Contamination, bioaccumulation and toxic effects of perfluorinated chemicals (PFCs) in the water environment: a review paper

Fatihah Suja, Biplob Kumar Pramanik and Shahrom Md. Zain

ABSTRACT

Perfluorinated compounds such as perfluorooctane sulfonate (PFOS) and perfluorooctane acid (PFOA) have been recognized as emerging environmental pollutants because of their ubiquitous occurrence in the environment, biota and humans. The paper focuses on the distribution, bioaccumulation and toxic effects of PFOS and PFOA in the water. From the available literature, tap and surface water samples in several countries were found to be contaminated with PFOS and PFOA. These compounds were detected globally in the tissues of fish, bird and marine mammals. Their concentrations from relatively more industrialized areas were greater than those from the less populated and remote locations. Blood samples of occupationally exposed people and the general population in various countries were found to contain PFOS and PFOA which suggested a possibility of atmospheric transport of these compounds. There is still a death of information about the environmental pathways of PFOS and PFOA. The presence of these compounds in the tap water, surface water and animal and human tissues indicates their global contamination and bioaccumulative phenomena in the ecosystems.

Key words | bioaccumulation, PFOA, PFOS, toxic effects, water environment

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INTRODUCTION

In the recent years, there are increasing concerns of perfluorinated chemical such as perfluorooctane sulfonate (PFOS) and perfluorooctane acid (PFOA), candidates for new class of persistent organic pollutants. Persistent organic pollutants (POPs) are an organic compound that remain intact in the environment for long periods, extremely resistant to degradation because of their very strong carbon-fluorine bonds and is most abundant in halogen family which most reactive to all elements, become widely distributed and accumulated in the fatty tissue of living organisms and are toxic to human and wildlife. Therefore, there is an emerging need to study PFOS and PFOA contamination environment, particularly in the water environment.

PFCs are emerging pollutants that have been used for over the last 50 years in a wide variety in industrial and commercial applications. PFCs used in industries were produced in processes of electro-chemical fluorination and telomerization respectively. In Electro-chemical processes, electric current was passed through dispersed solution of alky1 organics and hydrogen fluoride (HF), causing hydrogen atoms to be replaced by fluorine atoms (3M Company 1999) and telomerization process exclusively generated linear products with even number of carbon atoms. Perfluorooctane sulfonate (PFOS) and perfluorooctane acid (PFOA) are typical and predominant PFCs which have the following chemical formulas: $C_8F_{17}SO_3^-$ and $C_8F_{15}COO^-$, respectively. The chemical structures of these two compounds are shown in Figure 1.

PFOS and PFOA related compounds have wide range of applications in broad categories-surface treatment, paper coatings and performance chemicals. Surface treatment

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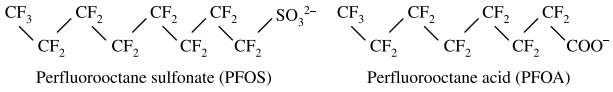

Figure 1 | Chemical structure of PFOS and PFOA.

applications provide soil, oil, and water resistance to clothing, carpets, car interiors and furniture and paper coatings include those for food packaging (containers, bags and warps) and performance chemicals include fire fighting foams, mining and oil well surfactants, photolithography, electronic chemicals, hydraulic fluid additives, floor polishes, photographic film, denture cleaners, shampoos, etc. while PFOA is used as an emulsifier (such as Teflon used for coating of cooking pans) and surfactant (such as soap and shampoos, etc). Because both PFOS and PFOA are persistent in the environment, bioaccumulative and potentially toxic to humans and animals, they are being proposed as candidates for a new class of POP.

Recent concerns with the toxic effects of PFOS and PFOA began in the early 2000s when the 3M Company, USA, the major PFCs manufacturer, decided to phase out the production of PFOS-related products. However, there are still a number of industries, such as the semi conductor etc., that still use PFOS in their production and manufacturers that produce PFOA and its related products for consumer usage. From over 200 research articles published so far, most of them came out after the year 2000 and dealing mainly with the topics of PFOS and PFOA distribution and toxicity in biota samples in industrials countries. Probably due to their presence at trace levels (ng/L), there are fewer articles dealing with the distribution of PFOS and PFOA in tap and surface water, much less about their treatment. Since PFOS has been applied in various products worldwide for the 40 years and PFOA is still being manufactured and used, there are possibilities that these compounds are released into the water environment through both point source (industrial and sewage treatment plant) and non-point source (surface runoff and atmospheric) discharges, bioaccumulated in the food chains and thus become a potential health risk to human and animals.

Exposure to PFOS and PFOA results in accumulation mostly in the serum and liver, causing hepatotoxicity (damage to the liver), the formation of adenomas (non cancerous tumours) in liver and thyroid tissues, and a decrease in serum cholesterol rodent (OECD 2002). Significant decreases in body weight and significant increases in external and internal abnormalities have been observed in rats (OECD 2002). There are not many studies of health effects in people. Mortality studies have shown an increased risk of some cancers (neoplasms of the male reproductive system, bladder cancer) among not only fluorochemical production workers but also general population of various countries. The general objective of this review paper is to create more awareness among water related professionals and researchers of this emerging environmental issue. Specifically, this paper aims to evaluate: (1) contamination levels of PFOS and PFOA in the water environment, including their applications and contamination sources, (2) extents of bioaccumulation and toxic effects of these compounds.

CONTAMINATION OF PFOS AND PFOA IN THE WATER

The global contamination of PFOS and PFOA in the water environment and in the animal and human tissues is an emerging environmental concern. These chemical have been detected in indoor and outdoor air, in rivers, lakes and groundwater, in wastewater treatment effluent, in landfills and in the marine environment. Water is the most non-biota environmental compartment of concern for PFOS and PFOA because these compounds have moderate water solubility, while atmospheric PFOS and PFOA might be not as such concern because of their involatile characteristics The characteristics of PFOS and PFOA, shown in Table 1, indicate that they are rather low in vapor pressure, highly soluble in water, and persistent in the environment.

Estimation of PFCs sources and fates in the environment is necessary and is useful for understanding the behavior of PFCs in the environment. Direct discharge from industries and consumption of aqueous fire fighting foam were considered as main sources of PFCs in surface water (Saita *et al.* 2004). Wastewater treatment plant was also considered as one possible source for environmental PFCs and occurrences of PFCs have already been reported

Table 1 | Physio-chemical properties of PFOS and PFOA (based on OECD 2002)

Properties	PFOA	PFOS
Molecular weight	414	500 (for acid)
Melting point	45–50°	≥400°C
Boiling point	189–192°C (736 mm Hg)	Not calculable
Vapor pressure	10 mm Hg (25°C)	3.31×10^{-4} pa (20°C)
Solubility in pure water	3.4 g/L	570 mg/L
pKa	2.5	NA
pH	2.6	7–8

in wastewater effluent in cities of USA (Boulanger *et al.* 2005). Degradation of volatile PFCs derivatives was suspected to be another source of PFCs in the environment. PFCs can enter the aquatic environment from a manufacturing company; after that they pollute the downstream intake and eventually enter in the tap water. The mechanism of mass flows and PFCs risk of humans is as reported in Figure 2.

Reported data on PFOS and PFOA concentrations were far less for understanding their distribution in the environmental water, especially the inland surface water. Surface water in developed countries and industrialized areas were usually highly polluted by PFCs, such as US (Hasen *et al.* 2002; Takino *et al.* 2003), Japan (Saito *et al.* 2003), Germany (Skutlarek *et al.* 2006) and coastal China (So *et al.* 2004). It was indicated that trace levels of PFOS and PFOA at low ng/L or μg/L levels in environmental water. There were possible link between contamination with production and use of these compounds in those countries.

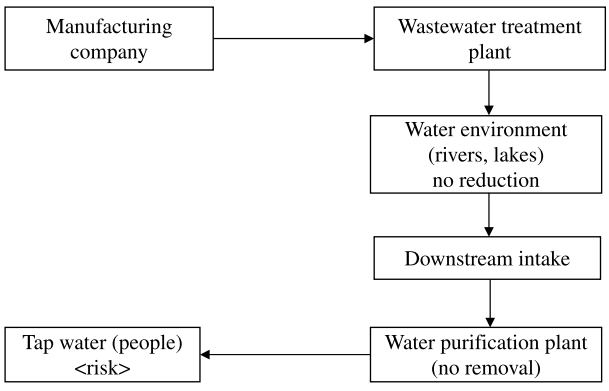

Figure 2 | Mechanism of Mass Flows and PFCs Risk.

Drinking water in those areas was also polluted by PFCs. Investigation of surface water in East Asia demonstrated very high pollution of PFOA and PFOS in Korea and China (So *et al.* 2004). Groundwater was very easy to be polluted by PFCs because most PFCs could strongly adsorb to particles. Boulanger *et al.* (2004) reported PFOS and PFOA concentrations in the Great Lakes are in the range of 21–70 and 27–50 ng/L respectively. The compounds were detected in Michigan State waters with mean concentrations ranging in 1.8–17 ng/L PFOS and 4.4–22 ng/L PFOA (Sinclair *et al.* 2004). Exceptionally high concentrations were measured at several hundreds ng/L for PFOS and up to μg/L level for PFOA in Osaka (Saita *et al.* 2004; Tanaka *et al.* 2006). The concentrations of PFOS and PFOA found in surface water of several countries, as reported in Table 2, are below the recommended concentrations.

Due to persistent and bio-accumulative characteristics, appearance of PFOS and PFOA at certain levels in drinking water poses a risk of human exposure to these chemicals. Occurrence of high concentrations of PFCs in drinking water indicated poor performance of current water treatment processes to remove PFCs from surface water (Saito *et al.* 2003; Skutlarek *et al.* 2006). Tap water of some cities in Canada, China, Malaysia, Sweden, Thailand and Vietnam were also found to contain PFOS and PFOA in the ranges from the limit of quantification levels to 13 ng/L for PFOS and 109 ng/L for PFOA (Lien *et al.* 2006*a*,*b*). The maximum PFOA concentrations were consistently higher than those of PFOS. The safety levels of PFOS and PFOA are not yet set for drinking water in any countries except a state in the USA. This could probably due to inappropriate number of scientific researches being carried out in the area. Therefore, the level of PFOS and PFOA is still questionable in majority of the world's drinking water. The Minnesota Department of Health, USA, recommended a safe concentration of PFOS and PFOA in drinking water to be 1 ug/L and 7 ug/L, respectively (3M 2005) and then revised them to be 0.3 μg/L for PFOS and 0.5 μg/L for PFOA (MDH 2007). The concentrations of PFOS and PFOA found in tap water of several countries, as reported in Table 3, are below these recommended concentrations.

Table 3 shows the results of tap water samples. PFOA was detected in all 18 tap water samples collected in Japan, while PFOS was detected in 16 samples. Relatively higher

Table 2 | PFOS and PFOA concentration in surface water collected from different countries

Country	Area	Site/City	PFOS (ng/L)	PFOA (ng/L)	Sampling date	Reference
Thailand	Phong River	1	0.2	<0.2	Jul-05	Lien *et al.* (2006*a*,*b*)
		2	0.1	1.3	Jul-05	
		3	0.5	0.7	Jul-05	
		4	0.2	<0.2	Jul-05	
		5	0.5	2.2	Jul-05	
		6	0.9	1.0	Jul-05	
		7	0.3	0.4	Jul-05	
		8	<0.1	0.7	Jul-05	
		9	0.1	1.0	Jul-05	
		10	<0.1	<0.2	Jul-05	
		11	0.1	8.8	Jul-05	
		12	0.3	0.4	Jul-05	
		13	0.2	1.0	Jul-05	
		14	0.4	1.1	Jul-05	
		15	0.2	3.8	Jul-05	
		16	0.6	2.5	Jul-05	
		17	1.1	3.0	Jul-05	
		18	0.2	3.1	Jul-05	
		19	<0.1	0.3	Jan-06	
		20	–	<0.2	Jan-06	
		21	0.2	0.6	Jul-05	
		22	0.1	1.7	Jul-05	
		23	0.2	0.7	Jul-05	
		24	0.1	0.7	Jul-05	
		25	0.3	0.7	Jul-05	
		26	0.2	1.3	Jul-05	
		27	0.1	2.0	Jul-05	
		28	0.2	1.9	Jul-05	
		29	0.2	0.6	Jul-05	
Malaysia	Kota Kinabalu	1	0.4	1.5	Sep-05	Lien *et al.* (2006*a*,*b*)
		2	0.2	0.3	Sep-05	
		3	1.6	2.6	Sep-05	
		4	1.2	2.2	Sep-05	
		5	1.9	3.2	Sep-05	
		6	0.1	0.3	Sep-05	
		7	o.1	<0.2	Sep-05	
		8	0.1	0.3	Sep-05	
		9	<0.1	<0.2	Sep-05	
		10	1.1	0.5	Sep-05	
		11	1.6	<0.2	Sep-05	

Table 2 | (*continued*)

Country	Area	Site/City	PFOS (ng/L)	PFOA (ng/L)	Sampling date	Reference
		12	3.4	0.5	Sep-05	
		13	<0.1	<0.2	Sep-05	
		14	0.1	<0.2	Sep-05	
		15	<0.1	0.2	Sep-05	
		16	1.2	0.3	Jan-06	
		17	<0.1	<0.2	Jan-06	
		18	2.0	<0.2	Sep-05	
		19	<0.1	<0.2	Jan-06	
		20	1.6	<0.2	Sep-05	
		21	<0.1	<0.2	Sep-05	
Vietnam	Hanoi	1	0.6	1.4	–	Lien *et al.* (2006*a*,*b*)
		2	1.3	6.1	–	
		3	<0.1	0.8	–	
		4	<0.1	0.3	–	
		5	<0.1	<0.2	–	
		6	0.1	0.2	–	
		7	0.2	1.7	–	
		8	<0.1	<0.2	–	
		9	0.1	0.4	–	
		10	<0.1	1.3	–	
		11	<0.1	1.0	–	
		12	0.8	6.6	–	
European Nordic Countries	Finland, Sweden, Norway, Denmark, Iceland, Faeroe Islands		<1	7.8	–	Berger *et al.* (2004)
United States	Alabama State	$N = 22$	10	25		Hasen *et al.* (2002)
	Great lake	$N = 8$	0.7	13		Boulanger *et al.* (2004)
	Michigan State	$N = 51$	0.8	8		Sinclair *et al.* (2004)
	Minnesota State	Remote areas $N = 4$	0.28	0.29		Simcik & Dorweiler (2005)
		Urban areas $N = 4$	0.28	0.29		Simcik & Dorweiler (2005)
Japan	Hokkaido-Tohuku District	Kushira	1.90	0.40	10 March-03	Saita *et al.* (2004)
		Rokkasho	2.63	0.66	11 March-03	
		Hirosaki	0.60	0.59	11 March-03	
		Morioka	1.15	3.77	13 March-03	
		Honja	1.40	0.55	14 March-03	
		Murayama	3.24	1.04	15 March-03	
		Murayama	1.77	4.22	15 March-03	
		Tsuruoka	2.82	0.47	15 March-03	
		Kahoku	3.27	3.58	16 March-03	
		Onoda	0.90	0.10	16 March-03	

Table 2 | (*continued*)

Country	Area	Site/City	PFOS (ng/L)	PFOA (ng/L)	Sampling date	Reference
		Shiroishi	0.58	0.83	16 March-03	
		Kouriyama	4.62	1.40	17 March-03	
		Iwaki	0.45	1.10	17 March-03	
		Fukushima	0.39	0.89	17 March-03	
		Fukushima	0.25	2.55	17 March-03	
		Fukushima	0.58	2.95	17 March-03	
	Kanto	Batou	0.33	1.67	18 March-03	
		Ujiie	4.98	3.87	18 March-03	
		Maebashi	3.53	3.24	19 March-03	
		Higashimurauama	3.31	3.03	19 March-03	
		Ohizumi	1.78	6.40	19 March-03	
		Saitama	19.88	7.56	20 March-03	
		Kawaguchi	19.61	14.46	20 March-03	
		Saitama	18.44	5.65	20 March-03	
		Okutama	1.74	0.40	17 March-03	
		Oume	1.00	0.33	17 March-03	
		Hamura	2.42	0.36	17 March-03	
		Akishima	0.72	2.55	17 March-03	
		Kawasaki	31.42	15.08	19 March-03	
		Kawasaki	3.66	4.89	19 March-03	
	Chubu Dist	Ojiya	6.04	1.96	15 March-03	
		Niigata	0.91	3.74	15 March-03	
		Mikawa	0.87	1.53	15 March-03	
		Niigata	0.62	2.86	15 March-03	
		Jyouetsu	2.00	3.50	15 March-03	
		Itakura	1.96	3.63	15 March-03	
		Hamakita	0.42	2.04	16 March-03	
		Kikukawa	0.41	2.36	16 March-03	
		Ooigawa	0.73	2.28	16 March-03	
		Shizuoka	0.86	0.28	16 March-03	
		Shibakawa	1.98	5.08	16 March-03	
		Toyohashi	2.32	1.64	13 March-03	
		Okazaki	0.96	2.79	13 March-03	
		Nagoya	0.24	1.50	13 March-03	
		Kaizu	3.88	16.28	13 March-03	
		Kasamatsu	0.46	2.17	13 March-03	
		Kaizu	1.33	3.88	13 March-03	
	Kinki Dist	Iwade	1.45	2.14	17 March-03	
		Yasu	4.12	10.34	19 March-03	
		Higashiyadogawa	9.29	140.56	12 March-03	

Table 2 | (*continued*)

Country	Area	Site/City	PFOS (ng/L)	PFOA (ng/L)	Sampling date	Reference
		Miyakojima	10.43	24.42	12 March-03	
		Suminoe	18.01	41.60	12 March-03	
		Kawanishi	3.81	4.88	13 March-03	
		Kawanishi	0.78	5.70	13 March-03	
		Amagasaki	37.32	456.41	13 March-03	
	Chugoku Dist	Soujya	0.87	1.41	11 March-03	
		Okayama	0.80	8.11	11 March-03	
		Kumayama	0.67	1.00	11 March-03	
		Hiroshima	0.65	1.22	13 March-03	
		Fukuyama	0.82	0.68	13 March-03	
		Miyoshi	0.42	1.56	13 March-03	
		Kurayoshi	0.55	1.66	10 March-03	
		Izumo	25.10	3.18	10 March-03	
		Houfu	0.69	0.51	12 March-03	
	Kyushu-Shikoku	Kaho	1.51	0.20	21 March-03	
		Nakama	0.96	1.71	21 March-03	
		Kurume	1.72	2.64	21 March-03	
		Mikitsuki	0.29	1.29	19 March-03	
		Ouchi	0.94	1.61	19 March-03	
		Yamakuni	0.35	1,38	11 March-03	
		Nakatsu	0.55	3.28	11 March-03	
		Isahaya	0.57	0.95	13 March-03	
		Tokushima	0.59	2.78	14 March-03	
		Marukame	14.86	13.82	15 March-03	
		Oosu	3.53	2.78	16 March-03	
		Shigenobu	0.30	2.50	16 March-03	
		Tosa	2.40	2.60	18 March-03	
		Kubokawa	0.40	2.56	18 March-03	
		Noichi	0.24	1.35	18 March-03	

concentrations of PFOA were found in Japan (Osaka, Kyoto and Ostu). PFOA was found the highest in tap water samples in Hangzhou (China) with a concentration of more than 100 ng/L. High concentrations of PFOS were also found in many China tap waters with concentrations of around 10 ng/L. This level is generally higher than that found in Japan.

The relations of PFOS and PFOA in tap water were geographically different. In Japan except one sample in Kagawa, PFOA concentrations were higher than PFOS. In china, PFOS concentrations were higher than PFOA in Shenzhen and Kunming but lower in Hangzhou. Both PFOA and PFOA were hardly detected in collected tap water samples in Penang and Kota Kinabalu (Malaysia), Hanoi (Vietnam) and Calgary and Vancouver (Canada).

EXTENTS OF BIOACCUMULATION AND TOXIC EFFECTS OF PFOS AND PFOA

Although PFCs have been produced and consumed "safely" for about fifty years, they were considered as persistent, bioaccumulation and toxic chemicals in scientific studies.

Table 3 | PFOS and PFOA concentration in tap water samples collected from different countries (Fujii *et al.* 2006)

Country	Sample identification	Site	PFOS (ng/L)	PFOA (ng/L)	Sampling date
Japan	Hokkaido	Sapporo	0.1	0.6	Aug-05
	Hyogo	Nishinomiya	–	0.3	Aug -05
	Kagawa	Kotohira	6.8	3.1	Oct-05
	Kyoto	Sakyo	0.9	6.7	Aug-05
		Yamashina	2.0	15.2	May-06
	Miyagi	Sendai	0.4	1.2	Mar-06
	Nara	Yamato-Koriyama	0.1	1.3	Aug-05
	Okayama	Kurashiki	0.6	4.2	Oct-05
		Okayama	0.1	7.5	Oct-05
	Osaka	Takatsuki	1.9	34.3	Aug-05
		Takatsuki	2.0	37.0	May-06
		Takatsuki	1.9	37.5	May-06
	Shiga	Otsu	1.5	8.3	Jul-05
		Otsu	–	9.5	Dec-05
		Otsu	2.5	13.9	May-06
	Tokyo	Tokyo	2.7	6.7	May-06
	Tottori	Tottori	0.1	0.7	Nov-05
	Yamagata	Yamagata	0.6	1.1	Mar-06
Canada	Alberta	Calgary	–	0.2	Sep-05
	BC	Vancouver	–	0.2	Sep-05
China	Shenzhen	Site 1	6.5	3.1	Oct-05
	Guangdong	Site 2	6.2	2.3	Oct-05
		Site 3	9.9	1.1	Jan-06
	Yunnan	Kunming	13.2	1.1	Oct-05
	Zhejiang	Hangzhou	1.5	109.0	May-06
Malaysia	Penang		–	–	Nov-05
	Kota Kinabalu	Site 1	0.1	0.1	Aug-05
		Site 2	–	–	Sep-05
		Site 3	–	–	Sep-05
		Site 4	–	–	Nov-05
Sweden	Orebro	Site 1	0.3	1.3	Mar-06
		Site 2	0.8	–	Mar-06
Thailand	Bangkok	Site 1	1.9	4.6	Dec-05
	Khon Kean	Site 1	0.2	3.4	Jul-05
		Site 2	0.1	0.2	Jan-06
		Site 3	0.1	–	Jul-05
Vietnam	Hanoi	Site 1	–	–	Jan-06
		Site 2	–	–	Jan-06

The presence of PFOS and PFOA in the surface water and tap water obviously pose some environmental concerns because they could be taken up by animals that inhabit the surface water and bioaccumulated in the food chains.

The majority of the information on the toxicity of PFCs (mainly PFOS and PFOA) comes from animal studies and information on adverse health effects in humans is limited to a small number of occupational studies (Calafat *et al.* 2006). For a brief overview of the toxic effects of PFOS and PFOA see Lehmler (2005). Despite the limited number of human studies, there are serious health concerns over the widespread exposure of human populations to PFCs, especially considering their highly persistent and bioaccumulative nature and increasing evidence of their potential developmental effects.

PFCs were detected in human blood, serum and plasma as well as in tissues (Maestri *et al.* 2006). PFCs in human serum seemed directly correlated with contaminations in surface water or drinking water, which were highly suspected to be caused by local industrial emissions. Among eleven countries, people in US (Olsen *et al.* 2003) and Korea were estimated to have the highest concentration of PFOS in human blood (>30 ng/mL). Whilst Indian people had the lowest concentration of 3 ng/mL (Kannan *et al.* 2004). Contamination of PFOS was identified in human serum of residents in Osaka and Kyota of Japan (Harada *et al.* 2004), and very high concentrations of PFOS were detected in the blood of people living in coastal cities of China. Despite of these locations with point source, however PFCs were also detected in countries which only consume PFCs products, such as Australia (Karrman *et al.* 2006) and Sweden (Karrman *et al.* 2004). PFCs were detected in human milk in Australia (Kuklenyik *et al.* 2004) and China (So *et al.* 2006), indicating a very high exposure to infants. PFCs have been also been found in umbilical cord blood (Inosue *et al.* 2004). Control and reduction of PFCs in industries and environment are in great need for the purpose of human health and environmental safety.

A summary of PFOS concentration in human blood samples collected from different countries (Table 4) shows the levels in whole blood to range from 1.7 to 37 ng/mL, while the concentrations in serum samples ranged from 3.6 to 1,656 ng/mL (Table 5).

Table 4 | Concentration of PFOS (ng/ml) in human blood from different countries

Country	Number of samples	PFOS (ng/ml)	Reference
USA, Atlanta	20	Serum 3.6–164 Mean NA	Kuklenyik *et al.* (2004)
USA	645	Serum <4.3–1,656 Mean 34.9	Olsen *et al.* (2003)
Northern Canada	NA	Plasma 2.8–57.9 Mean 36.9	Tittlemier *et al.* (2004)
Japan	26	Whole blood 2.0–20.2 Mean 8.1	Masunaga *et al.* (2002)
Japan	10	Whole blood 2.4–14 Mean 9	Taniyasu *et al.* (2003)
Sweden	66	Whole blood 1.7–37 Mean 18.2	Karrman *et al.* (2004)

NA, not available.

With respect to the effects of PFOS and PFOA on humans, not much information about acute and chronic effects is available. Alexander *et al.* (2003) suspected death of some workers exposed to PFOS to be caused by liver and bladder cancer. Gilliland & Mandel (1993) suggested a risk of mortality from prostate cancer in occupational workers exposed to PFOA. Both PFOS and PFOA have long half-lives in the human body (8.67 years and 1–3.5 years respectively) (Hekster *et al.* 2003). The excretion from the body is slow and occurs via the urine and faeces. PFOS and PFOA are both widely distributed in the body, especially in blood plasma, liver and kidney (Hekster *et al.* 2003).

On the contrary, for fish contamination, Taniyasu *et al.* (2002) found the presence of PFOS in blood and liver samples of fish collected from several places in Japan at concentrations of 2–834 ng/ml. PFC concentrations were found to be the greatest in the blood of the fish followed by the kidney then the liver, then gallbladder,

Table 5 | Concentration of PFOS in human serum from different countries (Kannan *et al.* 2004)

Country	Mean and range PFOS in sera (ng/ml)
USA (Michigan, Kentucky and New York) ($n = 175$)	49.5 (<1.3–164)
Colombia ($n = 56$)	8.2 (4.6–14)
Brazil ($n = 27$)	12.1 (4.3–35)
Italy ($n = 50$)	4.3 (<1–10.3)
Poland ($n = 25$)	44.3 (16–116)
Belgium ($n = 20$)	13.9 (4.5–27) (values are for blood plasma)
India ($n = 45$)	2.0 (<1–3.1)
Malaysia ($n = 23$)	12.4 (6.2–18.8)
Korea ($n = 50$)	21.1 (3.0–92)
Japan ($n = 38$)	17.1 (4.1–40.3)

n, No of Sample.

then adipose tissue and finally muscle tissue. In Canada, PFOS was found in all liver samples of fish collected from Great Whale River at Kuujuarapik and from Lake Minto, Quebec at concentration of 5.7 to 50 ng/g (Martin *et al.* 2004). A study of fish from Michigan waters of the Great Lakes and inland water bodies of New York detected PFOS in the livers of a number of species that were tested (Sinclair *et al.* 2004). PFOS was also detected in fish eggs at concentrations approximately twice those as in the livers from the same species of fish. PFOS is actively transferred from the adult female fish to their eggs. Furthermore, occurrence of PFOS in eggs has implications for early life stage effects.

A review of developmental effects caused by PFOS shows a number of adverse effects of this chemical after high dose administration to rats compared to other animals. Rodent studies reported of reduced birth weight, increased postnatal mortality, delayed sexual maturation, hepatotoxicity and haematological (blood) effects in rats (US EPA 2003, 2005).

In summary, a diversity of adverse effects has been reported in organisms exposed to various PFCs. Although these effects often occur only at levels higher than those expected to be encountered in the environment at present, this is not always be the case. Precise details of the mechanisms and potency of toxic effects are still relatively poorly understood for this group, for which the scale extent of environmental contamination has only recently emerged. More ever, what limited information does exist focuses primarily on PFOS and PFOA.

CONCLUSION

PFOS and PFOA are widespread in the global environment and are present in the tissues of aquatic and terrestrial living organisms including humans. Theses compounds, which are persistent in the environment, bioaccumulative and can cause toxicity, have been found in the water environment of various counties at several ng/L levels. PFCs can enter the aquatic environment from manufacturing companics which are the major source of PFOS and PFOA contaminations. PFCs in the environment are generally a concern because there is no known route of degradation either in the environment or by living organisms.

Both PFOS and PFOA have been found to be globally distributed in versatile living organisms including humans, birds, fish etc. in the range of several mg/l but their contaminations in animals in industrialized areas were more than those from the less populated and remote regions. The PFOS and PFOA were also found in blood samples of occupationally exposed people and the general population in various countries at concentrations ranging from traces levels to more than 100 ng/ml. However, epidemiological studies of occupationally exposed people indicated no significant health problems at the exposed PFOA levels. Consumption of contaminated water and foods are obvious routes of PFOA and PFOA intakes, but other intake routes such as inhalation of contaminated air is a possibility. The half lives of PFOS and PFOA in human bodies were estimated to be 8.5 and 1–3.5 years, respectively.

Although there have not been epidemiological effects of PFOS and PFOA on animals and humans, the presence of these compounds in tap water, surface water, animal and human tissues indicates their global contamination and bioaccumulative phenomena in the ecosystems. Regular monitoring of the contamination levels of PFOA and PFOA in the tap water and surface water and in animals and high tissues should be conducted.

In short to say that surface water, ground water and drinking water were polluted by PFCs in developed countries and industrialized areas, which showed positive correlation with PFC contaminations in biota and human blood. Unfortunately current water treatment processes were suspected ineffective to remove PFCs from surface water and wastewater but it is an emerging need to study PFOS and PFOA contamination environment, particularly in the water environment.

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