Distribution of Polychlorinated Biphenyls in Environmental Samples from an Electrical Power Station in Lagos, Nigeria

Bilikis Temitope Folarin, Temilola O. Oluseyi, Aderonke O. Oyeyiola, Kehinde O. Olayinka and Babajide I. Alo
Department of Chemistry, University of Lagos, Lagos, Nigeria

ABSTRACT
Concentration levels of 12 PCB congeners (PCB-18, 28, 31, 44, 52, 101, 153, 118, 138, 149, 180 and 194) were determined in soil, dust, sediment and water samples collected at Ijora Olopa Power Station, Lagos, Nigeria. The calibration factors of target PCBs were estimated to test the linearity of the GC-ECD within a concentration of 0.025 ng/µL to 0.400 ng/µL. RSD of the calibration factors ranged from 4.6% to 12.3%, indicating a good response. Mean total PCBs in samples increased in the order water < soil < dust < sediment, with average values of 23.0 ng/mL, 27.3 ng/g, 272.6 ng/g, and 510.6 ng/g respectively. One way ANOVA revealed the mean concentrations of PCBs in the four sample types to be statistically different. The study provides a baseline report on the presence of PCBs in environmental samples from an electrical power facility in Lagos, Nigeria.

ARTICLE HISTORY
Received 17 April 2018
Accepted 10 August 2018

KEYWORDS
Dust; polychlorinated biphenyls (PCBs); power station; soil; sediment; water

1. Introduction
PCBs are group of 209 persistent industrial chemicals referred to as “congeners”, that have been recognized among the twelve world’s most dangerous chemicals known to be detrimental to human health and the environment [1]. They cause a wide range of illnesses like some skin conditions such as acne and rashes; depression; irritation of the nose and lungs, to more severe conditions like gastro intestinal discomfort, changes in the blood and liver, and eventually, long term exposure which results to cancer [2,3]. PCBs were originally manufactured for use as coolants and lubricants in capacitors, transformers, and other electrical equipment because of their excellent insulating properties, chemical stability, and relative inflammability [4]. The production of PCBs was eventually stopped due to their numerous health and environmental hazards. Though there are no more production of new PCBs, these chemicals are found in many industrial applications particularly old power generation stations which used oil containing PCBs prior to the ban and also through past practices involving poor handling and testing procedures. They also continue to exist in some old capacitors, transformers, and other appliances [5,6]. Humans are exposed to PCBs via inhalation, ingestion and dermal contact with contaminated soil, dust or other media [7,8]. Due to their lipophilic nature, once PCBs enter the body, they are moved to fat reservoirs where they remain for long period of time, reaching concentrations that may be thousands of times higher than in water, sediment, or soil, a process known as “bio-magnification” [9].

Obsolete transformers and electrical wastes are important sources of PCBs and other toxic, persistent organic pollutants. Various PCBs congeners have been detected and reported with significant levels in environmental matrices such as water, soil, dust, and sediment [10–17] as well as biological samples such as biota, human blood, adipose tissue and breast milk and also in aquatic animals like fishes [18–21].

There is however a dearth of information on concentrations of PCBs in the Nigerian environment, more specifically in the vicinity of electrical power facility. This work was conducted to investigate the presence of PCBs in environmental samples from Ijora Olopa, a former power generation station in Lagos, Nigeria. The study reports the distribution of PCB congeners in the environmental samples obtained from this power station.

2. Materials and methods

2.1. Chemicals and standards
10 µg/mL PCB standard mixture containing PCB 18, 28, 31, 44, 52, 101, 118, 138, 149, 153, 180 and 194, internal standard (PCB 209, 200 µg/mL), were obtained from Sigma Aldrich, UK. The various calibration standard solutions were prepared by adding the appropriate amounts of primary standards to hexane (97% purity, HPLC grade obtained from Sigma Aldrich). A constant concentration of 1 µg/mL internal standard was added to the calibration standards and to the samples prior analysis.

CONTACT
Temilola O. Oluseyi, toluseyi@unilag.edu.ng
Department of Chemistry, University of Lagos, Akoka, Lagos, 101212, Nigeria

© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
Sodium sulphate anhydrous (Merck, Germany) was first activated before use. Florisil cartridges (Supelco 6 ml, 1 g bed), purchased from Sigma Aldrich were used for the extract clean up.

2.2. Samples collection and site information

Six soil samples, two sediment samples, two water samples and a dust sample were collected from ten points in the vicinity of Ijora Olopa power station in April, 2015 (Table 1). Soil and dust samples were collected in aluminium foil while sediment and water samples were collected in amber glass bottles. Samples were transported to the laboratory, where they were prepared and preserved appropriately before extraction. The soil samples were sieved through a 2 mm sieve while the sediment samples were dried in the oven at 35 °C.

2.3. Sample extraction, and clean up

Water samples were extracted with hexane using liquid–liquid extraction. Using a method similar to the EPA standard operating procedure (SOP) for PCBs extraction, soil, sediment and dust samples were mixed with equal weight of anhydrous sodium sulphate to form free flow mixtures which were then sonicated for 15 minutes in three successive extractions, combined extracts were concentrated to about 5 mL using a thermostated water bath, regulated at 40°C. Clean up of extracts was achieved by transferring the concentrated extract on a florisil cartridge, which had been conditioned with 5 mL hexane. Finally, the elution of adsorbed analytes was achieved by passing hexane through the florisil cartridge. PCB 209, the internal injection standard, was added to each of the cleaned extracts before the GC analyses. Cleaned extracts were stored at −4°C prior to analysis.

2.4. Instrumental analysis of PCBs

PCB identification and quantification were performed on an Agilent 6890 series gas chromatograph equipped with a 63Ni ECD and a split/splitless injector. Chromatographic separation of the PCB congeners was carried out on a 30 m Agilent Technologies (0.25 mm I.D.; film thickness 0.25 μm) fused silica capillary column (5% diphenylpolysiloxane, 95% dimethylpolysiloxane). The initial oven temperature was set at 60°C, held for 1 min, then increased to 180°C at a rate of 30°C/min, then increased to 200°C at a rate of 2.5°C/min, then increased to 270°C at a rate of 7°C/min. The temperatures of the injector and detector were 280°C and 300°C respectively. Splitless mode injection was employed. The following elution order of congeners was established: PCB: 18, 31/28, 52, 44, 101, 149/118, 153, 138, 180, 194 and 209 (internal injection standard).

2.5. Quality control

The calibration factor which measures the detector response to varying concentrations of target analytes was estimated. The RSD of the calibration factors for target analytes from the 5 point calibration standards were 4.6%, 9.2%, 3.8%, 5.9%, 5.4%, 4.4%, 6.2%, 7.8%, 6.6%, 12.3% for PCB # 18, 31/28, 52, 44, 101, 149/118, 153, 138, 180, and 194 respectively, indicating a good instrumental method [22]. The limits of detections were estimated for target analytes from the calibration factors at a signal to noise ratio of 3:1. For samples in which target PCBs were absent, values < LOD were reported. Blank determinations were carried out on every batch of sample and target analytes were absent. Internal injection standard (PCB 209) was added to the calibration standard as well as samples to correct for drift in retention times of the target analytes.

2.6. Data analysis

ANOVA and Cluster analysis were performed using SPSS 15.0 Windows Evaluation Version. To normalize the data, concentrations of PCBs were log-transformed prior to performing analysis of variance (ANOVA).

3. Results and discussion

3.1. Elution order and retention time of target PCBs

The optimum GC-ECD condition (section 2.4) was employed to analyse target PCBs in calibration standard mixture. The chromatogram of standard mixture showing the elution order, retention time and names of target PCBs is as shown in Figure 1. Some of the PCB congeners co-eluted (31/28; 149/118). Co-elution of peaks target PCBs is as shown in Figure 1. Some of the PCB congeners co-eluted (31/28; 149/118). Co-elution of peaks can be minimized by use of sophisticated columns. For congeners with different masses, the use of mass selective detector would be an advantage, since the MS has the ability to identify peaks with very close retention times based on their masses. ECD employed in this

| Sample points | Sample code (Description) | Latitude Longitude |
|---------------|--------------------------|--------------------|
| 1             | S1 (around the transformer plants) | N06°28.391′ E03°22.465′ |
| 2             | S2 (from the turbine yard) | N06°28.263′ E03°22.469′ |
| 3             | S3 (open storage for lubrication oil) | N06°28.275′ E03°22.471′ |
| 4             | S4 (car park) | N06°28.139′ E03°22.4834′ |
| 5             | S5 (drive way) | N06°28.254′ E03°22.4573′ |
| 6             | S6 (1 km away from the power station) | N06°28.819′ E03°22.356′ |
| 7             | W1/S/51 (primary water treatment plant) | N06°28.233′ E03°22.4864′ |
| 8             | W2/S/52 (turbine water reservoir) | N06°28.219′ E03°22.488′ |
| 9             | D1 (turbine yard) | N06°28.323′ E03°22.4577′ |

S: Soil; W: Water; SD: Sediment; D: Dust.
study has a major limitation of not being able to identify co-eluting peaks separately because retention time is the only criteria for identification of analytes so for such congeners, the concentrations reported are additive of the co-eluted peaks at their retention times [23,24].

3.2. Instrumental reproducibility

Precision of every injection of standard was determined by replicate injections \((n = 3)\) and reproducibility at \(n = 7\), in 4 days. The coefficient of variation within precision run and day to day precision ranged from 2.10 to 11.93% and 2.37 to 13.13% respectively. The chromatograms of the calibration standards were overlaid the show reproducibility of the peaks (Figure 2). The detector response to target PCBs were reproducible at varying concentrations \((0.025 \text{ ng } \mu\text{L}^{-1}, 0.050 \text{ ng } \mu\text{L}^{-1}, 0.100 \text{ ng } \mu\text{L}^{-1}, 0.200 \text{ ng } \mu\text{L}^{-1}, \text{ and } 0.400 \text{ ng } \mu\text{L}^{-1})\). The internal injection standard (PCB 209) introduced at a constant concentration (1 ng \(\mu\text{L}^{-1}\)) had similar response as evident in the overlaid chromatograms (Table 2).

3.3. PCBs in samples

3.3.1. PCBs in soil samples

Concentration of \(\Sigma\text{PCB}_{12}\) in soil samples varied for the different sampling points. Values of 34.60 ng/g, 43.60 ng/g, 10.43 ng/g, 19.42 ng/g, 25.34 ng/g, and 20.38 ng/g for S1, S2, S3, S4, S5, and S6 respectively.

| PCB # | 18 | 28/31 | 52 | 44 | 101 | 149/118 | 153 | 138 | 180 | 194 |
|-------|----|-------|----|----|-----|---------|-----|-----|-----|-----|
| S1    | 0.91 | 0.41 | 0.87 | 0.8 | 1.94 | 2.89 | 8.19 | 10.89 | 7.73 | 1.56  |
| S2    | < 0.10 | 2.98 | < 0.12 | 7.3 | 11.35 | 4.05 | 4.08 | 11.11 | 2.73 | < 0.10 |
| S3    | < 0.10 | 0.96 | 2.32 | 1.15 | 0.57 | 0.57 | 1.47 | 1.44 | 1.94 | < 0.10 |
| S4    | 4.84 | 1.84 | 1.09 | 0.89 | 0.56 | 0.91 | 2.78 | 3.58 | 2.93 | 0.72 |
| S5    | 1.53 | 0.93 | 1.36 | 0.8 | 1.18 | 2.21 | 5.65 | 7.05 | 4.62 | 0.62 |
| S6    | < 0.10 | 2.78 | 3.37 | 2.48 | 2.17 | 1.64 | 2.99 | 3.18 | 1.77 | < 0.10 |
| W1    | < 0.10 | 14.99 | 5.47 | 8.34 | 1.27 | 0.8 | 1.11 | 0.49 | 0.27 | < 0.10 |
| W2    | < 0.10 | 0.76 | 1.3 | 2.6 | 0.64 | 0.69 | 3.02 | 2.07 | 1.63 | 0.52 |
| SD1   | < 0.10 | 59.08 | < 0.12 | < 0.12 | 22.66 | 17.89 | 36.29 | 39.29 | 17.45 | 2.74 |
| SD2   | < 0.10 | 138.41 | 81.5 | 55.96 | < 0.12 | 110.39 | 214.8 | 159.32 | 43.33 | 22.13 |
| D1    | < 0.10 | 12.16 | 9.29 | 11.39 | 27.74 | 27.84 | 62.36 | 66.94 | 47.52 | 7.39 |
were obtained. Concentration increased in the order $S_3 < S_4 < S_9 < S_5 < S_1 < S_2$. The soil ($S_2$) from the turbine yard had the highest total PCB concentration followed by the soil around the transformer ($S_1$). The range (10.43–43.60 ng/g) of total PCBs in soil samples from this study exceeded those reported in urban soils from Nigeria [14] with range 8.71–26.28 ng/g; Municipal solid waste (MSW) landfill in Poland [25] with range 2.47–12.06 ng/g; urban soils in Shanghai [11] with range 0.23–11.3 ng/g; soil samples from New South Wales [26] with range 0.33–3.65 ng/g. The elevated levels of PCBs in soil samples from this study could be from heavy usage of PCB oils in the power station transformers which had leached into the soil over the years, though the power station is no longer in operation, but due to the persistent nature of PCBs, they are still found at such elevated levels.

3.3.2. PCBs in sediment and water samples
Total PCBs in sediment samples were generally higher than their corresponding water samples, this trend corroborated previous reports [12,13]. Sediments have been reported to act as sink for POPs like PCBs which is attributed to their high organic content [27,28]. SD1 and W1 had $\Sigma_{PCB_{12}}$ concentrations of 195.4 ng/g and 32.7 ng/mL respectively. SD2 and W2 had $\Sigma_{PCB_{12}}$ concentrations of 825.8 ng/g and 13.20 ng/mL respectively. Almost all the PCB congeners studied were present in the water samples but at values lower than the corresponding sediment samples. On the contrary, the two tetra-chlorinated congeners (PCB-44, S2) were present in the water sample from the water treatment plant (W1) but were $<$ LOD in the corresponding sediment (SD1). Similar results were obtained in the water sample at the turbine water reservoir (W2) with a concentration of PCB 101 at 0.64 ng/mL which was not detected in the sediment sample (SD2). The lower PCBs are slightly polar and have higher vapour pressure than the higher PCBs, when present in matrices in contact especially at low concentrations, they tend to partition towards the more polar matrix (fugacity). This is the likely reason why the lower PCBs were present in the water samples, but not detected in their corresponding sediment samples. The range of total PCBs in sediment samples (195.4–825.8 ng/g) and water samples (13.2–32.7 ng/mL) obtained in this study were above those reported for PCBs in Umgeni river, South Africa with range of 6.9–21.7 ng/mL in water and 102.6–427.8 ng/g in sediment [13]. Also another study reported PCBs in a lake in North China with range of 0.02–0.1 ng/mL in water and 6.0–29.6 ng/g in sediment [12].

3.3.3. PCBs in dust sample
All target PCBs studied were present in the dust sample except PCB 18. PCB-138, a hexa-chlorinated PCB was present at the highest concentration, closely followed by PCB 153 and then PCB 180 at concentrations of 66.9 ng/g, 62.4 ng/g and 47.5 ng/g respectively. $\Sigma_{PCB_{12}}$ in dust sample was 272.6 ng/g. The concentration of target PCBs in dust obtained in this study were higher than that reported by [17] for PCBs in dust from some Nigerian micro-environment.

3.3.4. Comparison of PCBs in matrices
Mean total PCB concentrations in investigated matrices were in the order: sediment $>$ dust $>$ soil $>$ water which corroborated previous studies [13,26]. Sediment samples had highest mean concentrations for almost all target congeners, except PCB 101 and PCB 180 which were more in dust (Figure 3). One way ANOVA performed to deduce if the mean concentrations of PCBs in the sample types (sediment, dust, soil, and water) vary significantly revealed the mean concentrations to be statistically different with p-value well below 0.05.

![Figure 3](image-url). Mean concentrations of target PCBs (ng/g, ng/mL) in samples.
Soil and dust samples revealed a similar congener profile. The first 3 PCBs with the highest mean concentrations are 138, 153, and 180. A similar trend of PCB (138 > 153 > 180) was observed in both matrices, indicating a similar source of contamination. Congenier profiles in sediment were slightly comparable to dust and soil. In sediment, the concentrations were in the order; PCB 153 > 138 > 28. PCB 28 had the third highest mean concentration. Water samples revealed a different congener profile. In water, lower PCBs were more predominant with concentrations in order of PCB 28 > 44 > 52, for the first three congeners with the highest concentrations. To statistically test the degree of similarity that exist in the pattern of target PCBs for the 4 sample types, hierarchical cluster analysis was performed using between-group linkage, euclidean distance method. The result revealed that dust and soil samples showed the greatest similarity at a distance of approximately 1. Sediment shared similarities with the dust and soil (at distance of approximately 5) while water was least similar to the other sample types. However the result from cluster analysis revealed that water shared little similarity with sediment at distance of about 19 (Figure 4).

4. Conclusion
PCBs in investigated power station samples exceeded those reported in areas far from power activities [11,12,26]. This therefore signifies that power activity is a major source of PCBs in the environment. However, due to the unique property of PCBs and other persistent organic pollutants (POPs), to travel long distances, they are found in areas far from where they are released. Further work needs to be done to investigate the variation in concentrations of PCBs across power stations in Nigeria.

Disclosure statement
No potential conflict of interest was reported by the authors.

ORCID
Bilikis Temitope Folarin  http://orcid.org/0000-0002-3518-4810
Temilola O. Oluseyi  http://orcid.org/0000-0002-5722-3403

References
[1] UNEP. Stockholm convention on persistent organic pollutants; 2009. Available from: http://chm.pops.int.
[2] U.S. Department of Health and Human Services (US DHHS). Public health service, agency for toxic substances and disease registry: ‘toxicological profile for polychlorinated biphenyls (PCBs)’; Nov 2000.
[3] Egloff C, Crump D, Chiu S, et al. In vitro and in vivo effects of four brominated flame retardants on toxicity and hepatic mRNA expression in chicken embryos. Toxicol. 2011;207:25–33.
[4] Boate AG, Deleersnyder J, Howarth A, et al. Chemistry of PCBs. The UN Water Virtual Learning Centre. Available from: http://wvlc.uwaterloo.ca/biology447/modules/intro/assignments/introduction2a.htm.
[5] Lauby-Secretan B, Loomis D, Grosse Y, et al. International agency for research on cancer monograph working group IARC, Lyon, France: carcinogenicity of polychlorinated biphenyls and polychlorinated biphenyls. Lancet Oncol. 2013;14(2):287–288.
[6] Carpenter DO. Polychlorinated biphenyls (PCBs): routes of exposure and effects on human health. Rev Environ Health. 2006;21(1):1–24.
[7] United State Environmental Protection Agency (USEPA). Public health levels for PCBs in indoor school air; Apr 2012. Available from: http://www.epa.gov/pcbsincaulk/maxconcentrations.htm.
[8] Labunska I, Abdallah MAE, Eulaers I, et al. Human dietary intake of organohalogen contaminants at e-waste recycling sites in eastern china. Environ Int. 2015;74:209–220.
[9] Nairn S, Hyatt JE, Prignano AL. Generating the right PCB data: determination of Aroclors versus PCB congeners- proceedings from 34th waste management conference. Phoenix (AZ): WM Symposia, Inc.
[10] Shen C, Huang S, Wang Z, et al. Identification of Ah receptor agonists in soil of e-waste recycling sites from taizhou area in china. Environ Sci Technol. 2008;42:49–55.
[11] Jiang Y, Wang X, Zhu K, et al. Polychlorinated biphenyls contamination in urban soil of Shanghai: level, compositional profiles and source identification. Chemosphere. 2011;83:767–773.
[12] Dai G, Liu X, Liang G, et al. Distribution of organochlorine pesticides (OCPs) and poly chlorinated biphenyls (PCBs) in surface water and sediments from Baiyangdian Lake in North China. J Environ Sci. 2011;23:1640–1649.
[13] Gakuba E, Moodley B, Ndungu P, et al. Occurrence and significance of polychlorinated biphenyls in water, sediment pore water and surface sediments of Umgeni River, KwaZulu-Natal, South Africa. Environ Monit Assess. 2015;187(9):568.
[14] Alani R, Olayinka K, Alo B. The level of persistent, bioaccumulative, and toxic (PBT) organic micropollutants contamination of Lagos soils. J Environ Chem Ecotox. 2013;5(2):26–38.
[15] Tue NM, Takahashi S, Suzuki G, et al. Contamination of indoor dust and air by polychlorinated biphenyls and brominated flame retardants and relevance of non-dietary intake in Vietnamese informal e-waste recycling sites. Environ Int. 2013;51:160–167.
[16] Syed JH, Malik RN, Li J, et al. Levels, distribution and air-soil exchange fluxes of polychlorinated biphenyls (PCBs) in the environment of Punjab Province, Pakistan. Ecotox Environ Saf. 2013;97:189–195.
[17] Harrad S, Abdallah MAE, Oluseyi T. Polybrominated diphenyl ethers and polychlorinated biphenyls in dust from cars, homes, and offices in Lagos, Nigeria. Chemosphere. 2016;146:346–353.
[18] Herrick RF, Meeker JD, Altshul L. Serum PCB levels and congener profiles among teachers in PCB-containing schools: a pilot study. Environ Health. 2011;10:56.

[19] Chen L, Yu C, Shen C, et al. Study on adverse impact of e-waste disassembly on surface sediment in east China by chemical analysis and bioassays. J Soil Sediment. 2010;10:359–367.

[20] Zhao G, Xu Y, Li W, et al. PCBs and OCPs in human milk and selected foods from Luqiao and Pingqiao in Zhejiang, China. Sci Total Environ. 2007;378:281–292.

[21] Zhao G, Xu Y, Li W, et al. Prenatal exposures to persistent organic pollutants as measured in cord blood and meconium from three localities of zhejiang, china. Sci Total Environ. 2007;377:179–191.

[22] EPA Method 8082a (SW-846). Polychlorinated biphenyls (PCBs) by gas chromatography; 2007.

[23] Muir D, Sverko E. Analytical methods for PCBs and organochlorine pesticides in environmental monitoring and surveillance: a critical appraisal. Anal Bioanal Chem. 2006;386:769–789.

[24] Bianco G, Novaro G, Bochicchio D, et al. Polychlorinated biphenyls in contaminated soil samples evaluated by GC-ECD with dual-column and GC-HRMS. Chemosphere. 2008;73:104–112.

[25] Melnyk A, Dettlaff A, Kuklinska K, et al. Concentration and sources of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in surface soil near a municipal solid waste (MSW) landfill. Sci Total Environ. 2015;530-531:18–27.

[26] Abdallah MA, Drage D, Harrad S. A one-step extraction/clean-up method for determination of PCBs, PBDEs and HBCDs in environmental solid matrices. Environ Sci-Proc Impact. 2013;15:2279–2287.

[27] Hellar-Kihampa H, De Wael K, Lugwisha E, et al. Spatial monitoring of organohalogen compounds in surface water and sediments of a rural-urban river basin in Tanzania. Sci Total Environ. 2013;447:186–197.

[28] Lai Z, Li X, Li H, et al. Residual distribution and risk assessment of polychlorinated biphenyls in surface sediments of the Pearl River Delta, South China. Bull Environ Contam Toxicol. 2015;95(1):37–44.