OVERALL ANALYSIS OF PFC MONITORING IN ASIA (UNU PROJECT PHASE VII)

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Introduction
In order to assist Asian countries in proper management of Persistent Organic Pollutants (POPs), UNU-IAS promoted monitoring of POPs with the intention of capacity building, networking and supporting of policymaking. Phase VII (2016–2018) of the project focused on the monitoring of perfluorinated compounds (PFCs) including those which are currently targeted or discussed in the Stockholm Convention on POPs as well as alternatives to them.

Materials and methods
Ten Countries (Republic of Korea, China, the Philippines, Vietnam, Thailand, Malaysia, Singapore, Indonesia, India and Pakistan) participated in the Phase VII and collected samples of surface water, sediment and biota (mainly fish) (Table1). Nine PFCs (PFOS, PFHxS, PFOA, PFBA, PFHxA, PFNA, PFDA, PFUnA and PFDoA) in the samples were measured by LC/MS/MS at the laboratories in Korea, China and Singapore. Some countries collected samples of additional media (e.g. tap water) and/or measured additional PFC compounds.

Results and discussion
While the monitoring results were analyzed in each country, UNU-IAS compiled all the data from the 2018 sampling to demonstrate the level of concentrations of the nine PFCs in Asia and to analyze the status of substitution from the restricted compounds such as PFOS.

Figs. 1, 2 and 3 show the concentrations of total PFCs in surface water, sediment and biota in the ten countries. The median of the data in each country were in the range of 1.4 to 1,025 ng/L for surface water, nd to 23.2 ng/g for sediment, and nd to 34.0 ng/g for biota.

Tables 2, 3 and 4 show the detection level and the range of concentrations of each PFC compound in surface water, sediment and biota. While PFOS and PFOA were dominant in some countries due to the considerable amount of their production, they were found around the same level as other PFCs in other countries. PFHxS and PFHxA, major alternatives to PFOS and PFOA, were detected in some countries.

PFUnA and PFDoA were detected more frequently in sediment and biota than in water, whereas their frequency and concentration level were not higher than other substances. The long-chain PFCs including PFNA and PFDA were present in the environment, which is considered to have been discharged as by-products of PFOA. The short-chain PFCs including PFBA were found in the environment, which is considered to be the result of degradation of long-chain compounds.

Through the project, the following three findings have been identified. First, the data of different PFCs in the environment in the Asian region in the same year are useful information for considering the region-wide policies and measures to address PFCs as well as analyzing their presence and fate in the environment.

Second, the project promoted the development of PFC monitoring network as well as policy-making processes. Participating institutes shared the data with related organizations, including local and national regulation authorities, and published them. The data were also provided for the effectiveness evaluation of the Stockholm Convention through National Contact Points of the Convention in some countries.

Third, the project contributed to capacity building for analyzing PFCs in participating institutes. Standard procedures have been summarized in some countries and additional training of national experts have been initiated in other countries. On the other hand, the process of compiling data has found out that there is still room for capacity development in terms of proper handling of data and samples. Continuous capacity building is recommended for further development of monitoring networks.

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Table 1 Situation of sampling in participating countries in Phase VII

Country	Place	Background affected on effluents	Measured media (2016–2018)			
			Surface water	Sedi-ment	Biota	Others
Republic of Korea (KOR)	Nakdong, Geum, Seomjin and Yeongsan rivers including estuary and nearby coastal areas	Agricultural and municipal effluents	2016–2018	2016–2018	2016–2018	Tap water (2016–2018)
China (CHN)	Jiutang River and coastal area in Ningbo city, Zhejiang province	Wastewater from industry	2016–2018	2016–2018	2016–2017	Drinking water, Soil (2016–2018)
The Philippines (PHL)	Manila Bay and Laguna Lake area	Industrial and municipal	2016–2018	2016–2018	2016–2018	Drinking water (2016–2018)
Vietnam (VNM)	Different points every year (Lakes in Hanoi, Bac Ninh Province, Nhue-Day River)	Municipal and industrial wastewater	2016–2018	2016–2018	2016–2018	Ground water, Tap water (2017)
Thailand (THA)	Several rivers flowing into Gulf of Thailand	Industry and rural/urban community	2016–2018	2016–2018	2016, 2018	Ground water (2018)
Malaysia (MYS)	Selangor river (2016–2017) and Langat river (2016–2018)	Residential, industrial and agricultural	2016–2018	2016–2018	2016, 2018	Drinking water (2017–2018)
Singapore (SGP)	Rivers, reservoirs and coastal areas	Urban and industrial	2016–2018	2016–2018	–	
Indonesia (IDN)	Rawa Pening Lake including a river flowing into lake, Central Java	From houses and agricultural areas	2017–2018	2017–2018	2018	
India (IND)	Kaveri River, Vellar River and Tamiraparani River in Tamilnadu Province	Urban, rural and industrial area	2016–2018	2016–2018	2016–2018	Drinking water (2016)
Pakistan (PAK)	River Indus including dams, rivers flowing into it and coastal areas	Industrial, agricultural and other effluents	2016–2018	2016–2018	2017–2018	Ground water (2016, 2018)

(Note) Nine PFCs (PFOS, PFHxS, PFOA, PFBA, PFHxA, PFNA, PFDA, PFUnA and PFDoA) were measured in all countries and additional 3–5 compounds were also measured in Korea (2016–2018), Vietnam (2016–2018) and Pakistan (2016).

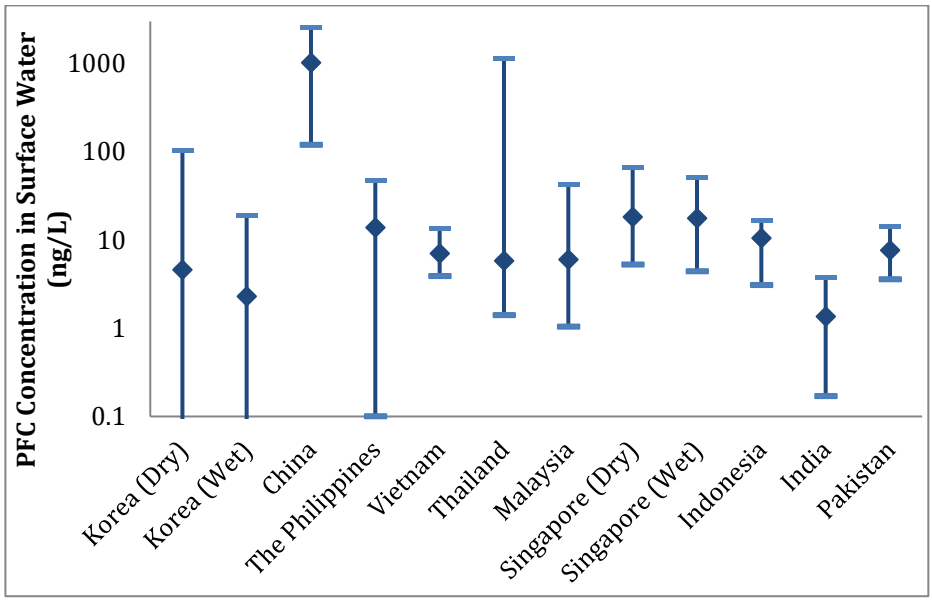

Fig.1 Comparison of PFCs level in surface water in 2018

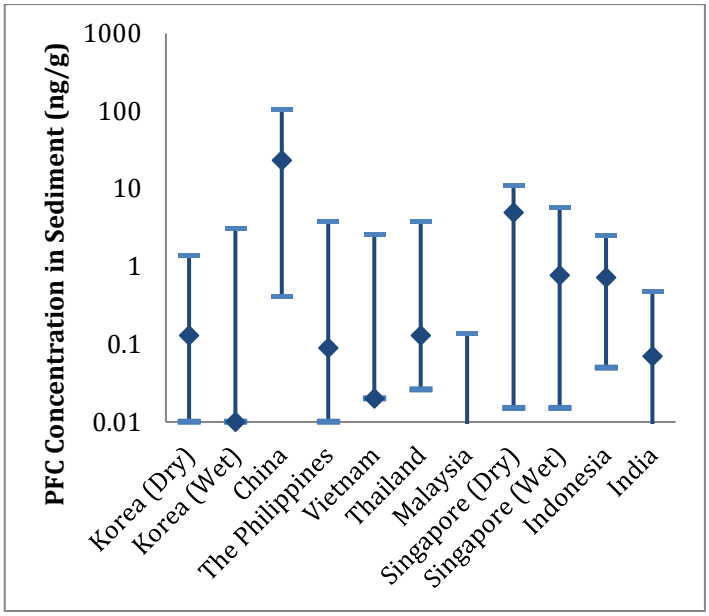

Fig. 2 Comparison of PFCs level in sediment in 2018
(Note: Not detected in Pakistan)

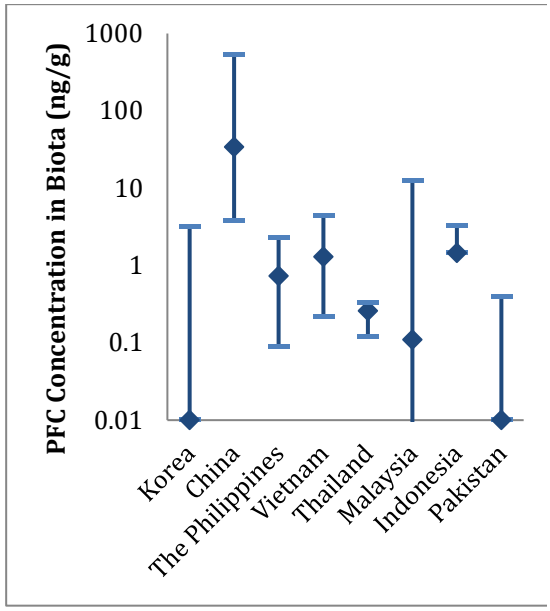

Fig. 3 Comparison of PFCs level in Biota in 2018
(Note: India: one sample as shown in Table 4)

(Note to Figs. 1–3) The bars and points show the maximum, median and minimum value. In case of "nd", the half of detection limit value is used for the chart.

Table 2 Measured data of each PFC compound in surface water in 2018

(Unit: ng/L)

Country (Season)		PFOS	PFHxS	PFOA	PFBA	PFHxA	PFNA	PFDA	PFUnA	PFDoA	Sum
KOR (Dry)	Detection	28/32	23/32	31/32	0/32	26/32	16/32	8/32	2/32	0/32	31/32
	Range	<0.06-11.6	<0.05–37.7	<0.08–27.3	<0.08	<0.11–36.1	<0.09–4.4	<0.10–89.5	<0.08–0.6	<0.13	<0.05–101.9
KOR (Wet)	Detection	25/32	26/32	30/32	0/32	2/32	9/32	6/32	1/32	0/32	31/32
	Range	<0.06–3.2	<0.05–9.8	<0.08–10.9	<0.08	<0.11–2.8	<0.09–2.1	<0.10–2.4	<0.08–0.4	<0.13	<0.05–18.7
CHN (Wet)	Detection	11/11	10/11	11/11	11/11	11/11	11/11	11/11	7/11	0/11	11/11
	Range	39–1889	<1.4–78.6	57–452	4.4–36.0	4.1–37.1	2.4–29.4	0.8–13.9	<1.0–14.9	<0.9	119–2551
PHL (Wet)	Detection	7/8	4/8	7/8	7/8	7/8	2/8	3/8	1/8	0/8	7/8
	Range	<0.4–4.0	<0.6–7.7	<0.3–7.8	<0.2–14.9	<0.2–14.5	<0.8–13.8	<0.5–1.8	<0.5–1.1	<2.0	<0.2–46.7
VNM (Rainy)	Detection	0/33	10/33	26/33	33/33	29/33	33/33	25/33	15/33	0/33	33/33
	Range	<0.04	<0.20–2.82	<0.02–3.03	1.70–5.88	<0.18–2.70	0.23–1.40	<0.04–1.22	0.17–0.73	<0.06	3.87–13.5
THA (Dry)	Detection	9/12	8/12	12/12	0/12	12/12	12/12	12/12	10/12	4/12	12/12
	Range	<0.03–27.0	<0.03–1113	<0.2–12.00	<0.03	0.89–15.0	0.14–1.60	0.07–1.67	<0.03–0.13	<0.03–0.17	1.4 –1148
MYS (Dry)	Detection	3/25	0/25	13/25	25/25	17/25	0/25	1/25	0/25	0/25	25/25
	Range	<0.23–10.5	<0.37–<0.37	<0.17–4.04	1.04–13.8	<0.05–14.3	<0.48	<0.12–1.10	<0.09–<0.31	<0.11	1.04–42.5
SGP (Dry)	Detection	4/5	2/5	4/5	4/5	4/5	4/5	0/5	0/5	2/5	5/5
	Range	<1.6–24.2	<1.9–9.7	<0.6–6.5	<2.4–13.6	<0.4–16.0	<0.4–5.3	<1.6	<0.9	<0.3–2.4	5.3–66.6
SGP (Wet)	Detection	3/5	2/5	5/5	4/5	5/5	3/5	0/5	0/5	0/5	5/5
	Range	<1.6–12.5	<1.9–2.7	1.4–5.0	<2.4–20.7	1.7–7.6	<0.4–2.8	<1.6	<0.9	<0.3	4.4–50.7
IDN (Dry)	Detection	2/4	1/4	4/4	3/4	4/4	1/4	2/4	3/4	1/4	4/4
	Range	<1.0–1.4	<1.0–1.5	1.0–2.2	<1.0–2.6	1.3–4.9	<1.0–1.2	<1.0–2.3	<1.0–1.6	<1.0–1.5	3.1–16.6
IND (Dry)	Detection	0/12	1/12	2/12	12/12	0/12	0/12	8/12	9/12	0/12	12/12
	Range	<0.08	<0.08–0.44	<0.28–0.77	0.17–1.94	<0.44	<0.14	<0.06–0.53	<0.07–0.30	<0.05	0.17–3.79
PAK (Wet)	Detection	0/16	0/16	12/16	16/16	0/16	2/16	0/16	0/16	0/16	16/16
	Range	nd	nd	nd –2.20	1.93–13.0	nd	nd –2.16	nd	nd	nd	3.57–14.2

(Note to Tables 2–4)
1) Measured data have been reported by the National Project Coordinators and compiled by UNU-IAS.
2) "nd" means "not detected" or "not quantified", but actual LOD/LOQ value is not shown in the report.

Table 3 Measured data of each PFC compound in sediment in 2018

(Unit: ng/g dw)

Country (Season)		PFOS	PFHxS	PFOA	PFBA	PFHxA	PFNA	PFDA	PFUnA	PFDoA	Sum
KOR (Dry)	Detection	10/32	0/32	23/32	0/32	0/32	4/32	8/32	6/32	2/32	29/32
	Range	<0.03–0.37	<0.02	<0.04–0.68	<0.04	<0.03	<0.04–0.23	<0.05–0.08	<0.04–0.15	<0.06–0.09	<0.02–1.36
KOR (Wet)	Detection	1/32	0/32	9/32	0/32	0/32	0/32	2/32	0/32	0/32	10/32
	Range	<0.03–0.49	<0.02	<0.04–1.44	<0.04	<0.03	<0.04	<0.05–1.67	<0.04	<0.06	<0.02–3.11
CHN (Wet)	Detection	6/8	0/8	8/8	0/8	4/8	4/8	4/8	6/8	0/8	8/8
	Range	<0.4–78.2	<0.4	0.4–10.4	<0.2	<0.2–1.8	<0.2–1.5	<0.2–2.6	<0.3–10.9	<0.2	0.4–105
PHL (Wet)	Detection	5/8	0/8	1/8	0/8	0/8	1/8	1/8	2/8	1/8	5/8
	Range	<0.04–0.64	<0.06	<0.03–0.21	<0.02	<0.02	<0.08–0.29	<0.05–2.15	<0.05–0.20	<0.20–0.34	<0.02–3.83
VNM (Rainy)	Detection	2/14	3/14	0/14	2/14	0/14	0/14	3/14	0/14	0/14	6/14
	Range	<0.09–0.10	<0.05–0.18	<0.07	<0.04–1.85	<0.04	<0.07	<0.05–0.57	<0.08	<0.04	<0.04–2.60
THA (Dry)	Detection	9/12	3/12	6/12	0/12	2/12	5/12	5/12	7/12	5/12	12/12
	Range	<0.02–0.45	<0.02–0.88	<0.02–0.05	<0.02	<0.02–0.05	<0.02–0.03	<0.02–0.05	<0.02–0.03	<0.02–3.66	0.03–3.82
MYS (Dry)	Detection	2/25	0/25	0/25	0/25	0/25	0/25	0/25	0/25	0/25	2/25
	Range	<0.05–0.14	<0.07	<0.03–<0.12	<0.01	<0.01–<0.04	<0.03–<0.10	<0.03–<0.09	<0.02–<0.06	<0.02	<0.01–0.14
SGP (Dry)	Detection	2/5	0/5	0/5	0/5	0/5	0/5	0/5	1/5	4/5	4/5
	Range	<0.16–5.6	<0.19	<0.06	<0.24	<0.04	<0.04	<0.16	<0.09–1.2	<0.03–5.7	<0.03–11.1
SGP (Wet)	Detection	2/5	0/5	0/5	0/5	1/5	0/5	0/5	1/5	3/5	4/5
	Range	<0.16–3.2	<0.19	<0.06	<0.24	<0.04–0.5	<0.04	<0.16	<0.09–1.0	<0.03–1.4	<0.03–5.6
IDN (Dry)	Detection	2/4	0/4	2/4	0/4	2/4	0/4	3/4	3/4	3/4	3/4
	Range	<0.1–0.27	<0.1	<0.1–0.12	<0.1	<0.1–0.16	<0.1	<0.1–0.16	<0.1–0.74	<0.1–1.10	<0.1–2.52
IND (Dry)	Detection	4/12	0/12	0/12	12/12	0/12	0/12	9/12	4/12	0/12	12/12
	Range	<0.08–0.41	<0.04	<0.28	0.01–0.02	<0.04	<0.05	<0.06–0.06	nd –0.03	<0.05	0.01–0.48
PAK (Wet)	Detection	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15
	Range	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Table 4 Measured data of each PFC compound in biota* in 2018

(Unit: ng/g ww)

Country		PFOS	PFHxS	PFOA	PFBA	PFHxA	PFNA	PFDA	PFUnA	PFDoA	Sum
KOR	Detection	4/12	0/12	0/12	0/12	0/12	0/12	0/12	0/12	0/12	4/12
	Range	<0.03–3.22	<0.02	<0.04	<0.04	<0.04	<0.05	<0.05	<0.04	<0.07	<0.02–3.22
CHN**	Detection	15/15	4/15	15/15	0/15	1/15	11/15	14/15	15/15	9/15	15/15
	Range	1.2–491	<0.4–4.4	1.2–41.7	<0.2	<0.2–8.1	<0.2–8.8	<0.2–10.2	0.3–16.6	<0.2–5.5	3.8–528
PHL	Detection	8/10	8/10	3/10	0/10	0/10	5/10	7/10	8/10	1/10	10/10
	Range	<0.02–1.12	<0.03–0.52	<0.02–0.04	<0.01	<0.01	<0.04–0.34	<0.03–0.20	<0.03–0.30	<0.08–0.09	0.09–2.30
VNM	Detection	19/22	18/22	22/22	0/22	0/22	22/22	19/22	22/22	19/22	22/22
	Range	<0.004–1.60	<0.02–2.12	0.039–1.87	<0.06	<0.018	0.051–0.151	<0.004–0.162	0.046–0.772	<0.006–0.187	0.22–4.35
THA	Detection	8/8	2/8	0/8	0/8	1/8	8/8	6/8	6/8	8/8	8/8
	Range	0.04–0.15	<0.02–0.03	<0.02	<0.02	<0.02–0.04	0.04–0.05	<0.02–0.05	<0.02–0.07	0.04–0.05	0.12–0.33
MYS	Detection	0/7	1/7	2/7	2/7	3/7	4/7	1/7	1/7	1/7	5/7
	Range	<0.05–<0.16	<0.07–0.96	<0.03–2.15	<0.01–1.46	<0.01–1.57	<0.03–2.01	<0.03–2.19	<0.02–1.31	<0.02–0.80	<0.01–12.5
IDN	Detection	3/3	3/3	1/3	0/3	2/3	0/3	2/3	2/3	3/3	3/3
	Range	0.23–0.42	0.49–1.82	<0.05–0.17	<0.05	<0.05–0.75	<0.05	<0.05–0.22	<0.05–0.16	0.10–0.36	1.45–3.27
IND***		0.15	<0.04	0.13	nd	0.15	<0.14	<0.06	<0.07	<0.05	0.43
PAK	Detection	0/3	0/3	0/3	0/3	0/3	0/3	1/3	0/3	0/3	1/3
	Range	nd	nd	nd	nd	nd	nd	nd–0.39	nd	nd	nd–0.39

*Mainly fish ** China: Data in 2017 *** India: One sample only