

# Characteristics, distribution and sources of polychlorinated biphenyls (PCBs) in coastal sediments from heavily industrialized area of Asalouyeh, Iran

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## ABSTRACT

In this research, the levels of polychlorinated biphenyls (PCBs) were investigated in marine sediments of Asalouyeh harbor, Persian Gulf. The samples were taken from industrial, semi-industrial and urban regions. The mean concentration levels of total ( $\Sigma$ ) 18 detected PCBs were 514.32, 144.67 and 31.6 pg/g dw for industrial, semi-industrial and urban stations, respectively. Based on a multivariate statistical analysis, it was found that high contamination levels of PCBs in sediments collected along the Persian Gulf were associated with releases from local industries. Total organic carbon content was significantly and positively correlated with the concentrations of PCBs congeners. World Health Organization-toxic equivalents (WHO 2005-TEQs) for PCBs ranged from 0.04 to 2.66 pg TEQ/g dw in the coastal sediments. The TEQs values in this study were upper than many reported worldwide in the literature for sediments. This suggests that there are high levels of contamination in the area due to existence of the analyzed contaminants.

**Key words** | Asalouyeh, PCBs, Persian gulf, sediments

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## INTRODUCTION

Polychlorinated biphenyls (PCBs) are from the class of persistent organic pollutants, which extensively spread in environment matrixes. Due to their persistence, undergoing

long range atmospheric transport, high bioaccumulation potential, toxicity and nonbiodegradability, disrupting endocrine systems and posing serious threats to ecosystems and

human health, they have recently attracted much attention (Hamlin & Guillette 2011; Jiang *et al.* 2011; Sobek *et al.* 2014). PCBs can also be released into the environment via various sources including scrap metal recycling, auto salvage yards, auto-crushing, repair activities, used oil, tar paper, tar roofing materials, plasticizers, hydraulic fluids and lubricants, miscellaneous uses, industrial and municipal wastewater discharge, leaching from landfills, weathering of asphalt, etc. (Ssebugere *et al.* 2013; Zhang *et al.* 2014).

In the environment, the main route for transport and deposition of PCBs to aquatic systems is atmospheric pathway. After being transferred to water body, due to low-water solubility, these contaminants tend to adsorb and accumulate in the particles and sediments for a long period of time and undergo partitioning, degradation and transportation processes. As a result, the sediments can act as a natural sink for the contaminants that re-suspended at the interface of water and sediment, particularly during lake mixing and also in flood events. These phenomena may increase accumulation and bio-availability of these pollutants and other toxic materials in the food chain (Ssebugere *et al.* 2013; Zhang *et al.* 2014) and may be taken up by microorganisms, and finally biomagnified in top predators such as human (Kelly *et al.* 2007). The main probable pathways of exposure to such contaminants in human are ingestion, dermal contact and inhalation (Dirtu & Covaci 2010; Chan & Wong 2013). In living organisms, these hazardous pollutants cause various toxic and biochemical responses including lesions, immunosuppression and immunotoxicity, disruption of the endocrine system and reproductive impairment, induction of gene expression, and body weight loss (Sormo *et al.* 2009). Thus, use and disposal of PCBs are now considered as major environmental issues worldwide and, as a consequence, knowledge about PCBs and concentration levels in the sediments is necessary to gain awareness about the present level of pollutions, risk evaluations, and plan remediation actions.

Asaluyeh harbor (26°30' -27°50'N, 51°01' -52°81'N) is located along the northern margin of the Persian Gulf and Oman sea, in the Province Bushehr, Iran. Asaluyeh industrial area with 100 square kilometers of land is well known for the numerous enterprises and industries of petroleum, petrochemical and natural gas refine industries. Therefore, many environmentally challenging problems can occur in the coastal areas of the Asaluyeh harbor, with sediment contamination being one of the most serious concerns in this industrialized area (Arfaeinia *et al.* 2016;

Raeisi *et al.* 2016). Regarding increased discharge of contaminants, marine sediment may be exposed to hazardous pollutants accumulated in the sediment (Karbasdehi *et al.* 2016, 2017). To the best of our knowledge, there is no comprehensive report yet on PCBs concentration levels, sources, spatial distribution and their composition in the region of the Persian Gulf. So the objectives of this study can be summarized as follows: (1) to illustrate the spatial distribution and homolog composition of PCBs in the sediments of Asalouyeh harbor in urban, semi-industrial and industrial areas along the Persian Gulf; (2) to trace the sources of PCBs and evaluate the correlation between PCBs concentration levels and environmental factors such as total organic carbon (TOC) content in the research areas; (3) to compare the findings with those reported in research elsewhere; and (4) to compare concentration levels of PCBs obtained in this work with available criteria, standards and guidelines for ecotoxicological and human health assessment.

## MATERIAL AND METHODS

### Materials, reagents and standards

All of the extraction solvents (such as acetonitrile, n-hexane, dichloromethane, toluene, etc.), and the calibration check solution of PCB were obtained from AccuStandard, Inc. (New Haven, CT, USA). The purity of reagents, solvents and standards used was over 99.9%. Sulfuric acid, alumina, C18-modified silica gel, acetonitrile, anhydrous sodium sulfate and silica gel were of analytical grade. To eliminate the background levels of pollutants, the silica gel was heated overnight at 200°C before use. Eighteen PCBs congeners (the four Non-ortho PCBs 169, 126, 81, 77 as well as eight Mono-ortho PCBs 189, 167, 157, 156, 123, 118, 114, 105 and six indicators PCBs 180, 153, 138, 101, 52 and 28) were quantified, as they are the most toxic compounds and have a common mode of action. Afterwards, all prepared stock solutions were stored in a fridge and maintained at 4°C until the analysis.

### Study area and sediment sample collection

Sediment samples were collected in March 2015 from 21 sampling sites (including eight sampling stations in the industrial area (S<sub>1</sub> to S<sub>8</sub>), four sampling stations in the semi-industrial area (S<sub>9</sub> to S<sub>12</sub>) and nine sampling stations in the urban area (S<sub>13</sub> to S<sub>21</sub>)) of Asaluyeh harbor (Table 1). Figure 1

**Table 1** | The sampling sites with geographic information and codes of sampling stations

Code	Area	Depth (m)	Geographic coordinates
S1	Industrial	23	N27°27'13.98" E52°36'57.11"
S2	Industrial	27	N27°29'28.72" E52°33'26.07"
S3	Industrial	19	N27°30'47.53" E52°32'50.37"
S4	Industrial	21	N27°31'59.99" E52°31'57.96"
S5	Industrial	23	N27°33'30.05" E52°30'47.70"
S6	Industrial	14	N27°34'45.55" E52°29'45.84"
S7	Industrial	31	N27°36'57.34" E52°27'46.09"
S8	Industrial	27	N27°37'41.84" E52°26'19.14"
S9	Semi-industrial	31	N27°38'16.70" E52°21'37.44"
S10	Semi-industrial	22	N27°40'40.26" E52°13'05.66"
S11	Semi-industrial	18	N27°42'27.94" E52°09'56.40"
S12	Semi-industrial	26	N27°45'36.94" E52°06'40.07"
S13	Urban	17	N27°46'38.10" E52°05'36.61"
S14	Urban	32	N27°47'48.75" E52°04'03.37"
S15	Urban	14	N27°48'17.00" E52°03'25.38"
S16	Urban	24	N27°48'49.24" E52°01'50.39"
S17	Urban	11	N27°49'06.53" E52°01'39.49"
S18	Urban	16	N27°48'58.04" E52°00'23.18"
S19	Urban	28	N27°48'41.29" E51°58'00.28"
S20	Urban	23	N27°48'24.11" E51°56'50.91"
S21	Urban	30	N27°48'29.34" E51°53'43.58"

reveals the locations of the sampling stations. The sediments were collected using an Ekman steel grab sampler (25 × 25 × 25 cm<sup>3</sup>). All samples were immediately transferred to glass jars, which have been pre-washed and kept in an icebox, then brought back to the laboratory and kept at -20°C until the extraction and analysis process. In the laboratory, the sediment sample was air-dried, grounded and sieved through a sieve of <0.5 mm to eliminate fine debris, dead organisms and other impurities. CHN analyzer (Perkin-Elmer, model 2400 CHN) was used to measure the TOC content of samples. All the devices used for sampling, transportation and preparation were pre-washed with n-hexane and acetone to minimize the probability of cross contaminations.

### Extraction and clean-up procedures

The sample extraction and purification procedures have previously been described completely by Ssebugere *et al.* (Ssebugere *et al.* 2013). In summary, 10 g of the sediment samples were spiked with <sup>13</sup>C-labeled PCBs and converted to a free flowing powder through mixing with Hydromatrix

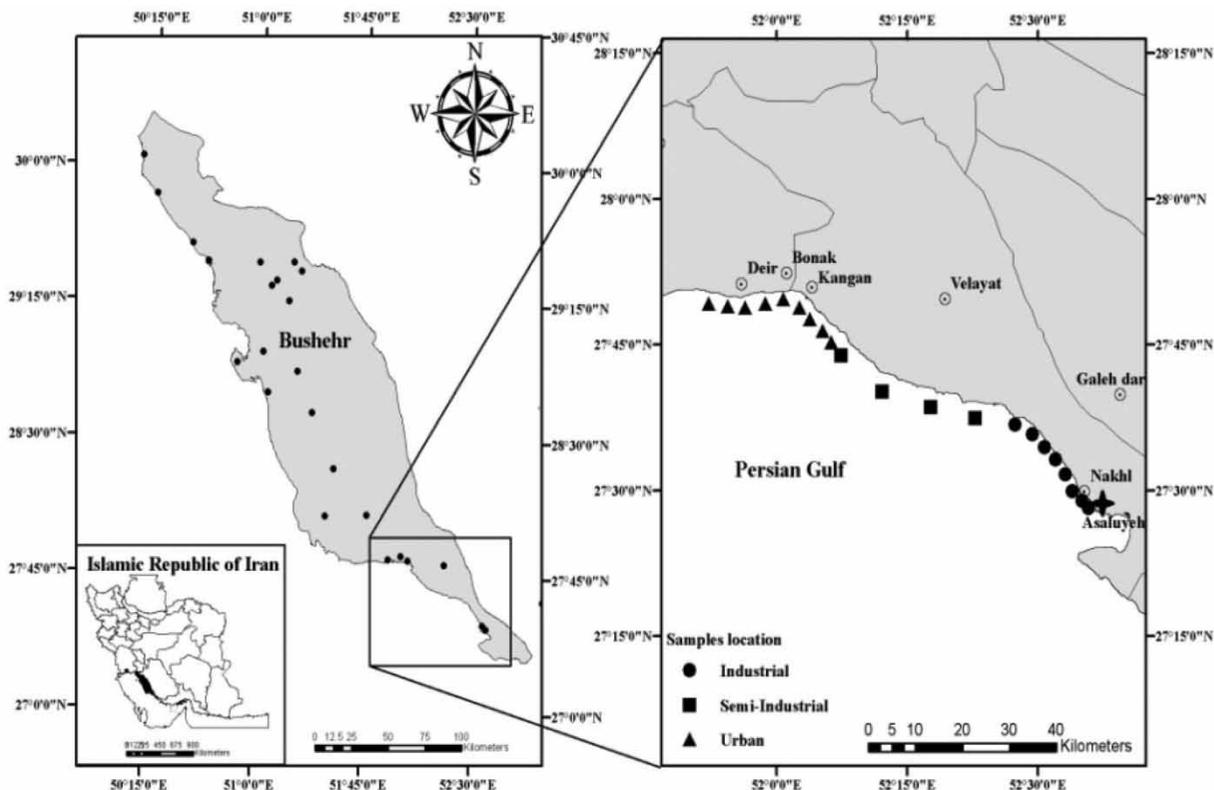
(Varian). ASE 200 accelerated solvent extraction system (Dionex Corporation, USA) was used for extraction of the sediment samples. Then, the extracts solution was filtered via silicagel-type columns and eluted by 120 ml n-hexane. A reversible carbon column (Carboxen1016, Supelco) was used for the first primary separation of the mono-ortho PCBs from the non-ortho PCBs. Mono-ortho PCBs were extracted with a mixture of n-hexane/dichloromethane solution and non-ortho PCBs were eluted with toluene. After extraction, the resultant volume was reduced to 1 mL aliquots on a rotary evaporator and purified as described by Ssebugere *et al.* (Ssebugere *et al.* 2013). The resulting eluted extracts were reduced to <1 mL with a rotary evaporator, poured into a vial containing internal recovery standards and then stored for gas chromatographic analysis.

### Instrumental analysis

The analysis of non-ortho PCBs was performed with a GC/HRMS system (Agilent 6890N GC coupled to Waters Auto specUltima MS) equipped with a 60 m × 0.25 mm DB-5/DB-5 ms columns (J&W Scientific, Folsom, CA, USA), operating under selected ion monitoring (SIM) mode. The carrier gas was helium at a flow rate of 1.0 mL/min. The following temperature program was used for GC oven: from a starting temperature 125°C for 1.5 min, rising to 200°C at a rate of 25°C min<sup>-1</sup> and then 4°C min<sup>-1</sup> to 310°C, and eventually holding it at 310°C for 16 min. The injection, transfer-line, ion source, and quadrupole temperatures were set at 300, 300, 230, and 150°C, respectively. The instrumental analysis of in d-PCBs and mono-ortho PCBs was carried out using HP 6890 gas chromatograph (Hewlett-Packard, USA) equipped with a non-polar DB-5MS capillary column (Agilent, USA), operating in SIM mode. Helium was employed as a carrier gas at a steady flow rate of 1 mL min<sup>-1</sup>. The temperature of oven was held at 90°C for 1.5 min, elevated to 180°C at 20°C min<sup>-1</sup>, held for 8 min, rising to 270°C at 3°C min<sup>-1</sup>, then to 310°C at 20°C min<sup>-1</sup> and held at 310°C for 10 min. Both of the injector and the transfer-line temperatures were adjusted at 285°C. Quantification was done using the <sup>13</sup>C isotopic dilution method.

### Quality assurance and quality control

For quality assurance and quality control, blank and spiked samples were analyzed along with the real samples which were extracted for determining the PCBs of the sediments.



**Figure 1** | The study area and sampling stations.

Recovery and internal standards were employed for analytical control. Recovery efficiencies were determined as the averages of extractions of recovery standards ranging from 48% to 103%. For both of the compounds, limits of detection (LOD) were adjusted to be three times as large as the standard deviation (SD) of the blank values. The mean of blank values was then deducted from all concentrations over the LOD values. The LOD was a function of the extracted mass and ranged within 0.02–1.01 pg for the PCBs.

### Data analysis

SPSS ver. 20 (IBM Corp., USA) was used for statistical processing of the data. To evaluate the possible sources of PCBs, principal component analysis (PCA) was used to conduct multivariate statistical analysis. Also, ArcMap 10.2 Geographical Information System (GIS) (ESRI, Redlands, CA) was utilized for mapping and the Raster Calculator of the ArcGIS Spatial Analyst extension to render to estimate concentration levels of PCBs anywhere that all of the predictors can be measured in sediments of Asaluyeh harbor in the Persian Gulf.

## RESULTS AND DISCUSSION

### The concentration levels of PCBs in the sediments

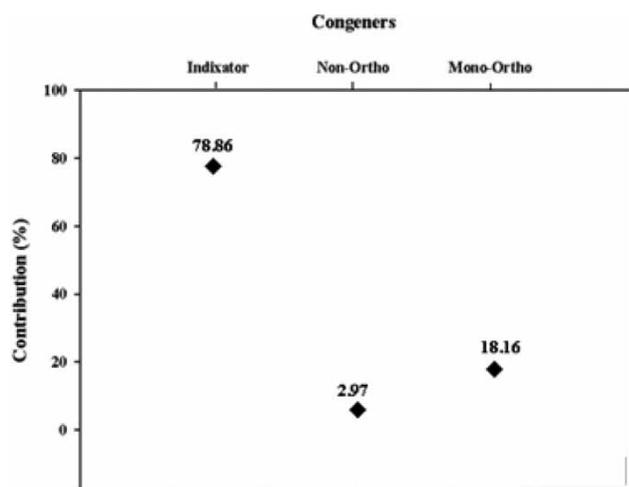
The concentration of PCBs in sediments, TOC content, and moisture content (MC) of the sediments are summarized in Table 2. All concentration levels in Table 2 are based on dry weight (dw). The concentration of PCBs including non-ortho, mono-ortho and indicator PCBs was quantified in the sediment samples. The sum ( $\Sigma$ ) PCBs of each group in the coastal sediment samples were determined and the concentration levels were 2,706 (2.97%), 16,516 (18.16%), 71,715 (78.86%) pg/gdw for non-ortho, mono-ortho and indicator PCBs, respectively (Figure 2). These results are different from those obtained by Vives (Vives *et al.* 2007) who reported the concentration levels of 11,000 and 3,000 pg/gdw for indicator and PCBs, but they are consistent with Nunes *et al.* (Nunes *et al.* 2011) report regarding low contribution of non-ortho (0.35–7.90%). The concentration levels of the  $\Sigma$  indicator PCBs in this study varied widely from 18 to 1,890 pg/gdw. As seen in Table 2, PCB 52, PCB 77 and PCB 118 had the highest concentration levels of the  $\Sigma$  indicator PCBs,  $\Sigma$  non-ortho PCBs and

**Table 2** | Mean concentration levels, ranges (pg/gdw) of PCBs, TOC and MCs of sediments in the study stations

Congeners	Alternate Name	Industrial stations	Semi-industrial stations	Urban stations
Indicator PCBs				
2,4,4'-Trichlorobiphenyl	PCB 28	892.87 (743–1,024)	298.5 (269–323)	51.67 (42–63)
2,2',5,5'-Tetrachlorobiphenyl	PCB 52	1,763.37 (1,627–1,890)	491.25 (433–554)	88.56 (73–112)
2,2',4,4,5,5'-Pentachlorobiphenyl	PCB 101	1,231 (1,098–1,352)	356.75 (339–370)	89.56 (74–109)
2,2',3,4,4',5'-Hexachlorobiphenyl	PCB 138	1,712.37 (1,589–1,833)	453 (398–518)	66.89 (33–97)
2,2',4,4',5,5'-Hexachlorobiphenyl	PCB 153	1,166 (987–1,316)	354.75 (213–476)	100.78 (76–128)
2,2',3,4,4',5,5'-Heptachlorobiphenyl	PCB 180	655 (598–716)	140.75 (127–154)	34.78 (18–42)
$\Sigma$ Indicator PCBs		9,907.5 (5,320–14,107)	1,396.6 (563–1,965)	648.33 (313–907)
Non-Ortho PCBs				
3,3',4,4'-Tetrachlorobiphenyl	PCB 77	76.62 (65–93)	17.5 (13–21)	6.5 (3–11)
3,4,4',5-Tetrachlorobiphenyl	PCB 81	26.37 (19–33)	12.25 (10–14)	1.95 (N.D.-4.2)
3,3',4,4',5-Pentachlorobiphenyl	PCB 126	19.75 (17–23)	8.5 (7–10)	1.6 (N.D.-3.1)
3,3',4,4',5,5'-Hexachlorobiphenyl	PCB 169	11.25 (9–14)	6.75 (6–8)	1.05 (N.D.-1.9)
$\Sigma$ Non-Ortho PCBs		268 (90–613)	45 (27–70)	25.22 (9.5–59)
Mono-Ortho PCBs				
2,3,3',4,4'-Pentachlorobiphenyl	PCB 105	380.75 (332–423)	93.75 (83–102)	23.55 (18–31)
2,3,4,4',5-Pentachlorobiphenyl	PCB 114	65 (59–73)	17 (16–19)	6.60 (3.6–9.7)
2,3',4,4',5-Pentachlorobiphenyl	PCB 118	893 (839–988)	246.5 (198–334)	62.54 (34–78)
2,3',4,4',5'-Pentachlorobiphenyl	PCB 123	81.90 (63–94)	26 (23–29)	6.85 (4.3–11)
2,3,3',4,4',5-Hexachlorobiphenyl	PCB 156	136.62 (129–154)	34 (31–38)	10.34 (7–13)
2,3,3',4,4',5'-Hexachlorobiphenyl	PCB 157	49.25 (43–55)	13.75 (12–16)	3.84 (1.9–6.3)
2,3',4,4',5,5'-Hexachlorobiphenyl	PCB 167	59 (49–67)	18 (16–19)	6.55 (5–8)
2,3,3',4,4',5,5'-Heptachlorobiphenyl	PCB 189	26.75 (19–33)	15 (12–18)	2.34 (1.4–3.1)
$\Sigma$ Mono-Ortho PCBs		1,693.12 (214–7,144)	232 (55–986)	139.4 (21–576)
$\Sigma$ 12 dl-PCBs		152.26 (90–7,144)	42.41 (27–986)	11.35 (9.5–576)
$\Sigma$ 18 PCBs		514.32 (90–14,107)	144.67 (27–1,965)	31.6 (9.5–907)
TEQ (WHO <sub>2005</sub> )		1.58 (0.006–15.8)	0.35 (0.001–3.4)	0.15 (0.0006–1.48)
TOC (%)		10 (8.9–11.)	10.2 (9.8–10.8)	10.2 (9.9–10.9)
MC (%)		75.3 (73.2–77.4)	72.3 (68.8–74.8)	74.4 (72.7–77.8)

$\Sigma$  mono-ortho PCBs with concentration levels of 1890 (station of S<sub>4</sub>), 93 (station of S<sub>3</sub>) and 988 (station of S<sub>6</sub>) pg/gdw, respectively. El-Kady *et al.* (El-Kady *et al.* 2007) reported a similar distribution of congeners in sediments gathered from River Nile in the region of Cairo. A possible explanation for the high concentration level of PCB 77 might be that it does not degrade easily. In most commercial PCB mixtures and environmental samples, mono-ortho PCB congeners are willing at high concentrations, and are environmentally persistent (Hornbuckle *et al.* 2006). Hence, it seems possible that the high levels of the mono-ortho PCBs are due to slow desorption kinetics. The concentrations of PCB169 were quantified at low levels across all

sampling stations (Table 2). A possible explanation for these results may be due to the limited mobility to molecular diffusion processes as well as more susceptibility to the dissolution loss process (Li *et al.* 2009). Thus, the low levels of PCB169 in the sediment samples in this study could be ascribed to the fact that it is more soluble in water (Ssebugere *et al.* 2013). The concentration levels of the  $\Sigma$  non-ortho PCBs varied from zero to 93 pg/gdw. The concentration levels of PCB 126 and 169 in stations S<sub>15</sub>, S<sub>16</sub> and S<sub>17</sub> were zero while PCB 153 was the major contributor in these stations. Also,  $\Sigma$  mono-ortho PCBs ranged from 1.4 to 988 pg/gdw and in all stations, the major contributor of mono-ortho PCBs was PCB 118 and the minimum



**Figure 2** | Percent contribution of PCBs congeners in the sediments.

concentration level was related to PCB 189 (Table 2). These findings further support the results of Vives *et al.* (Vives *et al.* 2007) and Loganathan *et al.* (Loganathan *et al.* 2008) studies.

A high concentration level of PCBs was also observed in sediment samples of the industrial stations of Asalouyeh with a concentration level of 74,062 pg/gdw, while the concentration levels of PCBs in semi-industrial and urban stations were 10,416 and 5,106 pg/gdw, respectively. The concentration level of PCBs in the industrial sediment samples was 7–14 times higher compared with other areas including semi-industrial and urban areas. The greater industrialization in the Asalouyeh harbor may account for the higher concentration levels of PCBs in the sediments, especially near gas sniper phases, which receive the greatest amount of transport and deposition to aquatic systems, industrial run-off and wastewater discharges from the big industries. The highest concentration levels of PCBs among the examined stations of three areas were related to PCB 52 in industrial as well as semi-industrial stations and PCB 153 in urban stations, all of which belong to the indicator group. Also, the maximum and minimum concentration levels of  $\sum$ PCB were observed in S<sub>4</sub> and S<sub>17</sub> in the industrial and urban areas, respectively. Figure 3 presents the spatial distribution of  $\sum$ PCB in the coastal sediment samples of Asalouyeh along the Persian Gulf.

### Predominant pollutants and major contributors to the TEQ

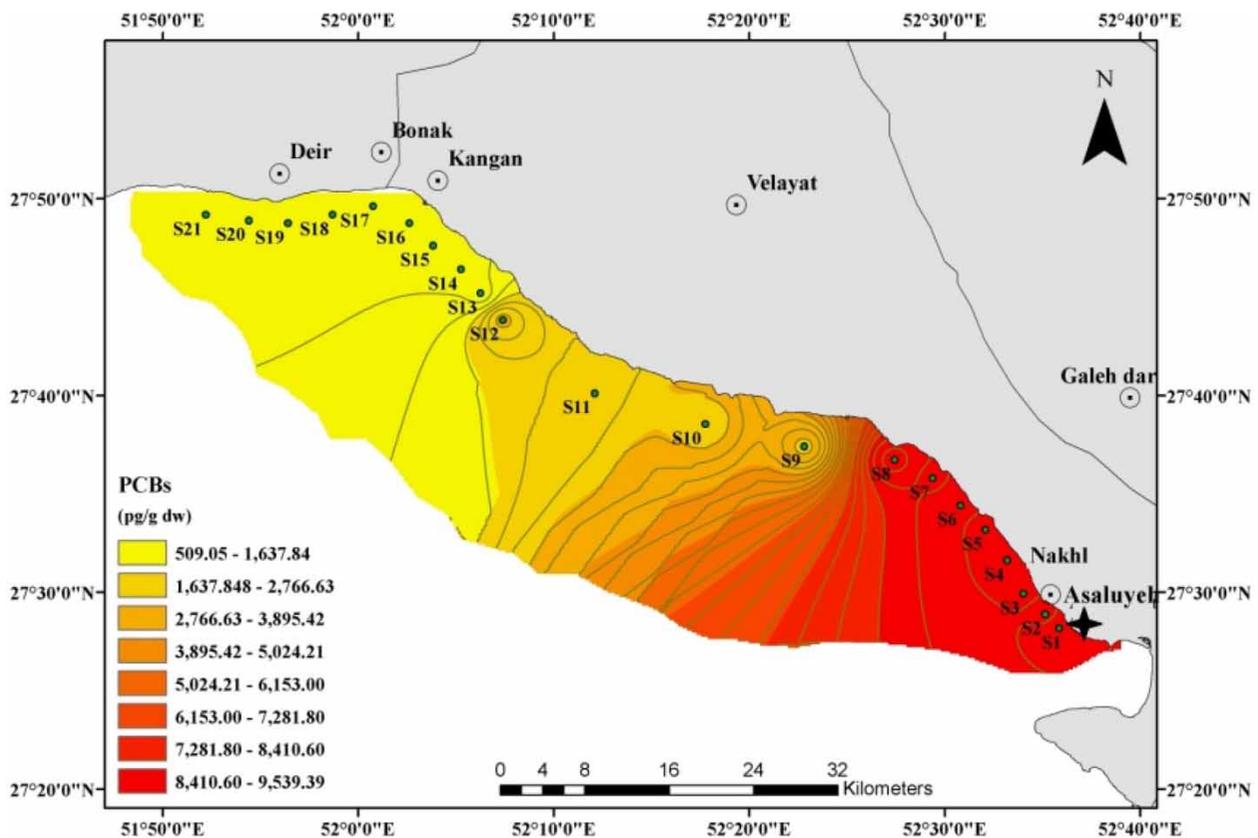
The contribution of  $\sum$ TEQs concentration levels for PCBs in sediments from different stations are presented in

Figure 4. As seen in this figure, the highest concentration level of  $\sum$ TEQs in sediments was observed in sampling station S<sub>1</sub> (16.26 pg TEQ/g dw), which is located in the industrial area.

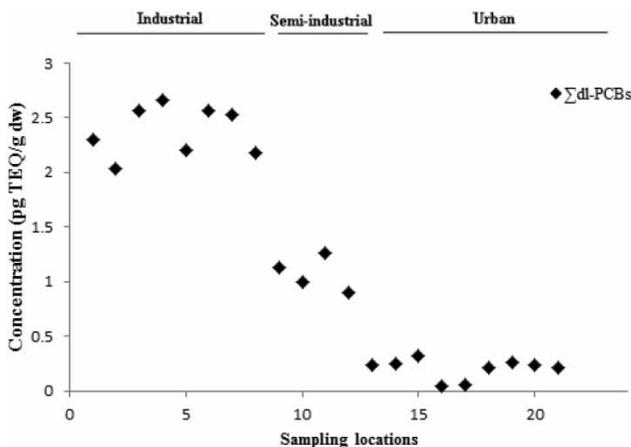
The toxic equivalent factors were applied to calculate the toxic equivalent (TEQs) set by the WHO, 2005. The WHO-TEQ values for sediment samples from three regions of Asalouyeh are shown in Table 2. As described in Table 2, the  $\sum$ WHO<sub>2005</sub>-PCBs-TEQs values in the study were 1.58 for industrial (ranging from 0.006 to 15.8 pg/gdw), 0.35 for semi-industrial (ranging from 0.001 to 3.4 pg/gdw) and 0.15 pg/gdw for urban stations (ranging from 0.0006 to 1.48 pg/gdw). The WHO<sub>2005</sub>-TEQs concentration for  $\sum$ PCB in sediments ranged from 0.04 to 2.66 pg TEQ/gdw with an average value of 1.19 pg/gdw. The station S<sub>4</sub> in the industrial area had the highest concentration level of PCBs with a value of 2.66 pg TEQ/g dw. The overall concentrations of  $\sum$ TEQs in sediments decreased with the increase in the distance from the industrial to semi-industrial and urban areas (Figure 4). WHO PCBs-TEQs values in the present study were higher than those of sediments from the Murchison Bay of Lake Victoria in Uganda (ranging from 0.04 to 0.64 pg TEQ/g) and Han river in Korea (ranging from 0.0118 to 0.626 ng TEQ/kg) (Kim *et al.* 2009; Ssebugere *et al.* 2014) and almost in the same range as those of the central South Africa (ranging from 0.02 to 4.4 ng/kgdw) (Nieuwoudt *et al.* 2009), but lower than the one in Krompachy and Slovak Republic (ranging from 1.9 to 148 pg TEQ/gdw) (Čonka *et al.* 2014).

### The relationship between the PCBs and TOC contents of sediments

The TOC concentrations in the sediment are shown in Figure 5. The TOC values ranged from 8.93 to 11.10% with an average value of 10.05% in industrial area, 9.78 to 10.83% with an average value of 9.93% in semi-industrial area and 9.87 to 10.91% with an average value of 10.01% in urban area, respectively. The increasing of TOC contents in sediment can increase bioactivity and bioaccumulation in the water system. S<sub>4</sub> had the highest TOC concentration. The sediment collected from S<sub>4</sub> (the estuary of a Koor River) received large amounts of municipal wastewater which is rich in organic matter. Moreover, the average value of TOC content in the industrial stations was more than the urban stations, in general. These findings showed that anthropogenic activities and industrial zone represent the main sources of sediment TOC contents and can exert a substantial influence on carbon cycling processes in



**Figure 3** | The spatial distribution of  $\Sigma$ PCB in the coastal sediments of Asalouyeh along the Persian Gulf.



**Figure 4** | Contribution of  $\Sigma$ TEQs concentration levels for PCBs in sediments from different stations of Asalouyeh harbor, Iran along the Persian Gulf.

coastal sediments. Effects on carbon cycling and the ecology of the marine ocean are also possible to the extent that coastal productivity may be subsequently exported (Arfaeinia *et al.* 2016).

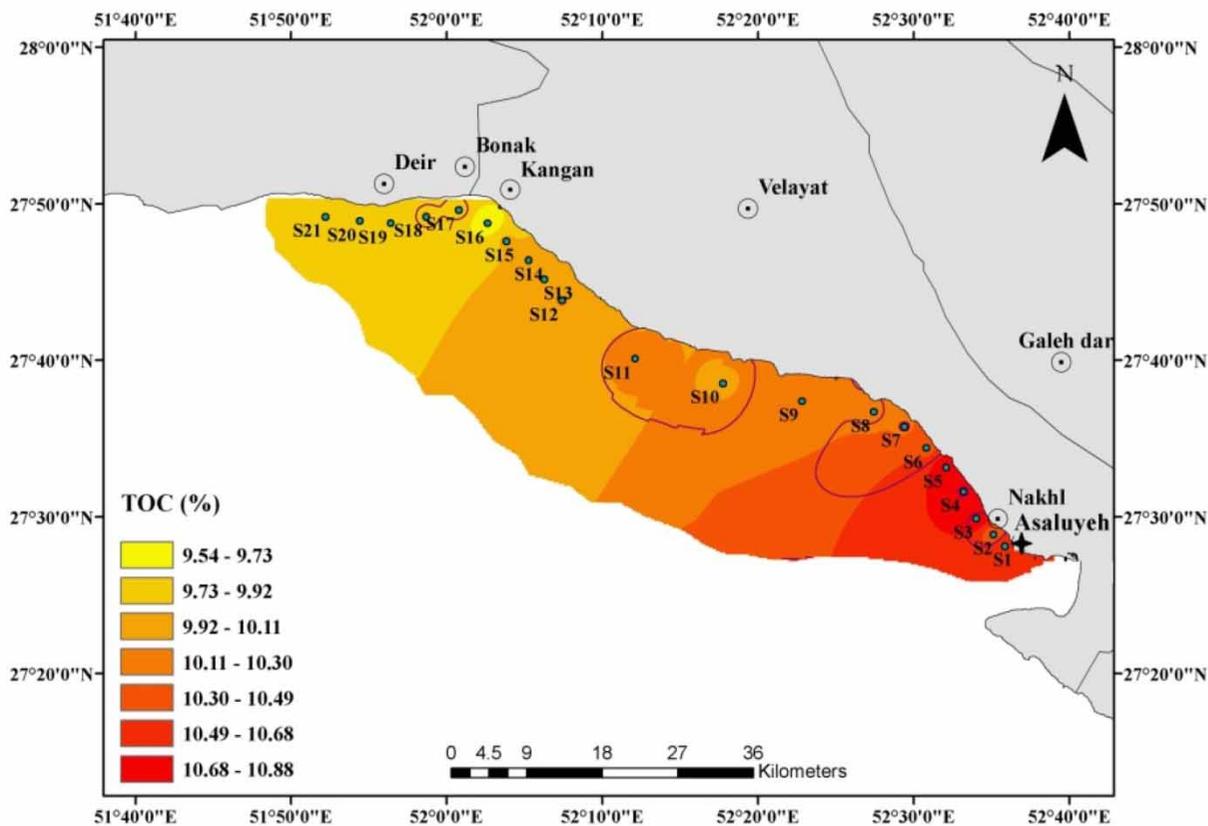
The relationship between the PCBs and TOC contents of sediments is shown if Figure 6. As seen in Figure 6,

linear regression correlations were found between the concentrations levels of PCBs with TOC (with  $R^2$  values of 0.748 and 0.739, respectively). These relationships imply that organic carbon could have an influence on the transport and distribution of these pollutants in the coastal area along the Persian Gulf. The correlation between the concentration levels of PCBs and TOC in surface sediments from Lake Maggiore in Italy and Switzerland, as well as Han River in Korea (Vives *et al.* 2007; Kim *et al.* 2009) is comparable with those found in surface sediments along the Persian Gulf in Iran.

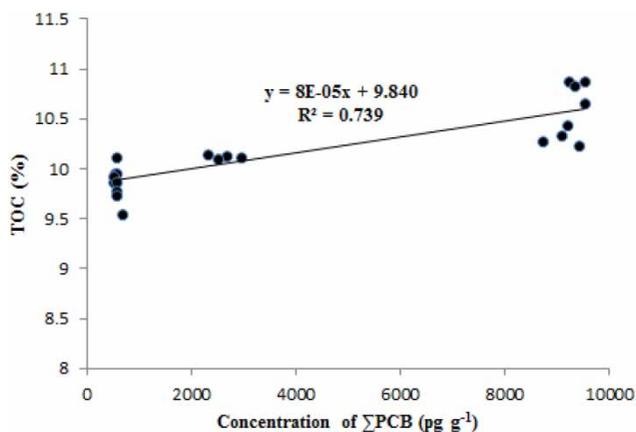
#### Source apportionment (PCA analysis)

PCA was carried out to investigate the percent congener profiles with potential possible sources of PCBs contaminations in the coastal sediments of Asalouyeh harbor.

The PCA results for PCBs are shown in Figure 7. As seen in the figure, PC1 had 44.7% of the total variances and was consisted of PCB 81, 105, 114, 156, 167, 169, 180 and 189. Among these, PCB105 and 114 are fallen in penta-PCB, PCB156, 167 and 169 are fallen in hexa-PCB and PCB180



**Figure 5** | The spatial distribution of TOC in the coastal sediments of Asalouyeh along the Persian Gulf.

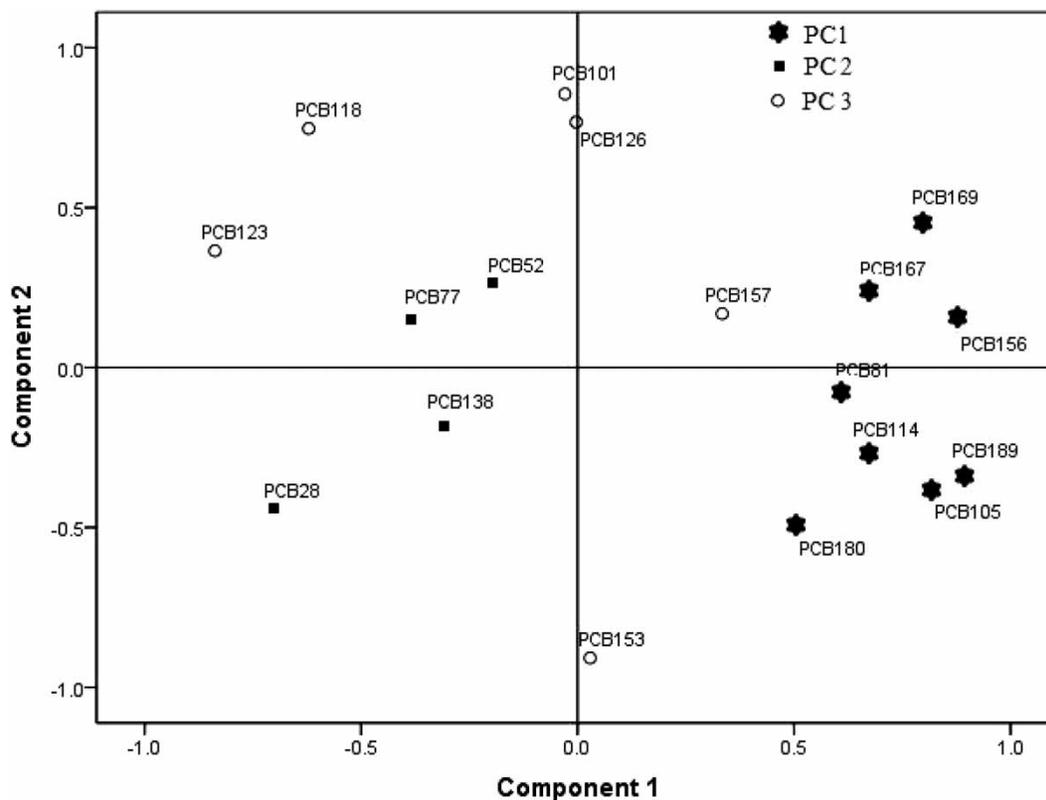


**Figure 6** | Correlations between  $\Sigma$ PCB concentration levels with TOC content (%) in sediments.

and 189 are fallen in hepta-PCB. Therefore, PC1 was characterized by penta-PCB as well as hexa-PCB and the secongengers have been used in some equipment such as electrical transformers, gas transmission turbines, electrical capacitors and vacuum pumps. These pollutants are

discharged into the environment from these sources in surface runoff, landfills and incineration of sludge (Konat & Kowalewska 2001). PCB169 is one of the most abundant penta-PCB congeners in PC1 which is released into the environment through emission gases of Al and Cu metalurgy (Ba *et al.* 2009).

In addition to penta and hexa-PCBs, hepta-PCBs were also one of the most dominant congeners in the PC1. Higher concentration levels of higher chlorinated PCBs originated mostly from the discharge of anthropogenic pollution (Hong *et al.* 2005). Thus, the hepta-PCBs of PC1 originated from local man-made sources. The other possible source for hepta-PCBs was the combustion processes. In a study by Haijun Zhang *et al.* (Zhang *et al.* 2010), it was confirmed that the PCBs can be released into the environment by emission gases of iron or esintering, hardwood burning and house coal. Moreover, Asaluyeh harbor lies on the northern margin of the Persian Gulf as one of the most important economic and industrial harbors in Iran. The petrochemical and natural gas refineries increase economic development in this region, but inevitably lead to many



**Figure 7** | Score plots of principal component analysis (PCA) from relative contributions of the PCBs for sediment samples as well as suspected sources.

environmentally challenging problems in the coastal line and marine environment. In addition, some other activities such as storagesystems for petroleum products, shipping, mariculture and fishing industry make it difficult to identify the precise origins of PCBs in the Asaluyeh region. Some environmental and geologic processes such as coastal transport or dechlorination, and sediment resuspension cause modification in the PCBs structures from their source (Tyler & Millward 1996). Thus, PC1 indicated the input of PCBs from mix sources of leakages from landfill, emission gases, discharges of local sources and combustion processes.

PC2 had 23.2% of the total variances and consisted of PCB 28, 52, 77 and 138. Among these PCB congeners, PCB28 fall in tri-PCB, PCB52 and 77 fall in tetra-PCB. Thus, PC1 was dominated by tri-PCB and tetra-PCB. These congeners of PCB (tri-PCB and tetra-PCB) can be found dominantly in the air. (Zhang *et al.* 2008) Some research (Gioia *et al.* 2006; Totten *et al.* 2006) has indicated that the volatilization of low chlorinated congeners from the upper water layer can sustain the PCB concentration level in the lower atmosphere near the water. Therefore, PC2 represents the atmospheric deposition.

## CONCLUSION

This study indicated the findings of the first survey of PCBs in the sediments of northern part of the Persian Gulf. The results showed that the concentration levels of PCBs varied widely from industrial to semi-industrial and urban areas, as, industrial and urban areas had the higher and lower concentration levels, respectively. Significant correlations were observed between TOC content with the concentration levels of PCBs congeners. The high concentration levels of penta-PCB and hexa-PCB obtained in this study indicated that the origins of the PCBs can be application of some equipment such as electrical transformers, gas transmission turbines, electrical capacitors and vacuum pumps in industrial process. WHO PCBs-TEQs values in this study were higher than many other values reported worldwide in the literature for sediments. This implies that there are high levels of contamination in the area due to existence of the examined contaminants. Finally, continuation of monitoring and mitigation measures particularly in the case of emerging pollutants is highly recommended in marine and industrial areas.

## DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

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## REFERENCES

- Arfaeinia, H., Nabipour, I., Ostovar, A., Asadgol, Z., Abuee, E., Keshtkar, M. & Dobaradaran, S. 2016 Assessment of sediment quality based on acid-volatile sulfide and simultaneously extracted metals in heavily industrialized area of Asalouyeh, Persian Gulf: concentrations, spatial distributions, and sediment bioavailability/toxicity. *Environmental Science and Pollution Research International* **23**, 9871.
- Ba, T., Zheng, M., Zhang, B., Liu, W., Xiao, K. & Zhang, L. 2009 Estimation and characterization of PCDD/Fs and dioxin-like PCBs from secondary copper and aluminum metallurgies in China. *Chemosphere* **75**, 1173–1178.
- Chan, J. K. Y. & Wong, M. H. 2013 A review of environmental fate, body burdens, and human health risk assessment of PCDD/Fs at two typical electronic waste recycling sites in China. *Science of the Total Environment* **463**, 1111–1123.
- Čonka, K., Chovancová, J., Sejková, Z. S., Dömötörövá, M., Fabišíková, A., Drobná, B. & Kočan, A. 2014 PCDDs, PCDFs, PCBs and OCPs in sediments from selected areas in the Slovak Republic. *Chemosphere* **98**, 37–43.
- Dirtu, A. C. & Covaci, A. 2010 Estimation of daily intake of organohalogenated contaminants from food consumption and indoor dust ingestion in Romania. *Environ. Sci. Technol.* **44**, 6297–6304.
- El-Kady, A. A., Abdel-Wahhab, M. A., Henkelmann, B., Belal, M. H., Morsi, M. K. S., Galal, S. M. & Schramm, K.-W. 2007 Polychlorinated biphenyl, polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofuran residues in sediments and fish of the River Nile in the Cairo region. *Chemosphere* **68**, 1660–1668.
- Gioia, R., Steinnes, E., Thomas, G. O., Meijer, S. N. & Jones, K. C. 2006 Persistent organic pollutants in European background air: derivation of temporal and latitudinal trends. *Journal of Environmental Monitoring* **8**, 700–710.
- Hamlin, H. J. & Guillette, L. J. 2011 Embryos as targets of endocrine disrupting contaminants in wildlife. *Birth Defects Research Part C: Embryo Today: Reviews* **93**, 19–33.
- Hong, S. H., Yim, U. H., Shim, W. J. & Oh, J. R. 2005 Congener-specific survey for polychlorinated biphenyls in sediments of industrialized bays in Korea: regional characteristics and pollution sources. *Environmental Science & Technology* **39**, 7380–7388.
- Hornbuckle, K. C., Carlson, D. L., Swackhamer, D. L., Baker, J. E. & Eisenreich, S. J. 2006 Polychlorinated biphenyls in the Great Lakes. In: *Persistent Organic Pollutants in the Great Lakes*. Springer, pp. 13–70.
- Jiang, J.-J., Lee, C.-L., Fang, M.-D., Ko, F.-C. & Baker, J. E. 2011 Polybrominated diphenyl ethers and polychlorinated biphenyls in sediments of southwest Taiwan: regional characteristics and potential sources. *Marine Pollution Bulletin* **62**, 815–823.
- Karbasdehi, V. N., Dobaradaran, S., Nabipour, I., Arfaeinia, H., Mirahmadi, R. & Keshtkar, M. 2016 Data on metal contents (As, Ag, Sr, Sn, Sb, and Mo) in sediments and shells of *Trachycardium lacunosum* in the northern part of the Persian Gulf. *Data in Brief* **8**, 966–971.
- Karbasdehi, V. N. et al. 2017 Indicator bacteria community in seawater and coastal sediment: the Persian Gulf as a case. *Journal of Environmental Health Science and Engineering* **15**, 6.
- Kelly, B. C., Ikonomou, M. G., Blair, J. D., Morin, A. E. & Gobas, F. A. 2007 Food web-specific biomagnification of persistent organic pollutants. *Science* **317**, 236–239.
- Kim, K.-S. et al. 2009 Survey on organochlorine pesticides, PCDD/Fs, dioxin-like PCBs and HCB in sediments from the Han river, Korea. *Chemosphere* **75**, 580–587.
- Konat, J. & Kowalewska, G. 2001 Polychlorinated biphenyls (PCBs) in sediments of the southern Baltic Sea – trends and fate. *Science of the Total Environment* **280**, 1–15.
- Li, A., Rockne, K. J., Sturchio, N., Song, W., Ford, J. C. & Wei, H. 2009 PCBs in sediments of the Great Lakes—distribution and trends, homolog and chlorine patterns, and in situ degradation. *Environmental Pollution* **157**, 141–147.
- Loganathan, B. G., Kumar, K. S., Masunaga, S. & Sajwan, K. S. 2008 Polychlorinated dibenzo-p-dioxins, dibenzofurans, and dioxin-like polychlorinated biphenyls in sediment and mussel samples from Kentucky Lake, USA. *Archives of Environmental Contamination and Toxicology* **54**, 20–30.
- Nieuwoudt, C. et al. 2009 Dioxin-like chemicals in soil and sediment from residential and industrial areas in central South Africa. *Chemosphere* **76**, 774–783.
- Nunes, M., Marchand, P., Vernisseau, A., Le Bizec, B., Ramos, F. & Pardal, M. A. 2011 PCDD/fs and dioxin-like PCBs in sediment and biota from the Mondego estuary (Portugal). *Chemosphere* **83**, 1345–1352.
- Raeesi, A., Arfaeinia, H., Seifi, M., Keshtkar, M. & Dobaradaran, S. 2016 Polycyclic aromatic hydrocarbons (PAHs) in coastal sediments from urban and industrial areas of Asalouyeh Harbor, Iran: distribution, potential source and ecological risk assessment. *Water Science and Technology*: wst2016265.
- Sobek, A., Wiberg, K., Sundqvist, K., Haglund, P., Jonsson, P. & Cornelissen, G. 2014 Coastal sediments in the Gulf of Bothnia as a source of dissolved PCDD/Fs and PCBs to water and fish. *Science of the Total Environment* **487**, 463–470.

- Sormo, E. G., Larsen, H. J., Johansen, G. M., Skaare, J. U. & Jenssen, B. M. 2009 Immunotoxicity of polychlorinated biphenyls (PCB) in free-ranging gray seal pups with special emphasis on dioxin-like congeners. *Journal of Toxicology and Environmental Health, Part A* **72**, 266–276.
- Ssebugere, P., Kiremire, B. T., Henkelmann, B., Bernhöft, S., Wasswa, J., Kasozi, G. N. & Schramm, K.-W. 2013 PCDD/fs and dioxin-like PCBs in surface sediments from Lake Victoria, East Africa. *Science of the Total Environment* **454**, 528–533.
- Ssebugere, P. *et al.* 2014 Polychlorinated biphenyls in sediments and fish species from the Murchison Bay of Lake Victoria, Uganda. *Science of the Total Environment* **482**, 349–357.
- Totten, L. A., Panangadan, M., Eisenreich, S. J., Cavallo, G. J. & Fikslin, T. J. 2006 Direct and indirect atmospheric deposition of PCBs to the Delaware River watershed. *Environmental Science & Technology* **40**, 2171–2176.
- Tyler, A. & Millward, G. 1996 Distribution and partitioning of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and polychlorinated biphenyls in the Humber Estuary, UK. *Marine Pollution Bulletin* **32**, 397–403.
- Vives, I. *et al.* 2007 Occurrence of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) in Lake Maggiore (Italy and Switzerland). *Journal of Environmental Monitoring* **9**, 589–598.
- Zhang, Z. *et al.* 2008 Analysis of polychlorinated biphenyls in concurrently sampled Chinese air and surface soil. *Environmental Science & Technology* **42**, 6514–6518.
- Zhang, H. *et al.* 2010 PCDD/fs and PCBs in sediments of the Liaohe River, China: levels, distribution, and possible sources. *Chemosphere* **79**, 754–762.
- Zhang, R., Zhang, F., Zhang, T., Yan, H., Shao, W., Zhou, L. & Tong, H. 2014 Historical sediment record and distribution of polychlorinated biphenyls (PCBs) in sediments from tidal flats of Haizhou Bay, China. *Marine Pollution Bulletin* **89**, 487–493.

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