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Perfluorooctane Sulfonate Contamination of Drinking Water in the Tama River, Japan: Estimated Effects on Resident Serum Levels

K. Harada,[1] N. Saito,[2] K. Sasaki,[2] K. Inoue,[1] A. Koizumi[1]

[1] Department of Health and Environmental Sciences, Kyoto University School of Public Health, Kyoto 606–8501, Japan
[2] Research Institute for Environmental Sciences and Public Health of Iwate Prefecture, Morioka Iwate, Japan

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Perfluorooctane sulfonate (PFOS) is a special class of chemical used in a variety of applications that include lubricants, paints, cosmetics and fire-fighting foams. PFOS has been reported to be globally distributed in variety of living organisms (Giesy and Kannan 2001, Kannan et al. 2001a, Kannan et al 2001b, Kannan et al 2002) and humans (Hansen et al 2001).

In a previous study (*Saito et al. submitted for publication 2002*), we showed that PFOS contamination in surface waters has occurred all over Japan: concentrations were found to be in the range of 0.2-157 ng/L with a geometric mean (geometric standard deviation) of 2.37 (4.13) (n=126), These levels were much lower than those found in the Tennessee River (Hansen et al 2002). However, we found that the middle stream of the Tama River was exceptionally heavily contaminated with PFOS. There could be some concerns about this Tama River PFOS contamination because a drinking water intake site is located in the Tama's lower stream.

Recently, a pharmacokinetic study using monkeys was reported (Seacat et al. 2002). Data obtained in this study seems to provide a deep insight into the kinetic aspects of PFOS. It is anticipated that this model may be useful for evaluating the internal dose levels in humans.

The present study had three aims. The first was to confirm that there was indeed surface water contamination in the Tama River and to pinpoint its source. The second was to confirm whether the tap water was contaminated. The third was to evaluate human exposure through drinking water by utilizing pharmacokinetic modeling. Together, these pieces of information would provide toxicological bases for risk assessment for residents who use drinking water from the Tama River.

MATERIALS AND METHODS

Surface water samples were collected from the Tama River in the midstream areas, as shown in Figure 1. We also collected tap water samples in Morioka and Miyako in Iwate, in Setagaya, Tokyo and in Kyoto city. Water samples, each of two liters, were collected in polyethylene telephthalate disposable containers with narrow-mouth bottle tops and screw caps. To minimize the possibility of occurrence of any sample contamination, the containers were thoroughly rinsed with methanol and with deionized water prior to use. The deionized water was used after passing it through a Presep-C Agri cartridge (Presep-C, 220 mg

Correspondence to: A. Koizumi

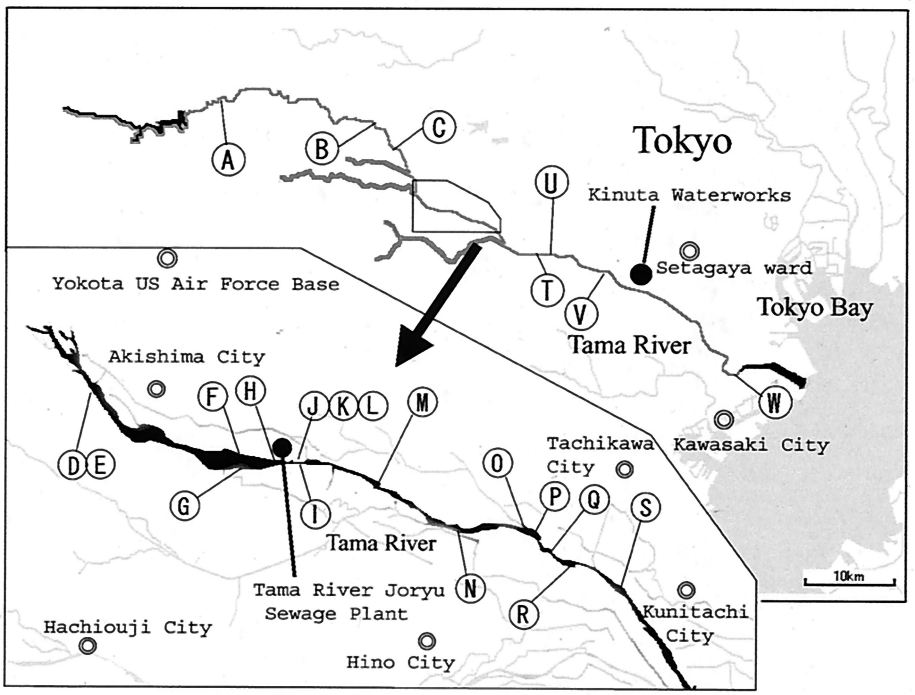

Figure 1. Geographic locations of the water sampling sites.

cartridge: Wako Pure Chemicals, Osaka Japan). Teflon bottles and Teflon-lined caps were avoided throughout the experiment to prevent sample contamination. Samples were stored at room temperature until analyzed. One liter of surface water sample was first filtered through glass fiber filters (1.0 mm f) (ADVANTEC GA 100, 55 mm ϕ, ADVANTEC, Tokyo Japan) to remove sediments and biota. Subsequently, the samples were passed through a membrane filter (Millipore JAWPO4700, 47 mm ϕ, pore size 1.0 mm)(Millipore, Tokyo Japan), and then through the Presep-C Agri column at a flow rate of 10 ml /min, using a Waters Concentrator System (Concentrator Plus, Waters Tokyo, Japan). The Presep-C cartridges were then eluted with 1.5 mL of methanol and concentrated at room temperature under nitrogen gas flow to 1 mL to be analyzed by LC/MS.

The details of the analytical methods have been submitted for publication (*Saito et al. Submitted for publication 2002*). Briefly, standard compounds were infused through a flow injection at a flow rate of 0.2 mL/min to adjust the ion sprayer and tune the mass spectrometer. Methanol extracts (10 µl injection volume) were chromatographed using HPLC with a flow rate of 0.2 mL/min. The total runtime was 20 min, without any equilibration time between samples. The mass spectra were taken on a liquid chromatography mass spectrometer equipped with an orthogonal spray interface; employing electron spray ionization in a negative mode. The fragmentor and Vcap voltages were 200V and 4000V, respectively. The nebulizer pressure was 50 psig and the drying N_2 gas flow rate was 10.0 mL/min. A selected ion monitoring mode was employed for the quantification of the PFOS. The calibration curves constructed for the PFOS ranged from 0.1 to 100 pg/µL. PFOS potassium salt (FW.538.22; Fluka, Milwaukee, WI) was used as a standard for PFOS.

Table 1. PFOS concentrations in waters sampled in the Tama River system.

Location	PFOS (ng/L)	Sampling Time	Sampling
A	1.7	Before March 2002	
B	0.7	Before March 2002	
C	1.6	Before March 2002	
D	1.3	Before March 2002	
E	4.1	24-Jun-02	Surface waters
F	7.8	24-Jun-02	
G	3.7	2-Aug-02	
H	2.1	2-Aug-02	
I	2.2	2-Aug-02	
J	440.0	2-Aug-02	Waters were sampled directly from the drain of the Tama River Joryu Sewage plant
K	303.0	26-Aug-02	
L	350.0	26-Aug-02	
M	90.0	24-Jun-02	
N	88.8	24-Jun-02	
O	157.0	Before March 2002,	
P	36.0	2-Aug-02	
Q	47.0	2-Aug-02	
R	107.0	24-Jun-02	Surface waters
S	82.3	24-Jun-02	
T	63.7	24-Jun-02	
U	58.7	24-Jun-02	
V	65.3	Before March 2002,	
W	50.3	Before March 2002,	

We developed a one-compartment pharmacokinetic model to analyze the monkey data (Seacat et al. 2002). In the one-compartment model, the serum concentration at T (days) is expressed as;

$$C(T) = (E/k)\,[1- \exp(-\ln 2 * T/T_{1/2})] \quad \text{---- Eq(1)}$$

where C(T) (μg/L) represents the serum concentration of the PFOS at time T days after the initiation of exposure. Other parameters represent; E: Daily intake (mg/day or ng/day); k: Clearance(L/day); $T_{1/2}$:Biological half-life (day); ln2: Natural logarithm of 2.

Volume distribution V (L/kg) is given as;

$$V = (k * T_{1/2})/\ln 2 \quad \text{---- Eq(2)}$$

We assumed that in the monkey, the half-life of the PFOS was 200 days (Seacat et al. 2002). We estimated the volume distribution from k. The validity of the model was evaluated based on whether the predicted values could simulate the observed values after exposure to 0.03 mg/kg/day and 0.15 mg/kg/day. Since the nonlinear behavior was obvious at a dose level of 0.75 mg/kg/day, we did not include data at this dose level.

The serum concentration after equilibrium (Ce) is given as;

$$Ce = E/k = E*T_{1/2}/(\ln 2*V)$$
$$= C(T) \qquad \text{---- Eq(3)}$$
where $T>T_{1/2}$

RESULTS AND DISCUSSION

We first confirmed water contamination in the Tama River at various sites at various times. Samples were collected systemically to detect the source of the PFOS, revealing that the Tama River Joryu Sewage plant discharges waters heavily contaminated with PFOS; at 303-440 ng/L (Table 1, J, K, L). The discharged waters from this plant were proved to contaminate the waters downstream of this plant. Although we tried to trace the source into the plant, we could not specify the origin because waters from more than 40 sewer systems drained into the plant.

We determined the PFOS concentrations in the drinking waters in the Morioka and Miyako(Iwate), Setagaya (Tokyo) and Kyoto areas (Table 2). In most of the drinking waters, the PFOS levels were less than 4 ng/L. However, we found a heavy contamination with PFOS in the drinking waters supplied by the Kinuta Waterworks, which uptake waters from the middle stream of the Tama River (Figure 1).

Table 2. Contaminations of tap waters with PFOS in Japan.

Sampling site		PFOS (ng/L)	Waterworks
Morioka city	A	0.3	Nakayashiki
	B	0.1	Sawada
	C	0.3	Yonai
	D	0.5	Shinjyo
Miyako		0.1	Shigemo
Kyoto	A	3.0, 4.0	Keage
	B	3.5	Matsugasaki
Setagaya	A	2.4, 2.6, 2.9, 4.0	Asaka
	B	43.7, 50.9	Kinuta (Site in figure 1)

* Each value represents a single tap water sample from each source.

We next constructed a pharmacokinetic model. It is reported that, at 183 days after exposure, serum PFOS levels were 16 μg/L at 0.03 mg/kg/day and 80 μg/L at 0.15 mg/kg/day. Using this data, we estimated that k=0.004 (L/day) and that the volume distribution was 30% of body weight.

The validity of the model was evaluated based on whether the estimated model could simulate the observed values. As shown, our simple model could simulate serum PFOS levels at two different dose levels (Figure 2).

We next scaled up this pharmacokinetic model to 60 kg humans. The exposure

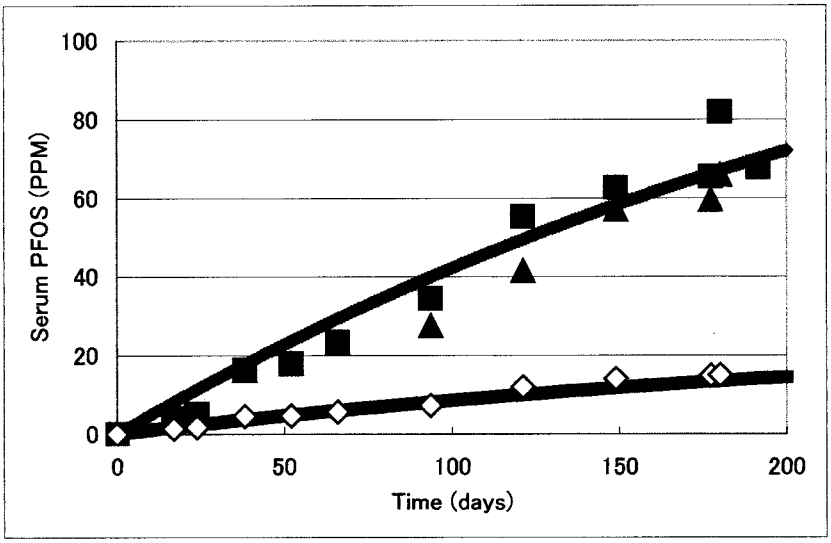

Figure 2. Simulation by a one-compartment model and observed values in monkey. Raw data were reported by Seacat et al. 2002. The solid squares and triangles indicate the male and female serum values at 0.15 mg/kg/day, respectively. Open diamonds indicate the combined male and female values at 0.03 mg/kg/day, which were difficult to separate.

levels were limited to drinking water, which was assumed to contain PFOS at 50 ng/L, 2L/day with complete absorption. We assumed that $T_{1/2}$ was between 1000-1500 days (cited in Olsen et al. 1999). The estimated serum concentrations after equilibrium [Ce, Eq (3)] were; 8 μg/L for $T_{1/2}$=1000 days, 12 μg/L for $T_{1/2}$=1500 days and 16 μg/L for $T_{1/2}$=2000 days.

We confirmed our initial concern that surface water contamination in the Tama River has resulted in drinking water contamination in the Setagaya area, which in turn, very likely increases the body burden of PFOS in residents who consume drinking water supplied from the Kinuta Waterworks. Because the drinking water deliveries were complicated in this residential area, it is hard to estimate the size of the targeted population drinking this contaminated drinking water.

The pharmacokinetic model predicts that such drinking water contamination is assumed to result in an 8-16 μg/L excess in plasma PFOS levels. At present, it is difficult to predict whether such elevations in serum levels of PFOS increase any health risks associated with PFOS. However, it should be pointed out that the mean serum PFOS levels in humans is reported to be 28.4 μg/L (Hansen et al. 2001). If so, the excess exposure through the contaminated drinking water will result in an extra 25-50 % rise in serum PFOS levels in those residents who drink tap water delivered from the Kinuta Waterworks.

This is the first report from anywhere in the world concerning PFOS contamination in drinking water. Our next step will be to pinpoint the source of the PFOS in the Tama River and to conduct further toxicological assessments. An epidemiological study may be necessary for conducting a risk assessment for

these residents.

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REFERENCES

Giesy JP, Kannan K (2001) Global distribution of perfluorooctane sulfonate in wildlife. Environ Sci Technol 35: 1339-1342

Hansen KJ, Clemen LA, Ellefson ME, Johnson HO (2001) Compound- specific, quantitative characterization of organic fluorochemicals in biological matrices. Environ Sci Technol 35: 766-70

Hansen KJ, Johnson HO, Eldrige JS, Butenhoff JL, Dick LA (2002) Quantitative characterization of trace levels of PFOS and PFOA in the Tennessee River. Environ Sci Technol 36: 1681-1685

Kannan K, Franson JC, Bowerman WW, Hansen KJ, Jones PD, Giesy JP (2001a) Perfluorooctane sulfonate in fish-eating water birds including bald eagles and albatrosses.Environ Sci Technol 35: 3065-3070

Kannan K, Hansen J, Wade TL, Giesy JP (2002) Perfluorooctane sulfonate in Oyster, *Crassostrea virginica*, from the Gulf of Mexico and the Chesapeake Bay, USA. Arch Environ Contam Toxicol 42: 313-318

Kannan K, Koistinen J, Beckmen K, Evans T, Gorzelany JF, Hansen KJ, Jones PD, Helle E, Nyman M, Giesy JP (2001b) Accumulation of perfluorooctane sulfonate in marine mammals. Environ Sci Technol 35: 1593-1598

Olsen GW, Burris JM, Mandel JH, Zobel LR (1999) Serum perfluorooctane sulfonate and hepatic and lipid clinical chemistry tests in fluorochemical production employees. J Occup Environ Med 41: 799-806

Saito N, Sasaki K, Nakatome K, Harada K, Yoshinaga T, Koizumi A (Submitted for publication) A new sensitive yet robust analytical method for perfluorooctane sulfonate reveals widespread contamination in surface waters in Japan.

Seacat AM, Thomford PJ, Hansen KJ, Olsen GW, Case MT, Butterhoff JL (2002) Subchronic toxicity studies on perfluorooctane sulfonate potassium salt in Cynomolgus Monkeys. Toxicol Sci 68: 249-264