number of volunteers (especially in the Lukunga district, $n = 17$) means that these results should be treated with caution. Considering smoking status, only PFOA levels were significantly related to this parameter but the significance of this observation is borderline ($p = 0.044$) and may be due to chance.

As is commonly observed in most of the general populations, the compounds with the highest median concentrations are totPFOS, linPFOS, and PFOA (1.70, 0.675 and 0.384 ng/mL, respectively), followed by PFHxS (0.270 ng/mL) and PFNA (0.166 ng/mL). Prior to our study, only four studies (excluding our pilot study) had measured the concentrations of PFAS in blood samples collected in African cohorts (Table 6). Dartey et al. (2021) quantified PFAS (and metals) in the blood of male electronic repair workers, lead battery repair workers, male referents who were not expected to be professionally exposed, and female petty traders who were recruited in Ghana. All 218 volunteers were adults

(ages 18–50), but the recruitment dates were not specified. The PFAS levels reported in this cohort were slightly higher (up to twofold) than those measured in our population. Two studies examined pollutant levels in mothers at or shortly after delivery. Hanssen et al. (2010) assessed contamination in the blood of 71 women recruited in South Africa. Compared to other African cohorts, the levels measured in this South-African population are relatively high and similar to those recently observed in Western countries (Table 6). This may be likely due at least partly to the earlier recruitment of this cohort (2005–2006) compared to the other three African cohorts. Indeed, recruitment took place only a few years after the first restrictions on the production and use of certain PFAS were implemented. Moreover, South Africa is one of the richest countries in Africa. Therefore, its lifestyle and level of economic development are more similar to those of Western countries than those of the other African countries listed in Table 6. The second study was performed in Tanzania on 48 women recruited in 2012 (Müller et al. 2019). In this case, the PFAS levels were slightly lower than those reported in our study. Finally, between 2012 and 2015, Sørensen et al. (2023) collected blood samples from 237 infants aged 4 to 7 months in Guinea-Bissau. Although levels measured in children are usually lower than those observed in adults, the PFAS concentrations in this cohort are slightly higher than those observed in our population of adults.

Overall, the PFAS concentrations measured in our population are similar to or slightly lower than those measured in other African cohorts. However, the picture changes when considering countries outside Africa. Table 6 reports the PFAS contamination observed in several cohorts recruited in different countries. To facilitate comparison between studies, all cohorts in Table 6 involved adults (18 years or older) not occupationally exposed to PFAS, recruited in 2015 or later. In Europe and North America, serum PFAS concentrations are several times higher than that measured in our cohort. However, the highest levels are currently observed in countries in the Asia-Pacific region, where levels are up to one order of magnitude higher than those measured in Kinshasa. For example, the median linPFOS concentration in the South Korean national cohort (KoNEHS) is 20 times higher (14.52 ng/mL) than that observed in our study (Kang and Kim 2024). The median PFOA level in a cohort of Chinese government employees living in an urban environment is over 50 times higher (19.1 ng/mL) (Li et al. 2025) than what was reported in our samples of volunteers recruited in Kinshasa. Very few studies assessed the contamination in regions other than Asia-Pacific, Europe and North America, nevertheless in Saudi Arabia, the level of contamination is also several times higher than those highlighted in Kinshasa (Banjabi et al. 2020). The low level of contamination measured in our population is not surprising; PFAS are mainly associated with advanced industrial sectors (e.g. metal electroplating

Table 6 Median PFAS concentrations (in ng/mL) measured in African populations or in general populations recruited in 2015 or later

Cohort	n	Years of recruitment	PFOA	PFNA	PFDA	PFUdA	PFHxS	PFOSlin	PFOStot	MeFOSAA	Reference
Democratic Republic of Congo, Kinshasa, general population (63.2% men, 36.8% women; age range: 18–80 years)	136	2022	0.384	0.166	<0.200	<0.200	0.27	0.675	1.7	<0.100	This study
African populations											
Democratic Republic of Congo, Kinshasa, pilot study (66.7% men, 33.3% women; age range: 25–66 years)	15	2019	0.48	0.11	<0.200		0.17	0.5			(Bayebila Menanzambi et al. 2021)
Ghana, selected working population (88.1% men, 11.9% women; age range: 18–50 years)	218	Unknown	0.59	0.25	0.14	0.13	0.34	1.4	2.6		(Dartey et al. 2021)
South Africa, pregnant women (at delivery) (100% women; age range: 16–41 years)	71	2005–2006	1.3	0.5			0.5	1.6			(Hanssen et al. 2010)
Tanzania, mothers after delivery (100% women; age range: 19–30 years)	48	2012	0.21	0.17	0.14	<LOQ	<LOQ	0.5			(Müller et al. 2019)
Guinea-Bissau, infants (52% boys, 48% girls; age range: 4–7 months)	237	2012–2015	0.68	0.21	0.19	0.12	0.1	0.77			(Sørensen et al. 2023)
General populations recruited in 2015 or later											
Belgium, Province of Liege, general population (50.4% men, 49.6% women; age range: 18–76 years)	242	2015	1.91	0.54	0.29	0.13	1.07	4.30			(Pirard et al. 2020)
Italy, thyroid cancer patients and healthy controls (22.3% men, 77.7% women; age range: 19–86 years)	224	2022–2023	1.8	0.4	<0.15	<0.15	0.5	2	4.1		(Cirello et al. 2024)
Switzerland, general population (47% men, 53% women; age range: 20–69 years)	630	2020–2021	1.32	0.41	0.24	0.11	1.24	4.58	6.55	<0.050	(Jaus et al. 2025)
USA, NHANES, general population (49.2% men, 50.8% women; age range: 18–80 years)	1700	2017–2018	1.3	0.5	0.2		1.1	3.3	4.8		(CDC and NCHS, (2019)
Canada, national cohort CHMS cycle 5 (49.8% men, 50.2% women; age range: 16–79 years)	1057	2016–2017	1.3	0.52	0.19	<LOQ	0.96	3.3			(Aker et al. 2023)
South Korea, KoNEHS 4, general population (48.7% men, 51.3% women; age range: ≥ 19 years)	2709	2018–2020	6.41	2.03	0.86		3.98	14.52			(Kang and Kim 2024)

Table 6 (continued)

Cohort	<i>n</i>	Years of recruitment	PFOA	PFNA	PFDA	PFUdA	PFHxS	PFOSlin	PFOS _{tot}	MeFOSAA	Reference
China, governmental employees (urban environment) (46.3% men, 53.7% women; age range: 18–60 years)	980	2018–2020	19.1	11.8	8.2	2.7	3	23.1			(Li et al. 2025)
China, adults in the China National Human Biomonitoring cohort (61.1% men, 38.9% women; age range: 18–79 years)	10,855	2017–2018	4.26	0.99	0.58	0.42	0.47	5.15			(Wu et al. 2023)
Saudi Arabia, adults (52.7% men, 47.3% women; age range: 40–89 years)	201	2017–2018	1.33	0.55	<0.050	0.08	1.19	5.08	<0.050		(Banjabani et al. 2020)

and biotechnology) and applications (e.g. ski waxing and firefighting foam), which are unlikely to occur on a large scale in a developing country such as the DRC (Glüge et al. 2020). However, as no data on PFAS contamination in environmental matrices, drinking water or food are available in the DRC, it is difficult to identify the main source of contamination in our population. Further studies on this topic are therefore essential to determine the potential exposure pathways to PFAS in Kinshasa.

The PFAS concentrations measured in our study populations are among the lowest recorded in the last decade. This suggests that PFAS have a relatively low impact on the health of Kinshasa's inhabitants compared to other regions worldwide. To evaluate the health impact of a pollutant (or family of pollutants) on a population, the concentrations measured in biological samples could be compared with the health-based guideline values proposed by different groups of experts. First, we used the human biomonitoring (HBM)-I values proposed by the German HBM Commission for PFOA and linPFOS (Hölzer et al. 2021). HBM-I values are the concentrations of compounds in biological matrices below which no adverse health effects are expected based on current knowledge. According to Hölzer et al. (2021), the HBM-I values for PFOA and linPFOS are 2 ng/mL and 5 ng/mL, respectively. These HBM-I values were chosen due to the potential effects of PFOA and PFOS on the reproductive system, birth weight, lipid profile, immunity, thyroid hormones, and uric acid metabolism. In our cohort, only one individual (0.7%) had serum PFOA above the HBM-I value, and none had serum PFOS above the HBM-I value (Table 7). These percentages are very low compared to those observed in other populations. In a Belgian cohort recruited in 2015, these proportions were 48% and 43%, respectively (Pirard et al. 2020). Data from the NHANES 2017–2018 cycle in the USA revealed that 27% of the population had serum PFOA levels above 2 ng/mL and 31% had PFOS concentrations above 5 ng/mL (Centers for Disease Control and Prevention (CDC) and National Center for Health Statistics (NCHS) 2019). Data from the Korean National Environmental Health Survey (KoNEHS) are not publicly available; however, Kang and Kim (2024) reported 10th percentiles at 3.01 ng/mL for PFOA and at 6.37 ng/mL for PFOS in this cohort. This indicates that more than 90% of participants in the KoNEHS cohort had PFAS levels associated with potential health risks.

Secondly, we compared our results with the 6.9 ng/mL threshold for the sum of PFOA, PFNA, PFHxS and PFOS, proposed by the European Food Safety Authority. This threshold corresponds to the maximum serum concentration required in breastfeeding mothers to prevent adverse effects on the immune system (reduced vaccination response) in breastfed children (EFSA Panel on

Table 7 Proportion of volunteers exceeding health based guidelines values and comparison with data from the cohort of the National Health and Nutrition Examination Survey (NHANES) 2017–2018 cycle. HBM-I: Human biomonitoring level I, NAS sum: National Academy of Sciences, Engineering and Medicine sum consisting in the sum of PFOA, PFNA, PFDA, PFUdA, PFHxS, totat PFOS and MeFOSAA

	Cohort			
	Kinshasa (present study)		NHANES 2017–2018 (USA) ^a	
	N	%	N	%
PFOA HBM^b				
<HBM-I (2 ng/mL)	135	99.3%	1234	72.6%
≥HBM-I (2 ng/mL)	1	0.7%	466	27.4%
PFOS HBM^b				
<HBM-I (5 ng/mL)	136	100.0%	1169	68.8%
≥HBM-I (5 ng/mL)	0	0.0%	531	31.2%
NAS sum^c				
<2 ng/mL	46	33.8%	178	10.4%
≥2 and <20 ng/mL	90	66.2%	1490	87.6%
≥20 ng/mL	0	0.0%	32	1.9%

^aCenters for Disease Control and Prevention (CDC) and National Center for Health Statistics (NCHS) (2019), ^bHölzer et al. (2021), ^cNational Academies of Sciences, Engineering and Medicine (2022)

Contaminants in the Food Chain 2020). In our sample, only five individuals (3.7%) exceeded this threshold. The third health guidelines selected come from the ‘Guidance on PFAS Exposure, Testing and Clinical Follow’ of the National Academies of Sciences, Engineering and Medicine (2022). This document proposes two thresholds for the sum of PFOA, PFNA, PFDA, PFUdA, PFHxS, totPFOS, and MeFOSAA. Below 2 ng/mL, no adverse health effects related to PFAS are expected. Between 2 and 20 ng/mL, there is potential for adverse effects, especially in sensitive populations. Above 20 ng/mL, the risk of adverse health effects increases. In our cohort, 33.8% had a PFAS sum below 2 ng/mL, 66.2% had a PFAS sum between 2 and 20 ng/mL, and no volunteer had a PFAS sum exceeding 20 ng/mL. Again, these percentages are relatively low compared to those in Western countries. In the 2017–2018 NHANES cohort, these proportions were 10.4%, 87.6%, and 1.9%, respectively. We can be pleased to note the high proportion of volunteers in Kinshasa presenting PFAS levels associated with no health risk compared to most of the studied cohorts worldwide. However, the guidelines of the German HBM Commission and the National Academies of Sciences, Engineering and Medicine were established prior to the International Agency for Research on Cancer (IARC) classifying PFOA as ‘carcinogenic to humans’ (Group 1) (Zahm et al. 2024). Some authors (Drury et al.

2024) have criticized this classification of PFOA as carcinogenic to humans, and the US EPA has stated that PFOA is ‘likely carcinogenic to humans’. Nevertheless, in its assessment of PFOA toxicity, the US EPA proposed an increase in the risk of renal cell carcinoma per 1 ng/mL increase in serum at $3.52 \times 10^{-3} \text{ (ng/mL)}^{-1}$ (U.S. Environmental Protection Agency 2024). This factor could be revised in the future as our understanding of PFOA’s carcinogenicity improves. Nevertheless, in its current state, this factor indicates that even in populations with low exposure to PFOA, the increased cancer risk is significant. The cancer risk associated with exposure to PFOA among the population of Kinshasa is therefore unlikely to be zero. While health risks related to PFAS should not be ignored, our previous studies have shown that exposure to some other pollutants is significantly higher, and the associated health concerns are far more significant. For example, in the same cohort as in the present study, we found that 57% of our volunteers exceeded the WHO threshold of 50 µg/L for blood lead levels, and 12.6% exceeded the level of 100 µg/L associated with anaemia, cognitive impairment, hypertension, and spontaneous abortion (Bayebila Menanzambi et al. 2025). We also measured several non-persistent pollutants in the urine of our volunteers, highlighting that 15% had urinary levels of mono-n-butyl phthalate (a plasticizer metabolite) that exceeded the HBM guidance value threshold of 190 µg/L proposed by the HBM4EU consortium (Apel et al. 2023). Finally, the levels of triclosan measured in our population are among the highest ever reported in the literature. Given the demonstrated endocrine-disrupting properties of this antiseptic, the presence of our population of volunteers recruited in Kinshasa among the most heavily exposed populations worldwide is concerning (Bayebila Menanzambi et al. submitted).

Our study is the only middle to large-scale study to assess PFAS serum concentrations in Africa since 2015, and the only one to take place in DRC. Our results are thus the first indicator of the PFAS contamination in Kinshasa. Nevertheless, the population of Kinshasa exceeds 17 million people living in a wide variety of environments and the surface of the city is 9965 km², an area similar to those of Cyprus for instance. Therefore, our limited cohort of 136 people could not be considered perfectly representative of the entire Kinshasa population. For instance, the median age in our study population is 33.5 years while the median age in DRC is below 20 years, the men are over-represented in our study population and finally, recruitment took place in churches and community associations which could induce a selection bias. Another limitation of our study is the limited number of variables explored in our questionnaire. For instance, we did not collect data related to occupation, diet and socioeconomic status.

Conclusions

Although the representativeness of our data is limited with regard to the entire Kinshasa population, our study provides the first indication of exposure to PFAS in the capital of the DRC. Environmental pollution is detrimental to human societies, particularly with regard to health concerns. Therefore, governments must dedicate resources to combatting this phenomenon. The DRC is one of the poorest countries in the world and has limited environmental legislations. As a result, resources should be allocated to combat the most problematic pollutants. This study is part of a broader project that aims to identify these pollutants. Further research is warranted, but our results suggest that exposure to PFAS in Kinshasa is relatively low compared to other countries and the associated health risks are therefore probably limited. In conclusion, whereas significant resources are allocated to combatting PFAS exposure in Western countries, in the case of the DRC, these resources would likely be better utilized in addressing other types of pollution.

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Data availability The datasets generated during and/or analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Declarations

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki and was approved by the National Health Ethics Committee of the Democratic Republic of Congo under the reference number 401/CNES/BN/PMMF/2022. All volunteers signed an informed consent.

Consent to participate Written informed consent was obtained from all individual participants included in the study. All participants in the study were informed about the research project and each of them signed the informed consent to participate in the study.

Consent for publication Participants signed informed consent regarding publishing their data for scientific purposes.

Competing interests The authors declare no competing interests.

Clinical trial number Not applicable.

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