Arch Environ Contam Toxicol (2016) 70:671–681
DOI 10.1007/s00244-015-0220-1

Ubiquitous Detection of Artificial Sweeteners and Iodinated X-ray Contrast Media in Aquatic Environmental and Wastewater Treatment Plant Samples from Vietnam, The Philippines, and Myanmar

Yuta Watanabe[1] · Leu Tho Bach[2] · Pham Van Dinh[2] · Maricar Prudente[3] · Socorro Aguja[4] · Nyunt Phay[5] · Haruhiko Nakata[1]

Received: 2 June 2015 / Accepted: 10 August 2015 / Published online: 25 August 2015

Abstract Water samples from Vietnam, The Philippines, and Myanmar were analyzed for artificial sweeteners (ASs) and iodinated X-ray contrast media (ICMs). High concentrations (low micrograms per liter) of ASs, including aspartame, saccharin, and sucralose, were found in wastewater treatment plant (WWTP) influents from Vietnam. Three ICMs, iohexol, iopamidol, and iopromide were detected in Vietnamese WWTP influents and effluents, suggesting that these ICMs are frequently used in Vietnam. ASs and ICMs were found in river water from downtown Hanoi at concentrations comparable to or lower than the concentrations in WWTP influents. The ASs and ICMs concentrations in WWTP influents and adjacent surface water significantly correlated ($r^2 = 0.99$, $p < 0.001$), suggesting that household wastewater is discharged directly into rivers in Vietnam. Acesulfame was frequently detected in northern Vietnamese groundwater, but the concentrations varied spatially by one order of magnitude even though the sampling points were very close together. This implies that poorly performing domestic septic tanks sporadically leak household wastewater into groundwater. High acesulfame, cyclamate, saccharin, and sucralose concentrations were found in surface water from Manila, The Philippines. The sucralose concentrations were one order of magnitude higher in the Manila samples than in the Vietnamese samples, indicating that more sucralose is used in The Philippines than in Vietnam. Acesulfame and cyclamate were found in surface water from Pathein (rural) and Yangon (urban) in Myanmar, but no ICMs were found in the samples. The ASs concentrations were two–three orders of magnitude lower in the samples from Myanmar than in the samples from Vietnam and The Philippines, suggesting that different amounts of ASs are used in these countries. We believe this is the first report of persistent ASs and ICMs having ubiquitous distributions in economically emerging South Asian countries.

Electronic supplementary material The online version of this article (doi:10.1007/s00244-015-0220-1) contains supplementary material, which is available to authorized users.

✉ Haruhiko Nakata
nakata@aster.sci.kumamoto-u.ac.jp; nakata@sci.kumamoto-u.ac.jp

[1] Graduate School of Science and Technology, Kumamoto University, 2-39-1 Kurokami, Chuo-ku, Kumamoto 860-8555, Japan

[2] Institute of Environmental Science and Engineering, National University of Civil Engineering (NUCE), 55 Giai Phong, Hanoi, Vietnam

[3] Science Education Department, De La Salle University, 2401 Taft Ave, Malate, Manila, 1004 Metro Manila, The Philippines

[4] De La Salle-Araneta University, Victoneta Compound, Malabon, Metro Manila, The Philippines

[5] Pathein University, Ayeyarwady Region, Pathein, Myanmar

Artificial sweeteners (ASs) and iodinated X-ray contrast media (ICMs) are water-soluble and highly persistent in the aquatic environment, and they can be used to identify the potential sources of aquatic pollution in developed countries. Large amounts of low-calorie ASs are currently used in a wide range of beverages and foodstuffs around the world. ASs provide no or negligible energy when consumed by humans, because they are not easily metabolized (Lange et al. 2012), so they also are used in drugs and in foods and drinks for diabetics. The representative ASs, acesulfame (CAS#: 55589-62-3), saccharin (128-44-9), and sucralose (56038-13-2) are high-intensity sweeteners, and they are 200, 600, and 300 times sweeter than sucrose,

respectively (Chattopadhyay et al. 2014). This is illustrated in Fig. S1. ASs have recently been found to be ubiquitously distributed in aqueous WWTP media in various countries, including China (Gan et al. 2013), Germany (Scheurer et al. 2009, 2011), Japan (Watanabe et al. 2014), Sweden (Neset et al. 2010), Switzerland (Buerge et al. 2009), and the United States (Oppenheimer et al. 2011; Subedi and Kannan 2014). Acesulfame, cyclamate, saccharin, and sucralose have generally been detected in WWTP influents at concentrations of around several micrograms per liter. Similar concentrations of acesulfame and sucralose have been found in WWTP influents and effluents, indicating that these ASs are persistent and are not easily biodegraded during the wastewater treatment processes (Buerge et al. 2009). No significant losses of acesulfame or sucralose were found after solutions of these ASs were stored for 2 or 3 years at 20–40 °C (Goldsmith and Merkel 2001; Lipinski and Hanger 2001).

Surface water bodies receive discharges of ASs from WWTPs, and this has resulted in ASs becoming ubiquitous environmental pollutants. Loos et al. (2009) analyzed 120 river water samples from 27 European countries for sucralose and found that sucralose is distributed widely in the aquatic environment. High sucralose concentrations (200–1000 ng/L) have been found in Germany, Switzerland, and the United Kingdom (Loos et al. 2009). Acesulfame has been found at maximum concentrations of 1100–4200 ng/L in samples from the River Rhine in Germany and at a maximum concentration of 25,000 ng/L in samples from Swiss lakes (Lange et al. 2012). Acesulfame, aspartame, cyclamate, saccharin, and sucralose have frequently been detected in the Haihe River, northern China, at concentrations ranging from several tens of to 1000 ng/L (Gan et al. 2013). Similar results have been found in Japan, where both ASs and natural sweeteners have been found in surface water samples (Watanabe et al. 2014). ASs also have been detected in groundwater samples. Von Stempvoort et al. (2011) found cyclamate and saccharin in groundwater samples from Canada. Acesulfame has been detected in groundwater from Switzerland (Buerge et al. 2009) and Japan (Watanabe et al. 2014). These results have suggested that ASs could be used as chemical tracers of domestic and municipal wastewater leaks into groundwater (Roy et al. 2014). However, little information is available on the occurrences, concentrations, and distributions of ASs in aquatic environmental media in South Asian countries.

ICMs are the most frequently intravascularly administered pharmaceuticals in hospitals. ICMs are used to allow images of organs and blood vessels to be acquired in diagnostic tests (Perez and Barcelo 2007). Like ASs, ICMs are highly water-soluble (Fig. S1), and some ICMs are persistent and resistant to microbial degradation during wastewater treatment (Ternes et al. 2007). ICMs are not adsorbed by sewage sludge (Kalsch 1999; Haiss and Kummerer 2006), so they are frequently detected in wastewater and the aquatic environment. The major ICMs, including iohexol (CAS# 66108-95-0), iopamidol (60166-93-0), and iopromide (73334-07-3) have been detected in the influents and effluents of WWTPs in Germany at concentrations in the low micrograms per liter (Ternes and Hirsch 2000). Iopromide also has been detected in wastewater in Spain (Carballa et al. 2004), and five ICMs, including diatrizoic acid (CAS# 117-96-4) and iomeprol (78649-41-9), have been found in treated wastewater in Jordan (Zemann et al. 2014). Very high ICMs concentrations have been found in hospital wastewater, implying that there are sources of ICMs to wastewater systems within medical facilities (Weissbrodt et al. 2009).

It has been found that ICMs are distributed widely in surface water in various countries. Iomeprol, iopamidol, and iopromide have been detected at concentrations of approximately 1 μg/L in river and creek water in Germany (Ternes and Hirsch 2000). High diatrizoic acid, iohexol, and iopamidol concentrations, of up to several hundred nanograms per liter, have been found in samples from a small river in Kumamoto, Japan (Watanabe et al. 2014). Large numbers of ICMs biotransformation products have been identified in drinking water, surface water, and wastewater from Germany (Kormos et al. 2011). However, as with ASs, little information is available on the occurrences and distributions of ICMs in Asian countries.

The occurrences and current pollutant status of a number of pollutants have been determined in the "Mussel Watch" programs, and these pollutants have included polybrominated diphenyl ethers (Ramu et al. 2007), polychlorinated biphenyls and organochlorine pesticides (Monirith et al. 2003), polycyclic aromatic hydrocarbons (Isobe et al. 2007), and emerging pollutants (Nakata et al. 2012). Pharmaceuticals recently have been found to be ubiquitous pollutants in surface water in tropical Asian countries (Managaki et al. 2007; Hoa et al. 2011; Shimizu et al. 2013; Tran et al. 2014a, b; Kuroda et al. 2015). However, little information is available on the concentrations and distributions of persistent water-soluble chemicals, including ASs and ICMs, in the environment in South Asian countries. In particular, no information, to the best of our knowledge, is available on the occurrences and concentrations of organic micropollutants in the environment in Myanmar, although monitoring data for general water quality (Akashi et al. 2006) and arsenic in groundwater (Van Geen et al. 2014) are available.

Based on this background, the first objective of this study was to determine the current ASs and ICMs pollution

statuses of Vietnamese WWTPs, surface water, and groundwater. The second objective was to determine the ASs and ICMs contamination profiles of river water samples collected in The Philippines and Myanmar.

Materials and Methods

Chemical Standards

Acesulfame K, aspartame, saccharin Na, and sucralose were purchased from Wako Pure Chemical Industries Ltd. (Osaka, Japan). Cyclamate was obtained from Alfa Aesar Johnson Matthey Company, Lancashire, UK. Iohexol, iopamidol, and iopromide were obtained from LKT Laboratories, Inc. (St. Paul, MN), Wako Pure Chemical Industries Ltd., and Toronto Research Chemicals (Toronto, Canada), respectively. Diatrizoic acid and metrizoic acid were obtained from Tokyo Chemical Industry Co. Ltd (Tokyo, Japan).

Sample Collection

The sampling locations are shown in Fig. 1, and detailed information on the locations is presented in Figs. S2, S3, and S4 and Table S1. Influent and effluent samples ($n = 14$) were collected from a wastewater treatment plant (WWTP) in Hanoi, Vietnam. This is a pilot-scale plant for simulating the capacity of wastewater treatment process to construct a large-scale WWTP in Vietnam. The WWTP has an average wastewater inflow of only approximately 3000 m^3/day. Influent and effluent samples were collected at the same time of day each day for a week. Water samples were collected from the Hong River ($n = 5$; sample ID HO1–HO5), a canal ($n = 1$), the Lu River ($n = 4$; LU2–LU5), and two ponds ($n = 2$; LU1 and LU6) in the Hanoi area, and these locations are shown in Fig. S2. We also collected river water samples ($n = 6$; HP1–HP6) from Haiphong City, which is in the southern part of Hanoi. Groundwater samples were collected from Hanoi ($n = 9$; HN1–HN9) and the Halong area ($n = 3$; HL1–HL3), and

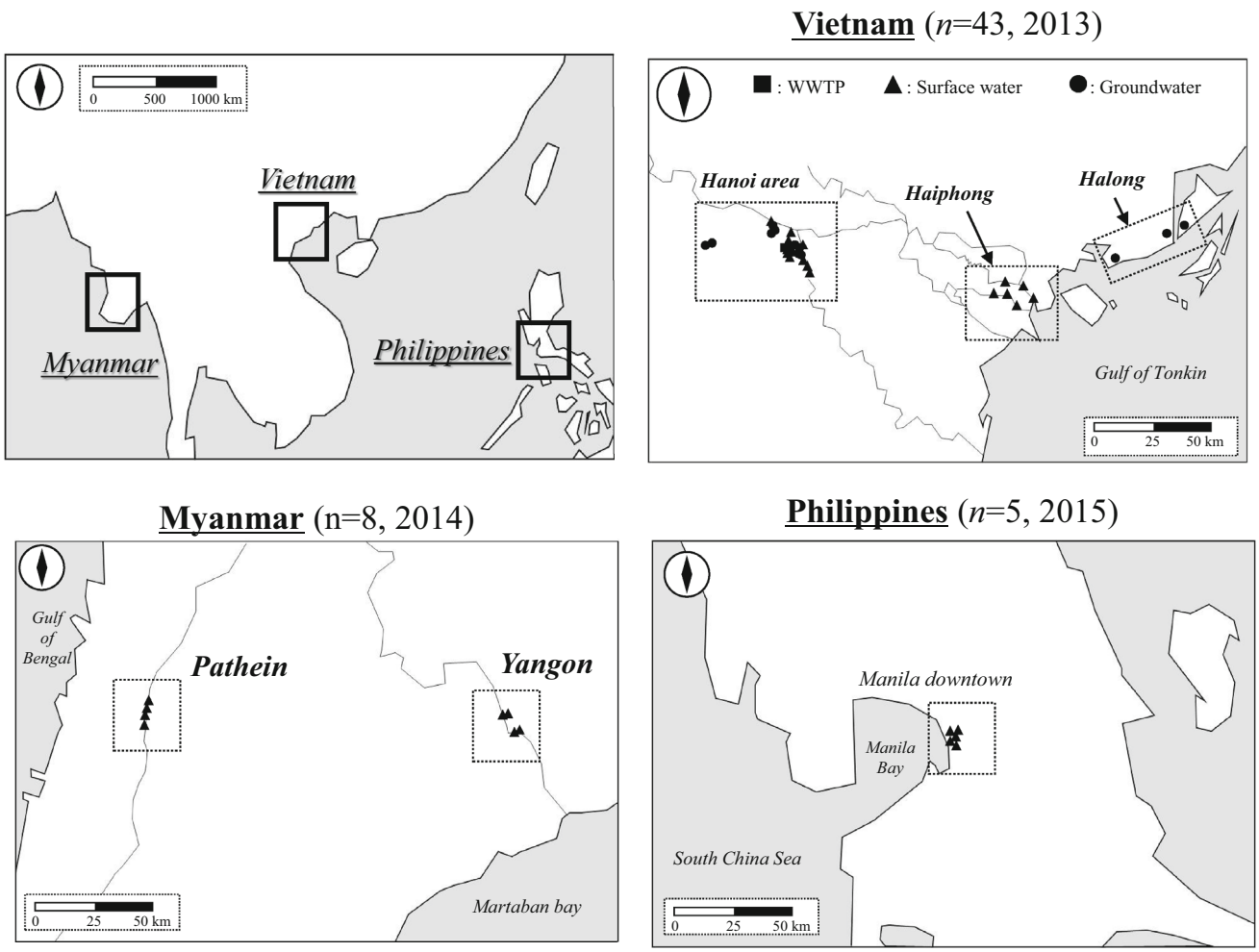

Fig. 1 Map showing the sampling locations in this study (the locations of the sites are shown in detail in Figs. S2–S4)

these locations also are shown in Fig. S2. The Vietnamese samples were collected between October and December 2013. Each sample was between 100 and 3000 mL and was collected using a plastic container. While still in Vietnam, each sample was filtered and then extracted using a solid phase extraction cartridge. In The Philippines, surface water samples were collected from the Pasig River ($n = 2$; PH1 and PH3), a small river ($n = 2$; PH2 and PH5), and Manila Bay ($n = 1$; PH4) in the downtown Manila area in June 2014. The sampling locations are shown in Fig. S3. In Myanmar, surface water samples were collected from the Pathein River ($n = 4$; PA1–PA4) and the Yangon River ($n = 4$; YA1–YA4) in December 2014, and these locations are shown in Fig. S4. All aqueous samples from the Philippines and Myanmar were stored at cooler box with ice and brought back to Japan to prevent microbial degradation of the analytes. We analyzed only filtered aqueous samples in this study, and the SPE cartridges and aqueous samples obtained were stored at deep freezer until chemical analysis.

Sample Preparation and Analysis

Between 500 and 1500 mL of a sample were filtered through a GF/A glass-fiber filter (Whatman, Dassel, Germany). Formic acid was then added to the sample to bring it to pH <2.8; then the sample was passed through a solid phase extraction cartridge (Oasis HLB, 200 mg; Waters, Milford, MA) at a flow rate of 5 mL/min. The cartridge was preconditioned with 5 mL of 40 % (v/v) acetonitrile in water and 5 mL of purified water. The cartridge was then centrifuged at 3000 rpm for 15 min to remove the residual water. Then, the analytes were eluted with 10 mL of 40 % (v/v) acetonitrile in water. The extract was evaporated to dryness and then redissolved in 1 mL of 2 % (v/v) acetonitrile in water containing 0.1 % formic acid.

The ASs and ICMs in the extracts were determined using a liquid chromatograph coupled to an electrospray ionization mass spectrometer (Agilent 1100 Series LC/MS SL; Agilent Technologies Inc., Santa Clara, CA). Different instrumental parameters were used to analyze the ASs and ICMs. ASs were separated using a reversed-phase column (ZORBAX Eclipse XDB-C18; 150-mm long, 2.1-mm i.d., 3.5-μm particle size with 5 mM of dibutylammonium acetate (eluent A) and 80 % acetonitrile in water (eluent B) mobile phases. The mobile phase flow rate was 0.2 mL/min. The ICMs were separated using a YCM-Pack ODS-AQ column (100-mm long, 4.6-mm i.d., 3-μm particle size) with 2 % (v/v) acetonitrile in water containing 0.1 % of formic acid (eluent C) and 100 % acetonitrile (eluent D) mobile phases. The mobile phase flow rate was 0.4 mL/min. The ions that were monitored were m/z 162 for acesulfame, m/z 293 for aspartame, m/z 178 for cyclamate, m/z 182 for saccharin, m/z 395 for sucralose, m/z 615 for diatrizoic acid, m/z 822 for iohexol, m/z 778 for iopamidol, m/z 792 for iopromide, and m/z 629 for metrizoic acid.

Quality Assurance

The ASs and ICMs concentrations were calculated using an external calibration produced using a standard solution. A standard mixture of ASs and ICMs was spiked into pure water to give a concentration of 1.0 μg/L of each compound, and the spiked water was passed through the analytical procedure to allow the recoveries of the target analytes to be determined. The means and standard deviations of the recoveries of ASs and ICMs were 98 ± 2.6 % for acesulfame, 85 ± 4.4 % for aspartame, 99 ± 1.4 % for cyclamate, 97 ± 2.4 % for saccharin, 110 ± 4.8 % for sucralose, 110 ± 0.72 % for diatrizoic acid, 86 ± 7.0 % for iohexol, 79 ± 2.6 % for iopamidol, 90 ± 4.2 % for iopromide, and 95 ± 1.8 % for metrizoic acid. The instrumental detection limits and quantification limits of ASs and ICMs were calculated as the following formula (Ministry of the Environment 2004):

$$\text{IDLs} = t(n-1,\ 0.05) \times 2 \times \text{SD}$$

$$\text{IQLs} = 10 \times \text{SD}$$

where $t\ (n-1,\ 0.05)$ gives the t value appropriate for the 95 % confidence level with $n-1$ degrees of freedom and the number of measurements.

IDLs and IQLs of ASs and ICMs ranged from 0.015 to 23 and 0.039 to 57 ng/L, respectively. A procedural blank was analyzed with every batch of samples so that peaks interfering with the analytes and contamination during the analytical procedure could be monitored. No analytes were detected in the laboratory/procedural blanks in this study.

Results and Discussion

Vietnamese Wastewater Treatment Plant Samples

Acesulfame, aspartame, cyclamate, saccharin, and sucralose were all detected in the WWTP influent and effluent samples. Saccharin was found at a higher concentration (median 13,000 ng/L) than were the other ASs. The other ASs decreased in concentration in the order aspartame (2100 ng/L), sucralose (1100 ng/L), cyclamate (580 ng/L), and acesulfame (360 ng/L). The concentrations found are shown in Table 1. These results suggest that large amounts of ASs are consumed by the general Vietnamese population. AS also have been detected in WWTP influents in other countries. Saccharin and sucralose were the dominant ASs in influent samples collected in Japan, and they were found at mean concentrations of 3600 and 2500 ng/L, respectively (Watanabe et al. 2014). Acesulfame (910 ng/

Table 1 Concentrations of artificial sweeteners and iodinated X-ray contrast media (ng/L) in aqueous samples collected from Vietnam, Philippines, and Myanmar during 2013–2014

Country	Vietnam											Philippines	Myanmar	
City	Hanoi		Hanoi				Haiphong	Hanoi			Halong	Manila	Pathein	Yang on
Matrices	WWTP		Surface water				Surface water	Groundwater			Ground water	Surface water	Surface water	
N	Influent 7	Effluent 7	Hong 5	Canal 1	Lu 4	Pond 2	Two rivers 6	Urban 4	Suburb 3	Rural 2	3	5	4	4
Artificial sweeteners														
Acesulfame														
Median	360	190	2.8	1100	870	530	2.9	0.40	8.8	44	68	1600	0.74	5.3
Min–Max	55–580	150–210	1.5–21	1100	240–890	460–610	1.0–14	0.30–0.49	0.41–110	0.69–86	4.5–130	220–7800	0.69–0.84	4.1–24
DF (%)*	100	100	100	100	100	100	100	50	100	100	67	100	100	100
Sucralose														
Median	1100	1100	47	340	1200	480	n.d.	n.d.	8.1	18	47	2300	n.d.	n.d.
Min–Max	750–1500	990–1100	n.d.–47	340	1000–1300	390–570	n.d.	n.d.	n.d.–8.1	n.d.–18	n.d.–47	490–8300	n.d.	n.d.
DF (%)	100	100	20	100	100	100	0	0	33	50	33	100	0	0
Saccharin														
Median	13,000	29	1.3	1700	13,000	260	10	n.d.	13	2.5	3	3800	n.d.	18
Min–Max	7600–13,000	23–36	0.092–42	1700	260–17,000	62–460	2.8–33	n.d.	n.d.–13	n.d .–2.5	0.44–3.6	290–9600	n.d.	14–71
DF (%)	100	100	100	100	100	100	100	0	33	50	100	100	0	100
Aspartame														
Median	2100	n.d.	n.d.	n.d.	2100	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Min–Max	570–3100	n.d.	n.d.	n.d.	1700–2600	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
DF (%)	100	0	0	0	50	0	0	0	0	0	0	0	0	0
Cyclamate														
Median	580	n.d.	4.0	410	710	47	5.9	n.d.	4.9	2.4	6.8	1000	3.6	19
Min–Max	87–810	n.d.	2.1–6.0	410	160–1100	47	5.6–6.1	n.d.	n.d.–4.9	1.8–3.0	2.4–65	240–1900	1.9–4.1	16–28
DF (%)	100	0	40	100	100	50	33	0	33	100	100	80	100	100
Iodinated X-ray contrast media														
Iopamidol														
Median	34	200	16	120	120	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	49	n.d.	n.d.
Min–Max	27–51	130–670	n.d.–16	120	21–230	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	32–67	n.d.	n.d.
DF (%)	43	100	20	100	50	0	0	0	0	0	0	40	0	0

Table 1 continued

Country	Vietnam											Philippines	Myanmar	
City	Hanoi		Hanoi				Haiphong	Hanoi			Halong	Manila	Pathein	Yang on
Matrices	WWTP		Surface water				Surface water	Groundwater			Ground water	Surface water	Surface water	
N	Influent 7	Effluent 7	Hong 5	Canal 1	Lu 4	Pond 2	Two rivers 6	Urban 4	Suburb 3	Rural 2	3	5	4	4
Iohexol														
Median	550	740	43	610	690	85	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Min–Max	180–1900	350–4000	n.d.–43	610	66–1500	60–110	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
DF (%)	100	100	20	100	100	100	0	0	0	0	0	0	0	0
Diatrizoic acid														
Median	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Min–Max	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
DF (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iopromide														
Median	100	25	52	140	180	120	n.d.	n.d.	n.d.	n.d.	n.d.	38	n.d.	n.d.
Min–Max	31–450	16–1600	13–90	140	51–1100	120	n.d.	n.d.	n.d.	n.d.	n.d.	14–44	n.d.	n.d.
DF (%)	86	100	40	100	100	50	0	0	0	0	0	80	0	0
Metrizoic acid														
Median	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Min–Max	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
DF (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Detection frequency (%)

L) and aspartame (81 ng/L) also were detected in the Japanese WWTP influent samples, but cyclamate was not detected, presumably because its use has been prohibited in Japan since the 1960s. Cyclamate (mean 33,000 ng/L) and acesulfame (mean 28,000 ng/L) have been detected in WWTP influents in Switzerland (Berge et al. 2009). Acesulfame (mean 22,000 ng/L), cyclamate (mean 21,000 ng/L), and sucralose (mean 30,000 ng/L) have been found to be the dominant ASs in WWTP influents in Germany (Scheurer et al. 2011), China (Gan et al. 2013), and the United States (Subedi and Kannan 2014), respectively. The different ASs concentrations and profiles that have been found in WWTP influents suggest that different sweeteners are preferred for use in foods and beverages among countries.

Sucralose was a dominant AS in the Vietnamese WWTP effluent samples (median 1100 ng/L). Acesulfame and saccharin were found in the effluent samples at median concentrations of 190 and 29 ng/L, respectively. The ASs concentrations in the effluent samples are shown in Table 1. The saccharin concentrations were much lower in the effluent samples than in the influent samples, because saccharin can be microbially degraded in the wastewater treatment processes. Similar results have been found in studies of wastewater from China (Gan et al. 2013), Germany (Scheurer et al. 2009), Japan (Watanabe et al. 2014), and Switzerland (Buerge et al. 2009). Aspartame and cyclamate were not detected in the effluent samples. Aspartame and cyclamate could have been adsorbed onto suspended solids or degraded in the wastewater treatment processes. Aspartame was found in 92 % of influent suspended solid samples in a previous study; this suggests that aspartame readily becomes adsorbed onto sewage sludge (Subedi and Kannan 2014). The mean acesulfame and sucralose concentrations in the effluent samples were comparable to the concentrations in the influent samples (Table 1). Similar results have been found for WWTP samples in other countries (Burge et al. 2009; Watanabe et al. 2014), suggesting that acesulfame and sucralose are persistent and not readily degradable in WWTPs.

Iohexol was found at a higher concentration (median 550 ng/L) than the other ICMs in the WWTP influent samples, and the median iopromide and iopamidol concentrations were 100 and 34 ng/L, respectively. The ICMs concentrations in the influent samples are shown in Table 1. Diatrizoic acid was not detected in either the influent or effluent samples. ICMs have previously been determined in wastewater samples from other countries. An iopamidol concentration of 6600 ng/L, an iomeprol concentration of 5700 ng/L, an iohexol concentration of 3700 ng/L, and an iopromide concentration of 1700 ng/L have been found in German WWTP influents (Kormos et al. 2011). Iopamidol and iohexol have been found to be the dominant ICMs in Japanese WWTP influents; the mean concentrations were 3800 and 2000 ng/L, respectively (Watanabe et al. 2014). Iopromide has been found at a concentration of 6600 ng/L in Spanish WWTP influent samples (Carballa et al. 2004). The ICMs concentrations found in our study were generally lower than have been found in developed countries, implying that relatively small amounts of ICMs are used in Vietnam.

Iohexol was the dominant ICM in the effluent samples (the median iohexol concentration was 740 ng/L), as was the case for the influent samples, and iopromide was found at the next highest concentration (median 200 ng/L). The iohexol and iopromide concentrations in the effluent samples were comparable to or higher than the concentrations in the influent samples, suggesting that these ICMs were not easily degraded in the wastewater treatment processes. ICMs have been found to be persistent in previous studies, and diatrizoic acid and iopromide were found not to be eliminated when sewage sludge was treated using standardized OECD degradation tests (Steger-Hartmann et al. 1999; Haib and Kummerer 2006).

Temporal trends in the ASs and ICMs concentrations in the wastewater samples over a period of a week were monitored. Interestingly, the ASs concentrations in the influent samples were lower on the Friday and Saturday than on other days (Fig. S5). In contrast, no significant changes in ASs concentrations were found over a period of a week in a Japanese study (Watanabe et al. 2014). Sucralose loads in WWTP influents were not significantly different between weekdays and weekend days in Sweden (Neset et al. 2010). High iohexol and iopromide concentrations were found on the Wednesday and Monday, respectively, and this may have reflected the days that medical diagnostic tests using ICMs were performed in the hospital nearby the WWTP.

Vietnamese River Water and Groundwater

ASs concentrations in the surface water samples from Hanoi are shown in Table 1. Acesulfame and saccharin were detected in many of the samples from the Hong River (a large river), and the median concentrations were 2.8 ng/L for acesulfame and 1.3 ng/L for saccharin (Table 1; Fig. 3). These concentrations were comparable to or lower than the concentrations that have been found in surface water from Germany (Scherer et al. 2009) and Japan (Watanabe et al. 2014). The ASs concentrations were different in the samples from different sites on the Hong River, and the saccharin concentration at site HO4 was 20 times higher than the concentration at site HO3. Similarly, the acesulfame, cyclamate, and sucralose concentrations were higher at site HO4 than at site HO3. A small canal runs between sites HO3 and HO4 downstream of

downtown Hanoi. High ASs and ICMs concentrations were found in the canal water (Table 1), implying that the ASs and ICMs inputs to the Hong River through the canal are significant.

We analyzed seven surface water samples from the Lu River (a small river) and small ponds in downtown Hanoi to allow the potential sources of the ASs in the Hong River to be identified. Extremely high ASs concentrations were found in the Lu River samples, and saccharin was found at a higher concentration (median 17,000 ng/L) than the other ASs. The highest saccharin concentration was found in the sample from site LU4 (Fig. S2). Aspartame, sucralose, and acesulfame levels also were high at the highest concentrations of 890, 1300, and 2600 ng/L, respectively, in Lu River. Cyclamate was found in the samples from all of the sites on the Lu River except site LU6 (a small pond). The cyclamate concentrations in these samples were 47–1100 ng/L. ASs concentrations in the pond water samples from sites LU1 and LU6 were low (Fig. 2). This may suggest that a significant amount of microbial and photochemical degradation of micropollutants occurs in ponds. A wide range of concentrations of the persistent pharmaceutical carbamazepine have previously been found in pond water from Hanoi (Kuroda et al. 2015).

The highest iohexol, iopamidol, and iopromide concentrations in the samples from the Lu River were 1500, 230, and 1100 ng/L, respectively. The ICMs concentrations were higher in the sample from LU4 than in the samples from the other sites on the Lu River, and the ICMs concentrations at site LU4 were similar to the ASs concentrations that were found in the Lu River. Interestingly, a significant relationship ($p < 0.01$) was found between the ASs and ICMs concentrations in the WWTP influents and the Lu River tributaries (mean levels of LU-1 to LU6 samples; Fig. 3). This strongly indicates that household wastewater is a major source of surface water pollution in Hanoi. Shimizu et al. (2013) found high sulfamethoxazole concentrations in river water in Vietnam; this suggests that there is relatively poor access to sewage treatment systems in Vietnam.

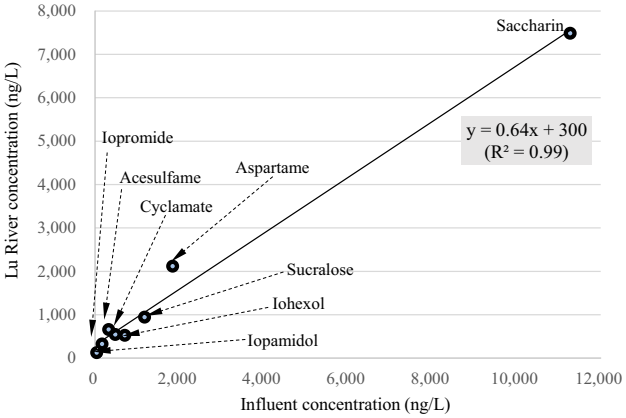

Fig. 3 Relationship between the concentrations of the artificial sweeteners and iodinated X-ray contrast media in the wastewater treatment plant influent and surface water samples from downtown Hanoi, Vietnam

The proportion of wastewater in river water was roughly estimated in a previous study from the ratio between the persistent pharmaceutical concentrations in WWTP influent samples and river water samples (Kuroda et al. 2015). Assuming that persistent ASs and ICMs are good chemical tracers of the leakage of wastewater into a river, the slope of the best-fit line between the concentrations in the influents and the river water was treated as an estimate of the proportion of wastewater in the river water (Fig. 3). The Lu River water was estimated to contain 64 % untreated wastewater. This proportion was higher than that in the Nhue River (14 %), where is another urban river in Hanoi, a pond (<1.5 %), and farmland samples (39 %), calculated using carbamazepine, which is a persistent pharmaceutical (Kuroda et al. 2015).

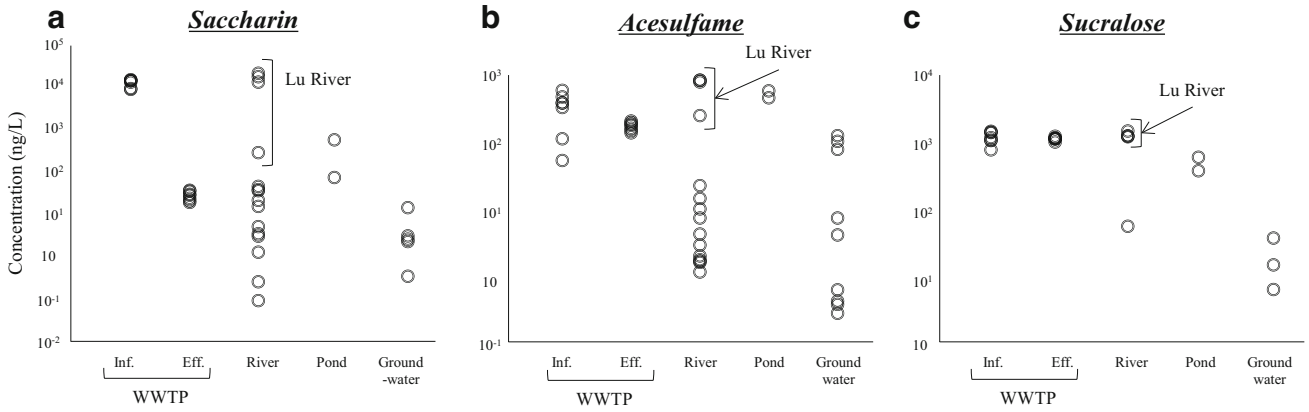

Fig. 2 Concentrations of **a** saccharin, **b** acesulfame, and **c** sucralose in the wastewater, river water, pond water, and groundwater samples from Vietnam

Acesulfame and saccharin were detected in six river water samples from Haiphong, with median concentrations of 2.9 and 10 ng/L, respectively (Table 1). Cyclamate was detected at sites HP5 and HP6 upstream of Haiphong (Fig. S2). The acesulfame and saccharin concentrations at sites HP5 and HP6 were comparable to the concentrations in the Hong River but lower than the concentrations in the Lu River. No ICMs were detected in any of the samples collected in Haiphong.

Groundwater samples were collected from rural, suburban, and urban areas in the Hanoi region ($n = 9$) and along the Halong Bay coast ($n = 3$) in northern Vietnam. The sampling sites are shown in Fig. S2. In general, the ASs concentrations and detection frequencies were lower in the groundwater samples than in the surface water and wastewater samples (Table 1). The acesulfame detection frequency was 75 %, and the detection frequencies of the other ASs decreased in the order cyclamate (50 %), saccharine (42 %), and sucralose (25 %). Aspartame and the ICMs were not detected in the groundwater samples. Interestingly, the acesulfame concentrations at different groundwater sampling sites varied widely. High acesulfame concentrations were found at sites HN2 and HN5, and cyclamate, saccharin, and sucralose (Fig. S2) were detected in the samples from these sites, but not in any of the samples from the other sites. The acesulfame concentrations were approximately one order of magnitude lower in the samples from sites HN1 and HN4 than in the samples from sites HN2 and HN5 even though the HN1 and HN2 sites were very close to the HN4 and HN5 sites (Fig. S2). A similar distribution profile was found in the groundwater samples from Halong. The acesulfame concentrations in the samples from HL2 and HL3 differed by a factor of approximately 30 (Fig. S2). These results suggest the possibility of household wastewater leakage from septic tanks into the groundwater in northern Vietnam. It has been reported that 90.5 % of human excreta enters septic tanks in Hanoi, but that 89.6 % of septic tanks have never been desludged and perform poorly (Harada et al. 2008). Our results suggest that ASs may be able to use as wastewater tracers in Vietnam.

River Water in The Philippines and Myanmar

Acesulfame, cyclamate, saccharin, and sucralose were detected in the river water samples from The Philippines (Table 1). ASs concentrations were different in the samples from different sites; the higher ASs concentrations were found at sites PR2 and PR5 (Fig. S3). AS concentrations in the samples from the downstream Pasig River sites (PH1 and PH3) and the Manila Bay site (PH4) were lower than the AS concentrations found in a small canal, probably because of the effects of dilution in the river environments. As in Vietnam, the saccharin concentrations (median: 9600 ng/L) were higher than the other ASs concentrations in the river water samples. However, unlike in Vietnam, the median acesulfame and sucralose concentrations (7800 and 8300 ng/L, respectively) also were high in the river water samples from The Philippines. Significant correlations were found in concentrations between saccharine and other ASs, between acesulfame and sucralose, between acesulfame and cyclamate, and between cyclamate and sucralose in surface water samples (Table 2). These correlations were different from those found in Vietnam, especially the relationship between the acesulfame and sucralose concentrations. Iopamidol and iopromide were found in samples from several sites, and the median concentrations were 50 and 38 ng/L, respectively. These concentrations were approximately one order of magnitude lower than those found in the Lu River in Vietnam, implying that ICMs are used less in hospitals around Manila in The Philippines than in Vietnam.

Acesulfame, cyclamate, and saccharin were detected in the river water samples from Yangon (an urban area) and Pathein (a rural area) in Myanmar. The acesulfame, cyclamate, and saccharin concentrations were higher in the samples from Yangon than in the samples from Pathein, suggesting that ASs are used more in urban areas than in

Table 2 Correlation coefficients of surface water concentrations between artificial sweeteners from Vietnam, The Philippines, and Myanmar

Vietnam ($n = 6$, Hanoi downtown area)				
	Saccharin	Acesulfame	Sucralose	Cyclamate
Saccharin	1			
Acesulfame	0.859**	1		
Sucralose	0.549*	0.179	1	
Cyclamate	0.968**	0.779**	0.627*	1
Philippines ($n = 5$, Manila downtown area)				
	Saccharin	Acesulfame	Sucralose	Cyclamate
Saccharin	1			
Acesulfame	0.977**	1		
Sucralose	0.992**	0.988**	1	
Cyclamate	0.869**	0.876**	0.830**	1
Myanmar ($n = 4$, Yangon downtown area)				
	Saccharin	Acesulfame	Sucralose	Cyclamate
Saccharin	1			
Acesulfame	−0.307	1		
Sucralose	NA	NA	1	
Cyclamate	0.935**	−0.214	NA	1

** $p < 0.01$, * $p < 0.05$

rural areas. As in Vietnam and The Philippines, saccharin was found at higher concentrations than the other ASs in the samples from Yangon. The median saccharin, cyclamate, and acesulfame concentrations in the samples from Yangon were, in decreasing order, 18, 19, and 5.3 ng/L, respectively. These concentrations were between one and two orders of magnitude lower than the concentrations that were found in the samples from The Philippines and Vietnam, indicating that ASs consumption is lower in Myanmar than in other two countries. Saccharin and cyclamate concentrations in the river water samples from Myanmar significantly correlated, but no correlations were found between the concentrations of the other sweeteners (Table 2). No ICMs were detected in the river samples from Myanmar.

Major political changes have allowed the economy of Myanmar to grow since 2011. The production and consumption of ASs in Myanmar are predicted to increase in the near future, and this is predicted to result in them becoming ubiquitous pollutants. The results of this study form baseline data for these anthropogenic chemicals in the aquatic environment of Myanmar, and continuous monitoring will be necessary to allow future changes in the pollution statuses of these chemicals in Myanmar to be understood.

Acknowledgments The authors thank Mr. Hiep and other students and staff members in National University of Civil Engineering in Vietnam for their assistance in the field sampling. This research was partly funded by J-RAPID and CREST programs of JST (Japan Science Technology Agency) and Kyoten Keisei B in Kumamoto University.

References

Akaishi F, Satake M, Otaki M, Tominaga N (2006) Surface water quality and information about the environment surrounding Inle Lake in Myanmar. Limnology 7:57–62

Buerge IJ, Buser H-R, Kahle M, Müller MD, Poiger T (2009) Ubiquitous occurrence of the artificial sweetener acesulfame in the aquatic environment: an ideal chemical marker of domestic wastewater in groundwater. Environ Sci Technol 43:4381–4385

Carballa M, Omil F, Lema JM, Llompart M, Gracia-Jares C, Rdgrigez I, Gomez M, Ternes T (2004) Behavior of pharmaceuticals, cosmetics and hormones in a sewage treatment plant. Water Res 38:2918–2926

Chattopadhyay S, Raychaudhuri U, Chakraborty R (2014) Artificial sweeteners: a review. J Food Sci Technol 51:611–621

Gan Z, Sun H, Feng B, Wang R, Zhang Y (2013) Occurrence of seven artificial sweeteners in the aquatic environment and precipitation of Tianjin, China. Water Res 47:4928–4937

Goldsmith LA, Merkel CM (2001) Sucralose. In: Nabors LO (ed) Alternative sweeteners. Marcel Dekker Inc., New York, pp 185–207. ISBN 0-8247-0437-1

Haib A, Kummerer K (2006) Biodegradability of the X-ray contrast compound diatrizoic acid, identification of aerobic degradation products and effects against sewage sludge micro-organisms. Chemosphere 62:143–153

Harada H, Dong NT, Matsui S (2008) A measure for provisional-and-urgent sanitary improvement in developing countries: septic-tank performance improvement. Water Sci Technol 58:1305–1311

Hoa PTP, Managaki S, Nakada N, Takada H, Shimizu A, Anh DH, Viet PH, Suzuki S (2011) Antibiotic contamination and occurrence of antibiotic resistant bacteria in aquatic environments of northern Vietnam. Sci Total Environ 409:2894–2901

Isobe T, Takada H, Kanai M, Tsutsumi S, Isobe K, Boonyatumanond R, Zakaria MP (2007) Distribution of polycyclic aromatic hydrocarbons (PAHs) and phenolic endocrine disrupting chemicals in South and Southeast Asian mussels. Environ Monit Assess 135:423–440

Kalsch W (1999) Biodegradation of the iodinated X-ray contrast media diatrizoate and iopromide. Sci Total Environ 225:143–153

Kormos JL, Schulz M, Ternes TA (2011) Occurrence of iodinated X-ray contrast media and their biotransformation products in the urban water cycle. Environ Sci Technol 45:8723–8732

Kuroda K, Nakada N, Hanamoto S, Inaba M, Katayama H, Do AT, Nga TTV, Oguma K, Hayashi T, Takizawa S (2015) Pepper mild mottle virus as an indicator and a tracer of fecal pollution in water environments: comparative evaluation with wastewater-tracer pharmaceuticals in Hanoi, Vietnam. Sci Total Environ 506–507:287–298

Lange FT, Scheurer M, Branuch H-J (2012) Artificial sweeteners: a recently recognized class of emerging environmental contaminants: a review. Anal Bioanal Chem 403:2503–2518

Lipinski GWR, Hanger LY (2001) Acesulfame K. In: Nabors LO (ed) Alternative sweeteners. Marcel Dekker Inc, New York, pp 13–30. ISBN 0-8247-0437-1

Loos R, Gawlik BM, Boettcher K, Locoro G, Contini S, Bidoglio G (2009) Sucralose screening in European surface waters using a solid-phase extraction-liquid chromatography-triple quadrupole mass spectrometry method. J Chromatogr A 1216:1126–1131

Managaki S, Murata A, Takada H, Bui CT, Chiem NH (2007) Distribution of macrolides, sulfonamides, and trimethoprim in tropical waters: ubiquitous occurrence of veterinary antibiotics in the Mekong Delta. Environ Sci Technol 41:8004–8010

Ministry of the Environment, Japan (2004). http://www.env.go.jp/chemi/kurohon/http2004/02moni-manu/000moni-manu.htm

Monirith I, Ueno D, Takahashi S, Nakata H, Sudaryanto A, Subramanian A, Karuppiah S, Ismail A, Muchtar M, Zheng J, Richardson B, Puidente M, Hue ND, Tana TS, Tkalin AV, Tanabe S (2003) Asia-Pacific mussel watch: monitoring contamination of persistent organochlorine compounds in coastal waters of Asian countries. Mar Pollut Bull 46:281–300

Nakata H, Shinohara R, Nakazawa Y, Isobe T, Sudaryanto A, Subramanian A, Tanabe S, Zakaria MP, Zheng GJ, Lam PKS, Kim E-Y, Min B-Y, We S-U, Viet PH, Tana TS, Prudente M, Frank D, Lauenstein G, Kannan K (2012) Asia-Pacific mussel watch for emerging pollutants: distribution of synthetic musks and benzotriazole UV stabilizers in Asian and US coastal waters. Mar Pollut Bull 64:2211–2218

Neset T-SS, Singer H, Longree P, Bader H-P, Scheidegger R, Wittmer A, Andersson JCM (2010) Understanding consumption-related sucralose emission: a conceptual approach combing substance-flow analysis with sampling analysis. Sci Total Environ 408:3261–3269

Oppenheimer J, Eaton A, Badruzzaman M, Haghani AW, Jacangelo JG (2011) Occurrence and suitability of sucralose as an indicator compound of wastewater loading to surface waters in urbanized regions. Water Res 45:4019–4027

Pérez S, Barceló D (2007) Fate and occurrence of X-ray contrast media in the environment. Anal Bioanal Chem 387:1235–1246

Ramu K, Kajiwara N, Sudaryanto A, Isobe T, Takahashi S, Subramanian A, Ueno D, Zheng GJ, Lam PKS, Takada H, Zakaria MP, Viet PH, Prudente M, Tana TS, Tanabe S (2007) Asian mussel watch program: contamination status of polybrominated diphenyl ethers and organochlorines in coastal waters of Asian countries. Environ Sci Technol 41:4580–4586

Roy JW, Van Stempvoort DR, Brickerton G (2014) Artificial sweeteners as potential tracers of municipal landfill leachate. Environ Pollut 184:89–93

Scheurer M, Brauch H-J, Lange FT (2009) Analysis and occurrence of seven artificial sweeteners in German waste water and surface water and in soil aquifer treatment (SAT). Anal Bioanal Chem 394:1585–1594

Scheurer M, Storck FR, Graf C, Brauch H-J, Ruck W, Lev O, Lange FT (2011) Correlation of six anthropogenic markers in wastewater, surface water, bank filtrate, and soil aquifer treatment. J Environ Monit 13:966–973

Shimizu A, Takada H, Koike T, Takeshita A, Saha M, Rinawati NN, Murata A, Suzuki A, Suzuki T, Suzuki S, Chiem NH, Tuyen BC, Viet PH, Siringan MA, Kwan C, Zakaria MP, Reungsang A (2013) Ubiquitous occurrence of sulfonamides in tropical Asian waters. Sci Total Environ 452–453:108–115

Steger-Hartmann T, Länge R, Schweinfurth H (1999) Environmental risk assessment for the widely used iodinated X-ray contrast agent iopromide (ultravist). Ecotoxicol Environ Saf 42:274–281

Subedi B, Kannan K (2014) Date of artificial sweeteners in wastewater treatment plants in New York State, U.S.A. Environ Sci Technol 48:13674–13688

Ternes TA, Hirsch R (2000) Occurrence and behavior of X-ray contrast media in sewage facilities and the aquatic environment. Environ Sci Technol 34:2741–2748

Ternes TA, Bonerz M, Herrmann N, Teiser B, Andersen HR (2007) Irrigation of treated wastewater in Braunschweig, Germany: an option to remove pharmaceuticals and musk fragrances. Chemosphere 66:894–904

Tran NH, Hu J, Li J, Ong SL (2014a) Suitability of artificial sweeteners as indicators of raw wastewater contamination in surface water and groundwater. Water Res 48:443–456

Tran NH, Urase T, Ta TT (2014b) A preliminary study on the occurrence of pharmaceutically active compounds in hospital wastewater and surface water in Hanoi, Vietnam. Clean Soil Air Water 42:267–275

Van Geen A, Win KH, Zaw T, Naing W, Mey JL, Mailloux B (2014) Confirmation of elevated arsenic levels in groundwater of Myanmar. Sci Total Environ 478:21–24

Van Stempvoort DR, Roy JW, Brown SJ, Bickerton G (2011) Artificial sweeteners as potential tracers in groundwater in urban environments. J Hydrol 401:126–133

Watanabe Y, Bach LT, Dinh PV, Nakata H (2014) Sweeteners and persistent pharmaceuticals in aquatic environment from urbanized cities with adequate and inadequate sewage treatment systems in Asia. In: Abstract of 35th SETAC annual meeting, p 150

Weissbrodt D, Kovalova L, Ort C, Pazhepurackel V, Moser R, Hollender J, Siegrist H, Mcardell CS (2009) Mass flows of X-ray contrast media and cytostatics in hospital wastewater. Environ Sci Technol 43:4810–4817

Zemann M, Wilf L, Poschko A, Schmidt N, Sawarieh A, Seder N, Tiehm A, Hotzl H, Goldscheider N (2014) Source and processes affecting the spatio-temporal distribution of pharmaceuticals and X-ray contrast media in the water resources of lower Jordan Valley, Jordan. Sci Total Environ 488–489:100–114