

Perfluoroalkyl and polyfluoroalkyl (PFAS) in tap water in the southern key economic region

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Abstract: *Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) are durable, artificial chemicals used widely in household products. Over time, they accumulate in the environment-contaminating water sources, air, and drinking water and pose potential health risks. This study investigates PFAS concentrations in tap water from Vietnam's Southern Key Economic Region (SKER), including Binh Duong, Long An, Tien Giang, Dong Nai, Ba Ria - Vung Tau, Binh Phuoc, Tay Ninh, and Ho Chi Minh City. Between May and August 2022, researchers collected 24 tap water samples from households and analyzed them using solid-phase extraction and UPLC-MS/MS. The analysis revealed that PFAS were detected in 21 out of 24 samples, with the number of compounds identified per sample varying between zero and six and an average of five. Among them, PFOS was the most frequently detected, appearing in 87.5% of the samples. Six compounds - PFHxA, PFHpA, PFOA, PFDA, PFBS, and PFOS – co-occurred in 4.2% of samples. Total PFAS concentrations ranged from undetectable levels to 6.83 ng/L, with an average of 1.12 ± 1.42 ng/L. The most prominent compounds-PFBS, PFOS, and PFOA-accounted for 36.4%, 26.6%, and 15.2% of total PFAS levels, respectively. Concentrations of PFOA and PFOS were below the U.S. EPA's 2023 Health Advisory Level of 4 ng/L, indicating low exposure risk ($HQ < 0.1$). Nevertheless, the potential for PFAS bioaccumulation suggests possible long-term health risks, highlighting the need for continuous monitoring of water sources in Vietnam to safeguard public health.*

Keywords: *PFAS, tap water; LC-MS/MS; the Southern Key Economic Region*

1. Introduction

PFAS encompass a broad category of artificially fluorinated organic substances containing fluorine, first created in the 1930s. Estimates suggest that the class comprises 5,000 to 10,000 distinct compounds [1, 2]. The carbon-fluorine bonds within PFAS molecules confer exceptional chemical stability and efficient surfactant characteristics. Consequently, PFAS have found widespread application across various industrial sectors and consumer products since their introduction, including in surface protection agents, non-stick cookware, waterproof clothing, stain-resistant textiles and carpets, and the production of fluorinated polymers [3-5]. These compounds are becoming increasingly prevalent in the aquatic environments of industrialized nations [6-8].

Although widely utilized, PFAS are increasingly acknowledged as persistent environmental pollutants, commonly known as "forever chemicals." Their resistance to natural degradation processes results in their accumulation within soil, water, and living organisms. Rising concerns about PFAS stem from their potential toxicity, bioaccumulation, and association with negative health impacts, including cancer, immune system suppression, and developmental abnormalities. [9-12].

Current research focuses on understanding their distribution, pathways of environmental persistence, and effective mitigation strategies. Global regulatory efforts aim to restrict the production and use of long-chain PFAS, while attention is also turning to short-chain alternatives and their environmental implications [12-14].

Vietnam faces growing chemical pollution due to rapid industrialization, making effective waste management strategies essential [15, 16]. Currently, data on PFAS production and imports in the country are not yet publicly available. Although extensive information on PFAS contamination is available globally, data on the sources and presence of PFAS in Vietnam remain limited. Previous studies have provided only preliminary insights into PFAS contamination in isolated regions of the country. Despite this, there have been no studies to date that specifically examine PFAS in tap water within Vietnam's major cities and key economic zones - regions characterized by dense industrial and residential activities, which could pose a risk of PFAS contamination in water sources. Additionally, as PFAS are classified as emerging contaminants, regulatory guidelines on permissible concentrations and pollution control for PFAS remain limited both globally and in Vietnam.

The SKER comprises eight provinces and cities: Binh Duong, Long An, Tien Giang, Dong Nai, Ba Ria - Vung Tau, Binh Phuoc, Tay Ninh, and Ho Chi Minh City. This region is a major driver of Vietnam's economic development, containing numerous industrial zones focused on sectors such as oil and gas, steel production, electric power, chemicals, and fertilizers. Rapid industrial growth in the SKER brings significant environmental challenges, with large volumes of industrial, agricultural, and household waste raising concerns over potential PFAS contamination [17].

The study aims to assess PFAS contamination in tap water from Vietnam's Southern Key Economic Region, which is both timely and essential. This research provides novel insights into PFAS concentrations in tap water across southern Vietnam, evaluates exposure risks and the need for ongoing water quality monitoring to safeguard public health, offers a foundation for water treatment technology development, and supports environmental managers in controlling PFAS emissions.

2. Material and methods

2.1 Sampling site

This study investigates the concentrations of PFAS in household tap water across the SKER of Vietnam. The SKER includes the provinces of Binh Duong, Long An, Tien Giang, Dong Nai, Ba Ria - Vung Tau, Binh Phuoc, Tay Ninh, and Ho Chi Minh City. In each province, three tap water samples were obtained from three separate residences between May and August 2022 (Figure 1). The study also included the collection of three blank samples and three field duplicate samples. The water samples were stored in 2 L HDPE (High-Density Polyethylene) bottles containing 2 g of ammonium acetate [18]. The HDPE bottles were pre-rinsed with methanol and Milli-Q water. Samples were maintained at 0–4°C until analysis for PFAS concentrations.

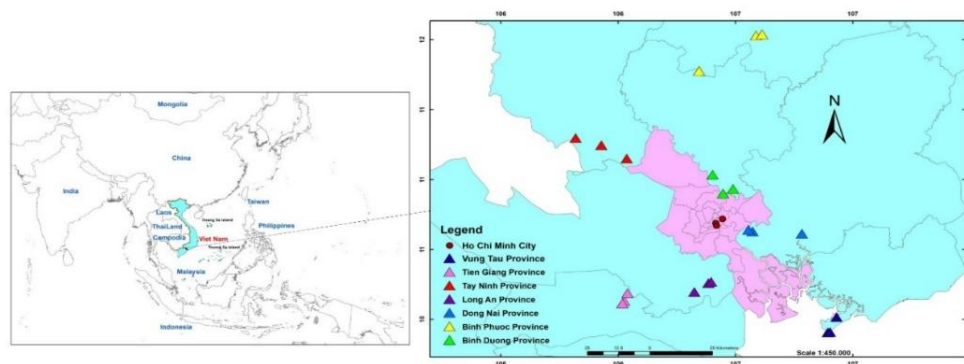


Fig. 1. Map of tap water sampling locations in the SKER

2.2 Chemicals and analytical procedure

Mixed 12 PFAS standard including perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorooctanoic acid (PFOA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnA), perfluorotridecanoic acid (PFTrDA), perfluorododecanoic acid (PFDoA), perfluorobutane sulfonic acid (PFBS), perfluorohexane sulfonic acid (PFHxS), perfluoroheptane sulfonic acid (PFHpS), perfluorooctane sulfonic acid (PFOS), 6:2 fluortelomersulfonate (6:2 FTS) at 1 were purchased from Wellington Lab. (Canada). Internal standards perfluoro-*n*-[1,2,3,4-¹³C₄] octanoic acid (MPFOA), sodium perfluoro-1-[1,2,3,4-¹³C₄] octanesulfonate (MPFOS) and surrogate standards perfluoro-*n*-[¹³C₈] octanoic acid (M8PFOA) & sodium perfluoro-1-[¹³C₈] octanesulfonate (M8PFOS) were at 50 ± 2.5 µg/mL were also from Wellington Lab (Canada). Methanol (HPLC grade, 99.7% purity), acetone (99.5% purity), ammonium acetate (99% purity), and ammonium formate (99% purity) were from Merck, Germany.

10 µL of a 20 ng/mL surrogate standard was added into 250 mL of tap water then allowed to equilibrate for 30 minutes prior to solid-phase extraction. The sample was processed using an Oasis HLB cartridge preconditioned with 4 mL of methanol (MeOH) and 4 mL of Milli-Q water, followed by sample loading at approximately 3 mL/min. The column was then dried to remove residual water, and PFAS compounds were eluted with 8 mL of acetone. The eluent was carefully evaporated under nitrogen (N₂) and reconstituted in 1 mL of MeOH: H₂O (1:4, v/v). The sample was subsequently filtered through a 0.22 µm nylon filter, and 10 µL of a 20 ng/mL internal standard was added prior to analysis using a UPLC-MS/MS Triple Quad™ 3500 (Sciex). The analytical method for PFAS followed the published method [19].

To determine the method detection limit, seven tap water samples were spiked with a 12-PFAS mixture at 0.1 ng/L and analyzed in replicates. The limit of detection (LOD) and limit of quantitation (LOQ) were determined using samples with concentrations close to the LOQ (n=7), resulting in LOD values ranging from 0.02 to 0.05 ng/L and LOQ values between 0.05 and 0.17 ng/L. No PFAS were detected in field blanks, and field duplicates showed repeatability (RSD: 0.37%–8.08%). Surrogate standard recoveries were 95.0%–118.5% (M8PFOA) and 99.5%–119.5% (M8PFOS). Spiked sample recoveries ranged from 77.5% to 119.5%.

3. Results and discussion

3.1 PFAS concentration levels and detection rates

In this study, the number of PFAS compounds detected in household tap water samples from the SKER ranged from non-detectable levels to six out of the twelve analyzed substances, including PFHxA, PFHpA, PFOA, PFDA, PFBS, and PFOS. Compounds such as PFHxS, PFHpS, PFUnA, PFTrA, PFDoA, and 6:2 FTS were not detected in any samples, suggested relatively low PFAS contamination levels in tap

water across these provinces, with some compounds absent (Figure 2). Similarly, a study conducted in China reported no detection of PFAS compounds such as PFHxS, PFDA, PFUnA, PFTrA, and PFDoA. In contrast, PFOA, PFOS, PFBS, PFHxA, and PFHpA were frequently identified, with PFOS and PFOA exhibiting concentration ranges of < 0.5–94.9 ng/L and < 0.1–475 ng/L, respectively [20].

The analysis of 12 PFAS compounds in household tap water samples across the SKER revealed diverse contamination patterns, with total PFAS concentrations ranging from as low as 0.03 ng/L in Tay Ninh to a peak of 3.14 ng/L in Dong Nai. Among the detected compounds, PFBS exhibited the highest individual concentration, reached 1.05 ng/L in Dong Nai, while PFOS also showed significant levels, peaking at 0.82 ng/L in the same region. In contrast, PFHpA exhibited the lowest concentrations, reaching up to 0.17 ng/L detected in Long An and PFDA, which appeared only in Ho Chi Minh City at 0.05 ng/L. Several PFAS compounds, including PFUnA, PFDoA, PFTrA, PFHxS, PFHpS, and 6:2 FTS, were not found in any of the samples, indicating either a scarcity of sources or the implementation of effective control measures in the area (Table 1).

Short-chain PFAS, such as PFBS (0.29 – 1.05 ng/L) and PFHxA (non-detectable – 0.36 ng/L), were among the most commonly identified and exhibited relatively higher concentrations across most locations. Short-chain PFAS are widely used as replacements for long-chain compounds in industrial processes and are recognized for their higher mobility in water [7, 10, 21], which likely explains their prevalence in this study. PFBS, in particular, was consistently detected in nearly all locations and contributed significantly to the total PFAS load, especially in Dong Nai (33.4% of total PFAS) and Ho Chi Minh City (26.4% of total PFAS). Long-chain PFAS, including PFOA (0.03–0.76 ng/L) and PFOS (0.06–0.82 ng/L), were also commonly detected but at generally lower concentrations compared to short-chain compounds. These long-chain compounds were typically associated with historical industrial use and legacy contamination, which persisted in the environment due to their high stability and bioaccumulative nature. Detection frequency varied among compounds, reflecting differences in sources and environmental behaviour. Compounds with shorter chains, like PFBS and PFHxA, were identified more reliably, indicating continuous contributions from industrial or urban activities. Conversely, PFDA and PFHpA (long-chain PFAS) were identified only intermittently, suggested the presence of localized contamination sources [7, 10, 21, 22]. The absence of certain compounds, particularly higher-chain carboxylic acids like PFUnA, PFDoA, and PFTrA, suggested either effective containment or their minimal use in regional industrial processes.

Overall, the results highlight the dominance of short-chain PFAS in water contamination profiles, with concentrations like PFBS at 1.05 ng/L and PFHxA at 0.36 ng/L, likely driven by their current industrial usage. Meanwhile, long-chain PFAS contributed to contamination in areas with historical industrial activity, with notable levels such as PFOS at 0.82 ng/L and PFOA at 0.76 ng/L. These findings emphasized the need for region-specific mitigation strategies targeting both short- and long-chain PFAS to address their distinct environmental behaviours and health implications.

Tab. 1: Levels of PFAS compounds present in domestic tap water within the SKER

(Unit: ng/L)

No.	Sampling sites	PFHxA	PFHpA	PFOA	PFDA	PFTrA	PFDoA	PFUnA	PFBS	PFHxS	PFHpS	PFOS	6:2 FTS	PFAS
1	Binh Duong - 1	0.088	0.034	0.070	ND	ND	ND	ND	0.284	ND	ND	0.784	ND	1.261
2	Binh Duong - 2	0.212	0.064	0.072	ND	ND	ND	ND	0.416	ND	ND	0.341	ND	1.104
3	Binh Duong - 3	0.075	0.039	0.016	ND	ND	ND	ND	0.174	ND	ND	0.692	ND	0.996
4	Long An - 1	0.484	0.512	0.416	ND	ND	ND	ND	1.516	ND	ND	0.176	ND	3.104
5	Long An - 2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	Long An - 3	ND	ND	ND	ND	ND	ND	ND	0.017	ND	ND	0.014	ND	0.032
7	Tien Giang - 1	ND	0.006	0.060	ND	ND	ND	ND	0.185	ND	ND	0.273	ND	0.524
8	Tien Giang - 2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.037	ND	0.037
9	Tien Giang - 3	0.274	0.068	0.035	ND	ND	ND	ND	1.644	ND	ND	0.079	ND	2.101
10	Dong Nai - 1	0.756	0.342	1.268	ND	ND	ND	ND	2.488	ND	ND	1.972	ND	6.826
11	Dong Nai - 2	0.150	0.032	0.452	ND	ND	ND	ND	0.370	ND	ND	0.271	ND	1.275
12	Dong Nai - 3	0.160	0.082	0.564	ND	ND	ND	ND	0.278	ND	ND	0.225	ND	1.308
13	Ba Ria - Vung Tau - 1	0.096	0.032	0.020	ND	ND	ND	ND	0.362	ND	ND	0.031	ND	0.542
14	Ba Ria - Vung Tau - 2	0.314	0.072	0.150	ND	ND	ND	ND	0.321	ND	ND	0.070	ND	0.926

No.	Sampling sites	PFHxA	PFHpA	PFOA	PFDA	PFTrA	PFDoA	PFUnA	PFBS	PFHxS	PFHpS	PFOS	6:2 FTS	PFAS
15	Ba Ria - Vung Tau - 3	0.229	0.072	0.079	ND	ND	ND	ND	0.462	ND	ND	0.096	ND	0.938
16	Binh Phuoc - 1	0.236	0.198	ND	ND	ND	ND	ND	0.033	ND	ND	0.025	ND	0.492
17	Binh Phuoc - 2	0.118	0.014	0.032	ND	ND	ND	ND	0.078	ND	ND	0.213	ND	0.456
18	Binh Phuoc - 3	0.066	ND	0.153	ND	ND	ND	ND	0.130	ND	ND	0.680	ND	1.030
19	Tay Ninh - 1	ND	0.029	ND	ND	ND	ND	ND	ND	ND	ND	0.053	ND	0.081
20	Tay Ninh - 2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21	Tay Ninh - 3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22	Ho Chi Minh City - 1	0.236	ND	0.200	0.066	ND	ND	ND	0.298	ND	ND	0.420	ND	1.221
23	Ho Chi Minh City - 2	0.264	0.072	0.328	0.057	ND	ND	ND	0.460	ND	ND	0.404	ND	1.585
24	Ho Chi Minh City - 3	0.296	ND	0.164	0.037	ND	ND	ND	0.271	ND	ND	0.306	ND	1.074

ND: not detected.

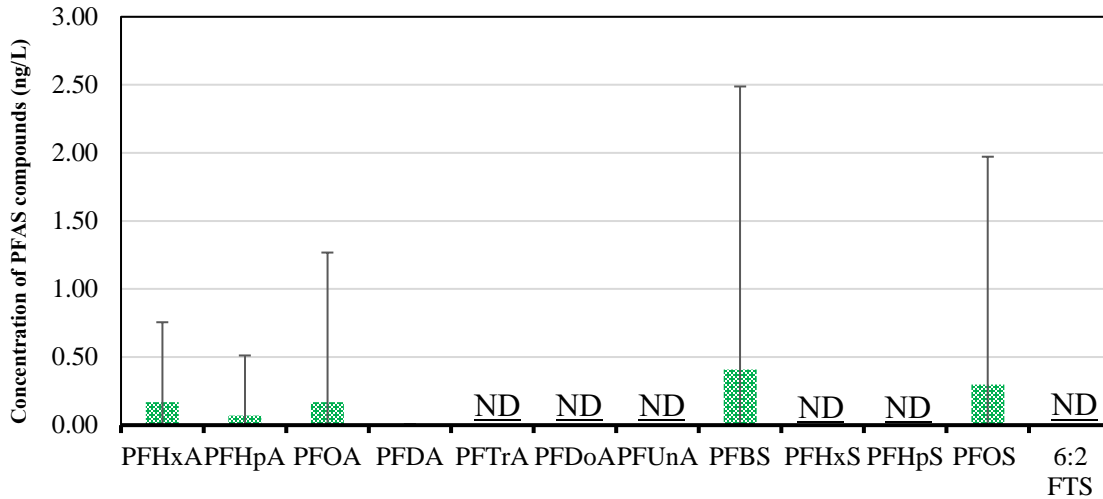


Fig. 2. PFAS concentrations in tap water within the SKER

Binh Duong, Dong Nai, and Ho Chi Minh City have been critical drivers of Vietnam’s economic growth for many years, focusing heavily on increasing Gross Regional Domestic Product (GRDP) through industrial development. However, this industrialization has caused considerable pollution in water sources, affecting both groundwater and surface water. The average PFAS concentration in Ho Chi Minh City was recorded at 1.29 ng/L, which was approximately 2.4 times lower than the average concentration in Dong Nai but 1.2 times higher than in Binh Duong (Figure 3). The total PFAS concentration in household tap water was highest in Dong Nai when compared to Ho Chi Minh City, Binh Duong, and nearby provinces. This difference may be linked to variations in water treatment systems across the regions.

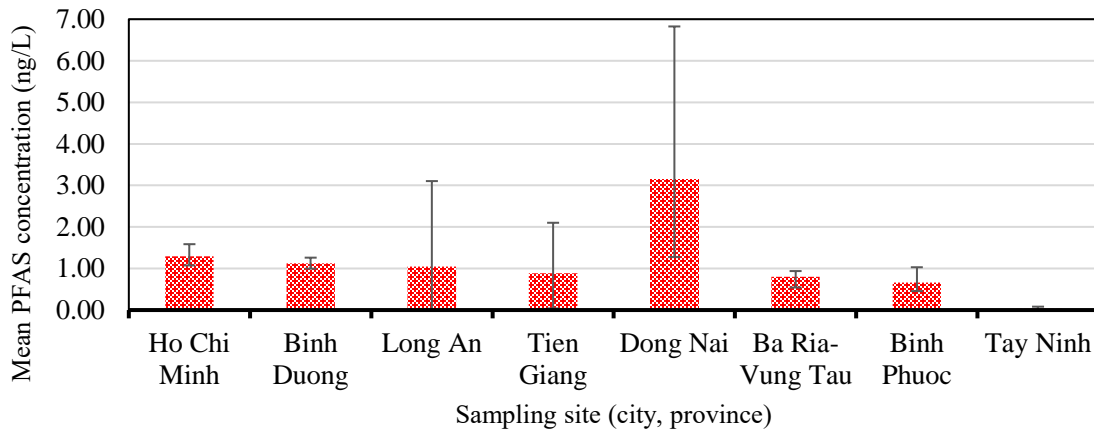


Fig. 3. Average ΣPFAS concentration in the Southern Key Economic Region

3.2 Spatial distribution and proportional analysis

PFAS, including PFOA, PFOS, and PFBS, were often found simultaneously in aquatic environments because they originate from familiar sources and were resistant to environmental degradation [23]. The bioaccumulation potential of these substances varied with chain length: PFOS and PFOA, with longer carbon chains, exhibit higher tendencies to accumulate in organisms, whereas PFBS, with its shorter chain, was generally less bioaccumulative but remains environmentally persistent, posing significant long-term risks in water systems. Regarding potential impacts on human and environmental health, PFOS and PFOA are associated with notable toxicity, linked to possible carcinogenicity and developmental concerns. Although PFBS is somewhat less toxic, it can still impact aquatic organisms and disrupt ecosystems, particularly in combination with other PFAS compounds [24-26].

PFAS concentrations across the SKER showed apparent regional differences, influenced by variations in industrial activity, urban growth, and the effectiveness of water treatment systems. Among the regions, Dong Nai recorded the highest levels of contamination, with a total PFAS concentration of 3.14 ng/L. It was dominated by PFBS (33.3%), PFOS (26.2%), and PFOA (24.3%), all of which are linked to industrial discharges and legacy pollution from older manufacturing practices [10, 13, 27]. The elevated levels in Dong Nai highlight intense industrial activity, particularly in sectors such as textiles, electronics, and chemical production.

Provinces such as Tay Ninh and Binh Phuoc reported the lowest total PFAS concentrations, at 0.03 ng/L and 0.66 ng/L, respectively. This is likely due to their lower levels of industrial activity and more efficient water treatment systems, which result in reduced contamination. Ho Chi Minh City, the region's primary metropolitan hub, recorded a moderate total PFAS concentration of 1.29 ng/L, primarily driven by PFOS (29.1%), PFBS (26.5%), and PFOA (17.9%). Similarly, Ba Ria–Vung Tau showed moderate contamination levels of 0.80 ng/L, reflecting a combination of industrial and urban sources, with PFOS (28.2%) and PFBS (22.5%) as dominant contributors.

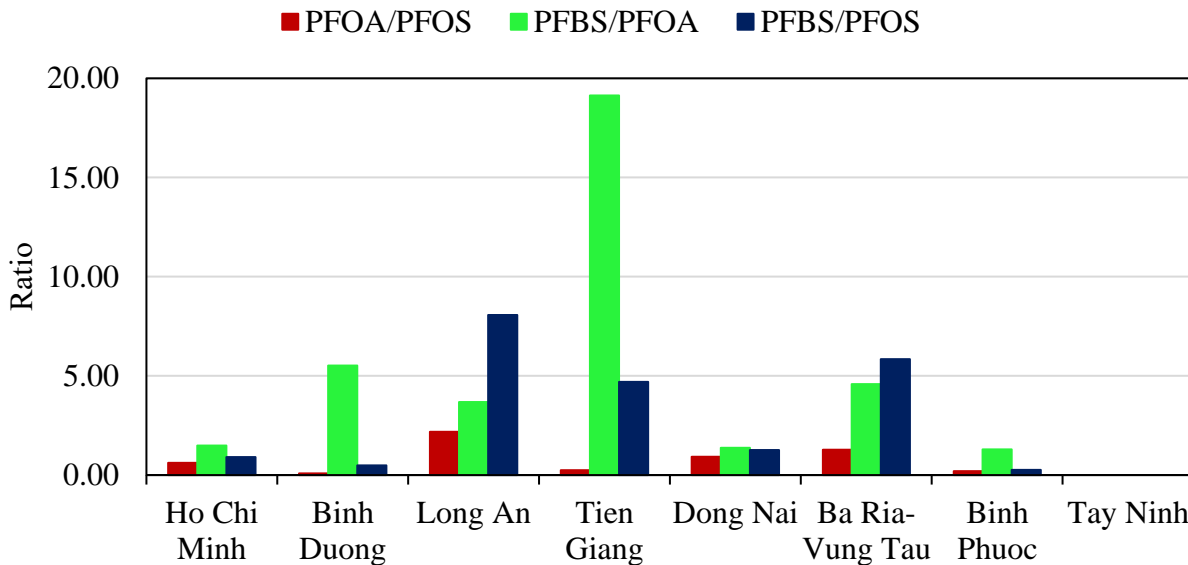
Proportional analysis of PFAS contributions revealed distinct trends across regions. Short-chain PFAS, such as PFBS, dominated in most provinces, likely due to their replacement of long-chain PFAS in industrial applications as a less bioaccumulative alternative. PFBS ranged from contributing 26.0% in Binh Duong to 33.3% in Dong Nai, demonstrating its widespread prevalence. However, long-chain PFAS like PFOA and PFOS also contributed significantly, particularly in areas with historical industrial activity or legacy pollution. For instance, PFOA accounted for 24.3% of total PFAS in Dong Nai, reflecting its industrial usage, while PFOS contributed 26.2% and 29.1% of total PFAS in Dong Nai and Ho Chi Minh City, respectively.

Studies of water environments reveal that PFOS and PFOA were often found in higher concentrations, primarily attributed to their extensive past industrial applications and prolonged half-lives. Meanwhile, PFBS, typically present at lower concentrations, was being detected more frequently as it is increasingly used as a replacement for PFOS and PFOA in various industrial processes. The comparative levels of these PFAS compounds helped identify contamination sources, differentiating between legacy pollution from past manufacturing activities (marked by higher PFOS and PFOA levels) and newer sources of contamination, indicated by increased PFBS levels [7, 28]. These results were consistent with findings from this study, where the PFOA/PFOS concentration ratio was mainly below one across sampling locations, ranged from 0.09 to 0.93, indicated potential health risks primarily linked to PFOS. However, in Long An and Ba Ria–Vung Tau provinces, the PFOA/PFOS ratios were 2.19 and 1.28, respectively (greater than 1), which may indicate a relatively higher presence of PFOA in drinking water [7]. The ratio of PFBS to PFOA in this research varied between 1.3 and 19.1, while the PFBS/PFOS ratio varied from 0.26 to 8.07 (Figure 4). These values suggested that PFBS may be gradually replaced by PFOA and PFOS [4, 29, 30].

The regional variations and proportional differences emphasized the influence of local industrial practices, urban infrastructure, and water management systems on PFAS contamination. Therefore, focusing remediation efforts on key areas like Dong Nai while maintaining low contamination levels in regions such as Tay Ninh relies on identifying these trends. The urgent need for clearly defined strategies to effectively address both short-chain and long-chain PFAS is underscored by this spatial analysis. Such measures were essential to safeguard the quality of drinking water and to promote environmental sustainability in the long

run. These long-chain compounds, while less frequently used today, persisted in the environment and are often released from soil and sediment into water systems [7, 31].

Fig. 4. PFOA, PFOS and PFBS ratio in tap water



In table 2, PFOA, PFOS, and PFBS were detected at concentrations higher than other PFAS compounds in tap water, with average concentrations of 0.17 ng/L, 0.30 ng/L, and 0.41 ng/L, respectively. Compared to global studies, the PFOA concentration in this study was nearly three times higher than that in Norway. At the same time, PFOS levels were similar, and PFBS levels were approximately five times higher. In Bangkok (Thailand), the PFOA concentration was comparable to that found in this study, though PFOS was not detected. For studies in Da Nang (Vietnam) in 2016 and in China in 2024, the PFOA concentration in this study was about 67 and 65 times lower, respectively, and the PFOS concentration was approximately 6 and 12 times lower. The PFBS concentration was four times lower than that observed in China and was undetected in Da Nang. In Shanghai, the concentrations of PFOA and PFBS were similar to those in this study, while PFOS levels were four times higher. In summary, the concentrations of PFOA, PFOS, and PFBS in this analysis were higher than those in Norway, comparable to levels in Shanghai, and significantly lower than in other studies.

Tab. 2. A comparison of tap water concentrations of PFOA, PFOS, and PFBS in the SKER with results from various international studies.

(Unit: ng/L)

Country	PFOA	PFOS	PFBS	References
SKER (Viet Nam)	0.17	0.30	0.41	This study
Da Nang (Viet Nam)	11.4	1.7	-	Nguyen Hoang Lam et al 2016 [32]
Bangkok (Thailand)	0.18	ND	-	Wadcharid Tabtong et al. 2015 [33]
Shanghai (China)	1.81	1.22	0.40	Ao et al. 2019 [34]
China	10.97	3.63	1.67	Li et al. 2024 [35]
Norway	0.058	0.25	0.077	Grung et al. 2024 [36]

3.3. Evaluating human risk from PFAS exposure

Exposure to PFAS in humans could occur through the consumption of food, drinking water, household dust, and indoor air [37]. The average daily intake (ADI) in $\text{ng kg}^{-1} \text{d}^{-1}$ was calculated through the drinking water exposure pathway [34]. We estimated the ADI for both males and females based on the assumption that males consume 3.7 litres of water daily while females consume 2.7 litres [38, 39]. The average body weights for males and females were estimated to be 62 kg and 50 kg, respectively, based on the Vietnamese Ministry of Health’s Vietnam Health and Nutrition Survey report (dated April 15, 2021) and WHO’s 2020 Global Health Report.

$$ADI = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

In this formula, C denotes the median PFAS concentration in the samples, IR refers to the ingestion rate, EF indicates the exposure frequency, ED represents the exposure duration, BW corresponds to the body weight, and AT signifies the average exposure time.

The hazard quotient (HQ) was calculated to offer an initial quantitative evaluation of the health risks posed by PFAS to humans [34].

$$HQ = \frac{ADI}{RfD}$$

Here, RfD represents the reference dose of PFAS ($\text{ng kg}^{-1} \text{bw day}^{-1}$), with RfD values for PFOA and PFOS being $333 \text{ ng kg}^{-1} \text{bw day}^{-1}$ and $25 \text{ ng kg}^{-1} \text{bw day}^{-1}$, respectively [40]. Due to a lack of specific RfD values for other PFAS, the RfD for PFCA was assumed to be similar to PFOA, while PFSA was considered to be identical to PFOS [34].

Based on the HQ value guidelines provided by Lemly et al. [41], an $HQ < 0.1$ indicates no risk; HQ between 0.1 and 1.0 indicates a low risk; HQ between 1.1 and 10 indicates a moderate risk; and $HQ > 10$ indicates a high risk. The results in Table 3 show that HQ values for the studied PFAS compounds were shallow, suggested no risk for both males and females, with HQ ranging from 0 to 0.0065 and 0 to 0.0059, respectively. For total PFAS in tap water samples, HQ values were 0.014 for males and 0.015 for females (Table 3). Although the HQ values in this study were well below the warning threshold, the bioaccumulative potential of these compounds could lead to long-term and unpredictable effects, warranted regular monitoring programs and further research on other exposure pathways [37]. Additionally, the number of PFAS compounds studied here represents only a tiny subset of the PFAS family; hence, actual exposure levels may exceed the calculated HQ values.

Tab. 3. The hazard quotient (HQ) of PFAS for both male and female

Compound	PFHxA	PFHpA	PFOA	PFDA	PFBS	PFOS	∑ PFAS
Male	0.0024	0.0006	0.0012	0	0.0065	0.0046	0.015
Female	0.0022	0.0005	0.0011	0	0.0059	0.00420	0.014

4. Conclusions

The findings of the study indicated that up to six of the twelve PFAS compounds were identified in tap water samples, with PFBS, PFOS, and PFOA exhibiting the highest average concentrations of 36.4%, 26.6%, and 15.2%, respectively. The concentrations of both PFOA and PFOS were below the U.S. EPA’s 2023 allowable limit of 4 ng/L. Notably, PFOS concentrations generally exceeded those of PFOA. In contrast, PFBS concentrations were higher than both PFOS and PFOA, suggesting that PFBS is increasingly replacing PFOA and PFOS in local water sources.

The total PFAS concentration was highest in Dong Nai Province, followed by Ho Chi Minh City and Binh Duong Province, indicated geographical variation in PFAS levels. Risk assessment analysis showed that all six identified PFAS compounds had a hazard quotient (HQ) of less than 0.1 for both males and females, suggesting a low level of human exposure through tap water. However, the presence of unidentified PFAS compounds and the potential for exposure through other pathways underscore the need for continued attention to potential health risks.

This study marked the first detailed assessment of PFAS in household tap water across the SKER and provided valuable insights into the occurrence and distribution of PFAS. These findings contributed critical information on water quality for public awareness and regulatory use and supported decision-making in water management and pollution control for the region.

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