Nigerian Research Journal of Engineering and Environmental Sciences 3(2) 2018 pp. 601-615

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Polychlorinated Biphenyls in Soils and Earthworms near Electric Power Sub-Stations in Benin City: Contamination Levels and Distribution Patterns

[1]Asemota, O.C., *[2]Enuneku, A.A., [1]Tongo, I. and [1]Ezemonye, L.I.N.
[1]Laboratory for Ecotoxicology and Environmental Forensics, Department of Animal and Environmental Biology, Faculty of Life Sciences, University of Benin, PMB 1154, Benin City, Nigeria.
[1,2]Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, PMB 1154, Benin City, Nigeria.
*alex.enuneku@uniben.edu

ARTICLE INFORMATION

Article history:
Received 03 July, 2018
Revised 02 September, 2018
Accepted 10 September, 2018
Available online 30 December, 2018

Keywords:
Polychlorinated biphenyls
Contamination
Soil
Earthworm
Electric power stations
Persistent organic pollutants

ABSTRACT

Soil and earthworms from Benin City, Southern Nigeria were examined to determine the levels and distribution of polychlorinated biphenyls (PCBs) congeners near electric power substations (EPS). Two power substations (EPS Sapele Road and EPS Ugbowo) were sampled. A rural area (Okhun Village) was sampled as control station. PCBs analysis for 19 congeners were carried out using a Gas Chromatograph, HPGC 5890 series II fitted with an electron capture detector (ECD). Cluster analysis (CA) congregated PCBs congeners into three groups with PCBs 7 and 18 forming a cluster. One cluster was formed by PCB 60 alone while other PCBs analyzed formed the last cluster. The major contributor to the total dioxin-like PCBs was PCB 105, which accounted for 53% in EPS Sapele Road, 47% in EPS Ugbowo and 33% in Okhun Village. Commercial PCBs mixtures are known to contain a high proportion of PCB 105. The mean levels of PCBs in soil in all studied areas ranged from 0.001µg/kg to 0.022 µg/kg while the mean levels of the PCBs in earthworm samples ranged from 0µg/kg to 0.003 µg/kg. These levels were significantly lower than the levels in soil ($p<0.05$). It was observed that a significant positive correlation ($p<0.05$, $R = 0.829$) occured between PCB levels in soil and earthworm samples. In this study, levels of PCBs in soil samples were generally below the ecological benchmark of 0.3 mg/kg. Nonetheless, the occurrence of these toxic compounds in the environment raises serious worries owing to their persistence and toxic potentials.

1. INTRODUCTION

At present, soils and soil in-fauna in Africa are under threat of continuous pollution owing to anthropogenic campaigns geared towards provision of the basic necessities of life including energy for all (FMEnv 2009; Fayiga *et al.*, 2018). As a result, environmental contaminants such as PCBs are released from municipal electrical processes and products into soil with potential ecological and human health risks. PCBs are a family of chlorinated and synthetic persistent organic pollutants (POPs) which are non-ionic and toxic chemical compounds comprising 209 congeners depending on the number and position of chlorine that is substituted onto the biphenyl moiety (US EPA, 2011). They represent organic hydrocarbons that have 1 to 10 chlorine atoms attached to biphenyl rings. PCBs are one of the most widespread environmental pollutants and can be found in various environmental matrices (Voorspoels *et al*., 2004). Thirteen of the 209 congeners are known to exhibit toxic responses comparable to those caused by 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD), the most toxic dioxin (Van den Berg *et al*., 2006). PCBs pose a severe environmental problem due to their low degradability, high toxicity and strong bioaccumulation potentials (Tu *et al*., 2011). The notable physical properties of PCBs and their extreme chemical stabilities have been the reasons for their broad industrial application (Tillmann *et al.,* 2005). They are widely used as coolants and lubricants in transformers, generators, capacitors contained in electrical and electronic products, flame-retardants, plasticizers and additives in pesticides (Gioia *et al*., 2014; Holt *et al*., 2016). Contamination of soils with polychlorinated biphenyls has often resulted from their manufacture, handling, use, and disposal (Chekol *et al*., 2004).

PCBs are usually released into environmental compartments over long periods through leakages arising from commercial use of electrical equipment, accidental fires and incineration of PCB waste owing to their persistent character (Danse *et al.,* 1997; Kim *et al*., 2017). Their environmental fate is governed by the number of chlorine atoms in the biphenyl ring. The persistence and stability of PCBs rises as the number of chlorine atoms per molecule increases. They are known for long range transport abilities, and have been detected in the remote areas (Chen and Hale, 2010). Global, national and regional inventories of PCBs have been carried out to inform efforts at source reduction, while monitoring campaigns have also been executed out to help identify hot spot regions (Klanova *et al*., 2009). The most recent inventory of PCB production estimates the cumulative global production at 1.3 million tonnes (Breivik *et al.,* 2007). A considerable part of PCBs produced globally has been destroyed and part remains in use or awaits destruction, while a substantial proportion has been released into the environment. The major portion of PCBs in the environment is positioned in soil compartments near previous localization of their production and usage (Vasilyeva and Strijakova, 2007). Soils are important reservoirs for several contaminants, both inorganic and organic. Soils have been reported to act both as sinks and sources for PCBs in the natural ecosystems (Dalla *et al.,* 2004; Sandu *et al.,* 2013). PCBs get to soil through wet and dry deposition from the atmosphere, accumulation in vegetation and xenobiotic add-ons through leakages and accidents (Mac Donald *et al.,* 2000).

Undoubtedly, PCBs are one of the most toxic chemicals with potentially serious health implications to a variety of animal species including humans (Loganathan *et al.,* 1995; Hansen and O'Keefe, 1996). International concerns for PCBs are the potential toxic effects and tendency to bioaccumulate up the food chain even to man through trophic transfer (Zaborski, *et al.,* 2011; Zani *et al.,* 2013). Available reports show that elevated levels of PCBs occur off the West African coast (Gioia, 2008; Nizzetto *et al.,* 2008). This could have serious environmental health implications as many developing nations of Africa including Nigeria still use old electrical transformers and equipment containing PCBs. Several studies have shown that PCBs are present in Nigerian environment (Ezemonye, 2005; Fagbote and Olanipekun, 2010). Over time, Nigeria has imported PCBs in dielectric fluids from 58 different countries (Okoh, 2015).

Earthworms make up approximately 60–80% of the soil biomass, have close contact with soil, affect soil structural properties and fertility, and have been used extensively as bioindicators of soil contamination (Duan *et al*., 2017). They are good sentinel organisms of soil chemical pollution and soil health because they are in direct contact with soil pore water (Kammenga *et al.,* 2000). They act as a link in the transport of pollutants from the soil to consumers in the terrestrial food web higher up the food chain.

Data on PCB pollution of tropical African environments are limited. The aim of this study was to determine the contamination levels and distribution patterns of PCBs in soils and earthworms near electric power sub-stations in Benin City, southern Nigeria.

2. MATERIALS AND METHODS

2.1. Study Location

This study was carried in Benin City, Edo State. While choosing the sample stations, high-to-medium voltage transformer substations for electricity supply to households and industries were considered. Top soil and earthworm samples were sampled for six (6) months from two stations and a relatively pristine area. The geographic coordinates of the sites were; Station 1 – EPS Sapele Road (06°17.756''N, 005°37.900''E), Station 2-EPS Ugbowo (06°23.260''N, 005°36.737''E)., Station 3-Okhun Village (06°26.555''N, 005°35.321''E).

2.2. Sample Collection

The extraction of During sample collection, top soils (100g) were taken from each site at a depth of 0 – 30cm using a hand driven stainless soil auger according to the method described by Taru *et al.* (2014). Khomich et al. (2008) reported that the highest concentrations of PCBs are found in top soil layer. They were labeled and taken to the laboratory. In each station, 3 soil samples were randomly taken at a distance of about 200 m from one another. Fifty-four (54) earthworm samples (*Apporectodea longa)* were sampled from the three stations according to Owa *et al.* (2013). The top soil was turned slowly with care using a spade while earthworms were picked into containers and subsequently transported to the laboratory. Afterwards, they were washed with distilled water. Earthworms were later identified according to Sims and Gerrard (1985) and Nature Watch (2003).

2.3. Extraction of PCB Residues

PCBs residues were extracted from soil samples according to methods described by Bentum et al. (2016). Ten grams (10 g) of soil (air-dried) was extracted with 100 ml of hexane-acetone mixture (1:1 v/v) for sixteen hours with the aid of an automated soxhlet apparatus and then concentrated to 10 mL. Hexane was introduced and it was concentrated to remove the acetone. It was subsequently dried with sodium sulphate and then concentrated further. Then 10 mL of concentrated extract was transferred using three 5 mL hexane rinse of the flask into a separatory funnel for clean-up. Afterwards, 10 mL of the extract was cleaned up with sulphuric acid, followed by clean-up with 5 mL of 5% (w/v) $KMnO_4$ in order to decompose other organic compounds in the extract. Clean-up with copper granules was done to precipitate sulphur in the extract which might interfere with the gas chromatographic analysis and finally with silica gel. The column was eluted with 100 mL of hexane: dichloromethane (7:3 v/v). One ml of the cleaned-up extract was transferred into a pre-cleaned 2 ml vial with acetate ethyl resins and added to the vial to make the total volume 2 mL.

Samples of frozen earthworms were used for extraction. Tissues (10 g) were homogenized and then eluted with hexane: acetone (1:1 by volume). They were afterwards spiked with internal (surrogate) standards (1 ml decachlorobiphenyl). Samples were later extracted with extraction thimbles using a Soxhlet apparatus for 4 h with 100 mL hexane and acetone. A rotary evaporator was used to concentrate the resultant extract to 2 mL. The sample extract was cleaned up for removal of any sulphur or lipid using a silica column impregnated with sulpuric acid, alumina, and florisil. Afterwards, 10 mL of n- hexane was used to condition the column prior to clean up. The extracts of the samples, blanks and spike samples were transferred into florisil column using a Pasteur pipette until they were eluted. The elute was collected into a conical flask. The process was doubly repeated. The column was further rinsed with 10 mL hexane. The elute was concentrated to 1ml on

O.C. Asemota et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(2) 2018 pp. 601-615

a rotary evaporator and transferred into 2 mL glass GC Vials using a pasteur pipette for analysis. Recovery of the column was determined with 0.01L Decachlorobiphenyl.

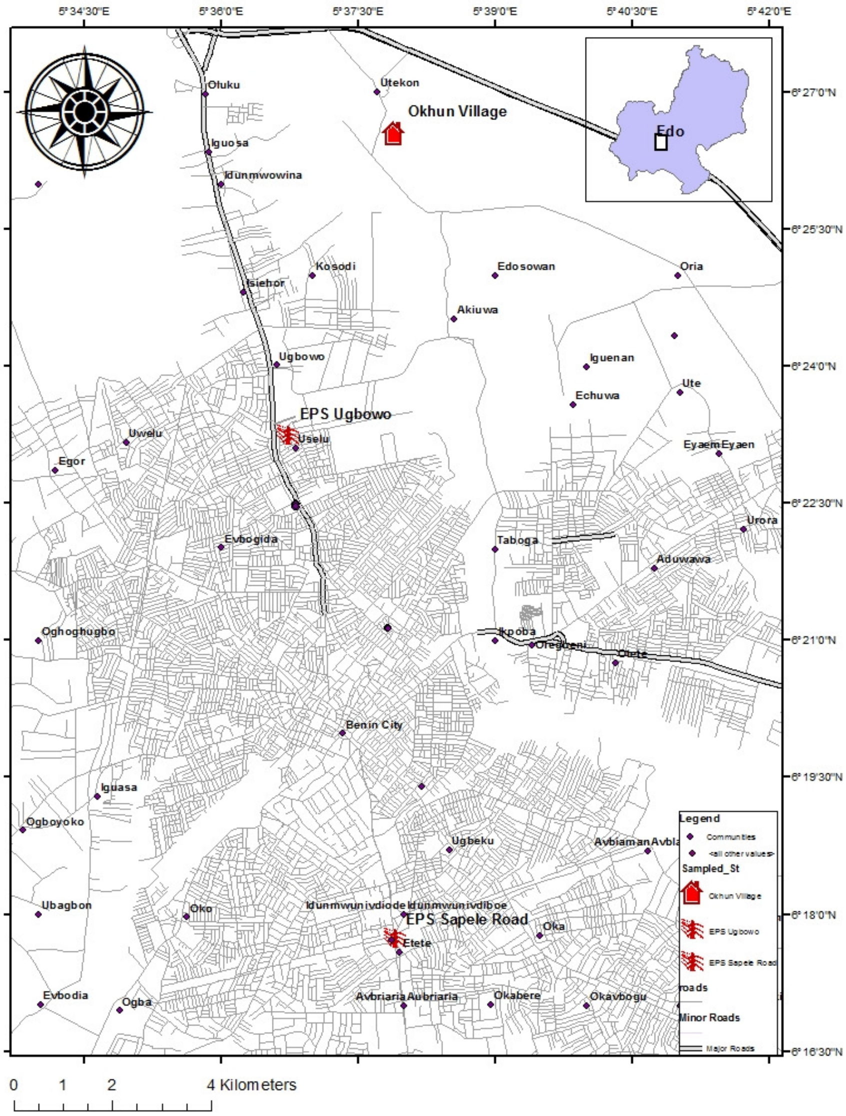

Figure 1: Map of Benin City showing the sampled points

2.4. Gas Chromatography (GC) Analysis

Instrumental analysis of samples was done using Hewlett – Packard (HPGC 5890 series II) equipped with a 63Ni Electron Capture Detector (ECD) with 15mCi activity and auto sampler was employed for the analysis. A VF-5ms of 30 mm capillary column with 0.25 mm internal diameter and 0.25µm film thickness equipped with 1 m retention gap (0.53, deactivated) was used for the chromatographic separation. The carrier gas was Helium and the temperature program used was as follows: Oven temperature: the initial temperature was set at 60ºC for 2 minutes and ramped at 25ºC to 300 for 5 minutes and allowed to stay for 15 minutes giving a total run timer of 58 minutes. The injector setting was a pulsed spitless mode with a temperature of 25°C at a standard pressure. The injection volume was 1.0 mL. Detector temperature was 320°C (held for 5 minutes). Nitrogen gas was used as a makeup gas maintained at a constant flow rate of 29 mL / minute. PCBs were identified according to retention time and quantified by reference to an internal standard. Decachlorobiphenyl was used as a recovery standard.

2.5. Quality Assurance/Quality Control

Prior to sample analysis, relevant standards were analyzed in order to check instrumental performance, peak heights and resolution. A procedural blank was run in parallel with every batch of 6 samples and the results were corrected accordingly. Reproducibility of the method was monitored by repeated analysis of spiked quality control samples. The mean recoveries were 96-110%. Limit of detection was 0.001µg/kg.

2.6. Data Analysis

Results in this study are presented as mean ± standard error. Prior to conducting parametric tests, data characteristics were tested for homogeneity of variance and normality. Shapiro-Wilk's test was conducted including a visual inspection of histograms, normal Q-Q plots which showed that data were not normally distributed as the null hypothesis was rejected at $p<0.05$. Data were then log-transformed were then log-transformed by base 10 logarithm transformations to stabilize variances. One-way analysis of variance was carried out to test for significant differences in PCBs concentrations (spatial and temporal) and subsequently, Tukey's post-hoc tests were done to locate the differences using SPSS version 16. Multivariate tests (PCA and Cluster Analysis to understand PCBs distribution patterns were conducted using JMP version 10 (SAS Institue).

3. RESULTS AND DISCUSSION

3.1. PCBs Levels in Soil Samples

PCBs were detected in soil samples from the three EPS stations sampled. PCB congeners have been found in all environmental compartments: sediment, soil, air, water, even in breast milk and fatty deposits of polar bears and whales (Stojić *et al.,* 2014). Figure 2 shows the mean levels of PCBs from soils of Okhun Village. Nine (9) PCBs congeners were detected in soil samples. It was observed that PCB 43 had the highest levels with a mean of 0.004±0.005µg/kg and a range of 0.000-0.016µg/kg. The total mean level (µg/kg) of all the PCBs congeners was 0.029 ± 0.001µg/kg. This was significantly lower ($P < 0.005$) than the levels in EPS Sapele Road and Ugbowo. The mean levels of PCBs from soil samples of EPS Sapele Road are shown in Figure 3. Nineteen congeners were detected. PCB60 had the highest level with a mean of 0.022 ± 0.039µg/kg and a range of 0.000 - 0.143 µg/kg. The mean levels of PCBs from soil samples of EPS Ugbowo power substations are shown in Figure 4. PCB60 also had the highest level with a mean of 0.009 ± 0.025µg/kg and a range of 0.000 - 0.107µg/kg.

O.C. Asemota et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(2) 2018 pp. 601-615

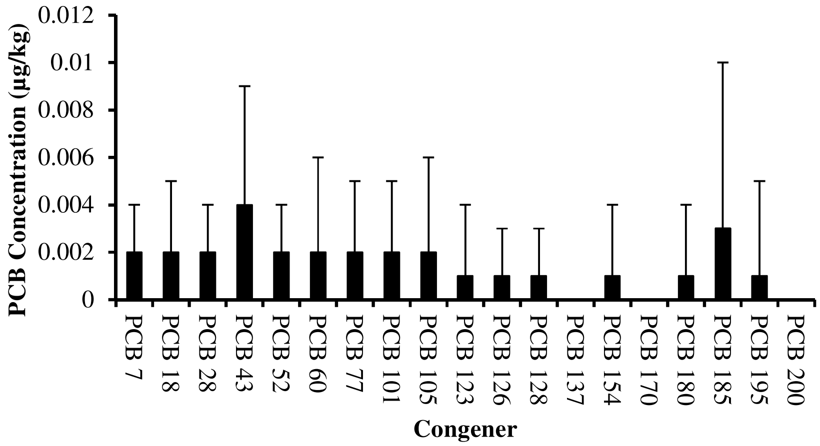

Figure 2: Mean levels of PCBs in soil from Okhun

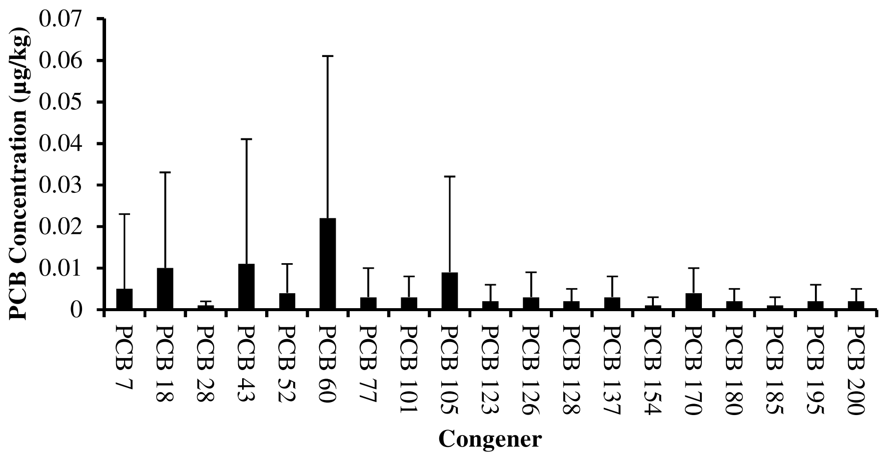

Figure 3: Mean levels of PCBs in soil from at EPS Sapele road

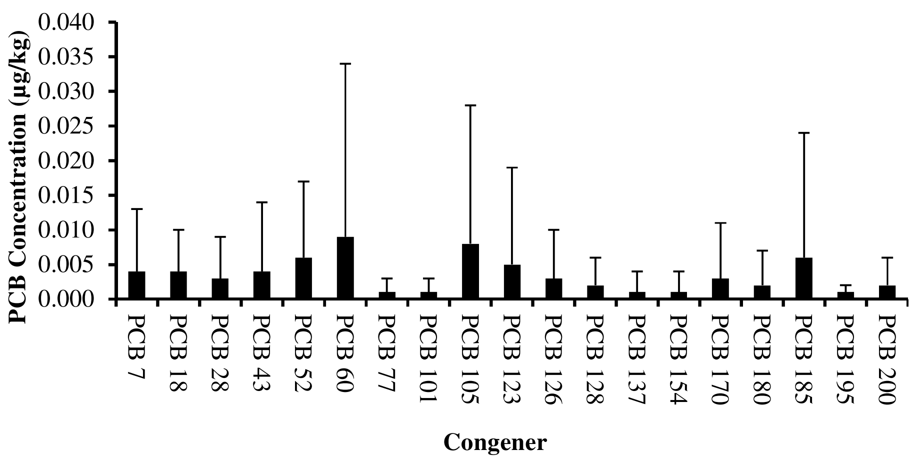

Figure 4: Mean levels of PCBs in soil from electrical power sub-station at EPS Ugbowo

O.C. Asemota et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(2) 2018 pp. 601-615

In this study, PCBs were detected in all stations sampled including the rural village. PCBs have been reported to occur in major parts of the global ecosystems including air, water and soil (Mac Donald *et al.,* 2000). The occurrence of PCBs in the rural village sampled was probably because once they are released into the environment and they spread due to long range transfer (Blais *et al.,* 2003). Previous studies have shown that PCBs are present in the Nigerian environment (Okoh, 2015). This may be due to poor management of damaged electrical equipment, leakages during refilling and indiscriminate discarding of waste containing PCBs. PCBs are not leachable in soils and are easily absorbed by soil constituents. All congeners of PCBs have low volatility and highly lipophilic, with the consequence that more than 99% of the environmental PCBs mass are found in soil (Bi *et al.,* 2002). In Ghana, Bentum *et al.* (2012) studied the accumulation of metals and PCBs in soils around electric transformers in the Central Region of Ghana and reported that the total PCB levels ranged between 1.32 and 12.94 µg/kg. In this study, PCBs levels in soils were below the ecological benchmark of 0.3 mg/kg which applies to agricultural and residential/parkland land uses (OMEE, 1994).

3.2. Distribution Patterns of PCBs Congeners in Sampled Locations

A 3D scatterplot of PCBs in soils of sampled areas is shown in Figure 5. PCA and CA were executed in order to elucidate the contamination patterns of PCBs congeners. PCA bi plot in Figure 6 presents a score plot of PCBs congener contamination patterns for soil and the relationship existing between PCB congeners and the first two components. PC1 accounted for 40.4% of the variation while PC2 makes up 18.1% in the dataset. These two components together accounted for 58.5% of the total variation. All the PCB congeners sampled had a positive correlation with PC1. PCB congeners 60, 123, 128, 154, 180, 185, 195, 200 and 209 had a negative correlation with PC2. In the loading plot PCBs congeners formed different clusters. This was further and more clearly depicted in the dendogram generated by cluster analysis (CA) in Figure 7 based on Ward's method. The dendrogram shows that the 16 PCBs congeners were grouped into three clusters. PCBs 7 and 18 formed a cluster. PCB 60 formed another cluster alone while the remaining PCBs studied formed the last cluster. It is interesting to note that PCB 60 had the highest level in soil for all study areas.

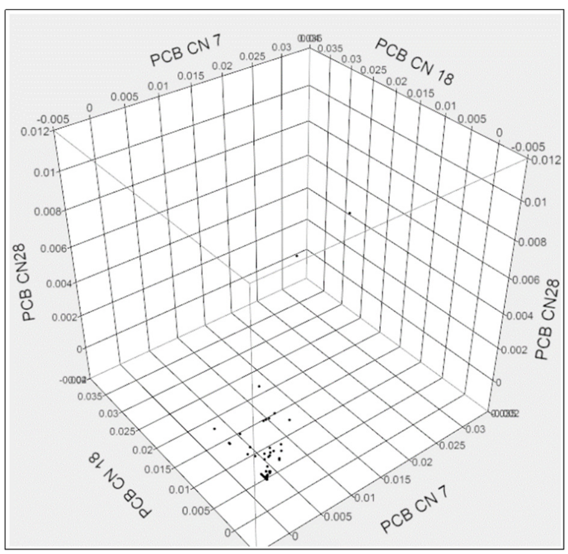

Figure 5: A 3D scatterplot of PCBs in soils of sampled areas

O.C. Asemota et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(2) 2018 pp. 601-615

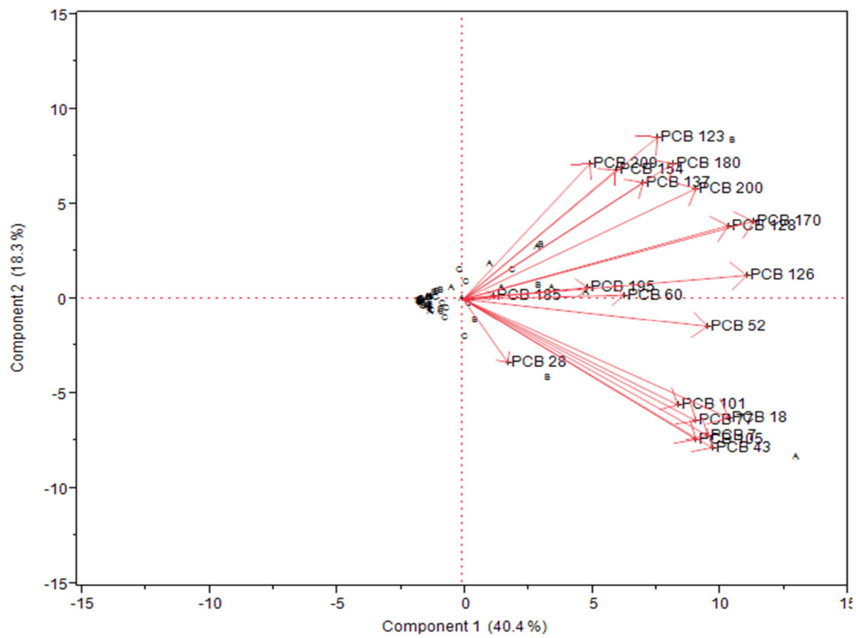

Figure 6: Bi-plot of PCA showing distribution patterns of PCBs congeners in sampled locations. A=Okhun, B= EPS Sapele road, C= EPS Ugbowo

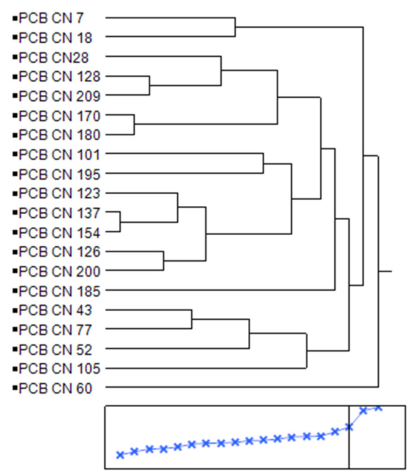

Figure 7: Dendogram and scree plot showing similarity between PCB congeners sampledPercentage Occurrence of PCBs Congeners in Soil Samples

In Okhun Village, PCB43 had the highest percentage occurence (14 %) of the total PCBs congeners. PCBs177, 170 and 200 were not detected. Soil samples from EPS Sapele Road showed that PCB60 was the most abundant congener making up 24 % of the total PCBs residues in soil. PCBs 18, 43 and 105 were 11 %, 12 % and 10 % respectively. PCB 60 also had the highest percentage occurrence (14 %) in soil samples from EPS Ugbowo while PCBs 52, 105, 123 and 185 were 9%, 12%, 8%, and 9% respectively. PCBs 77, 101, 137, 154, and 195 had the lowest percentage distribution of 2 % each.

O.C. Asemota et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(2) 2018 pp. 601-615

3.3. PCBs Levels in Earthworm Samples

The mean levels 9 PCB congeners (µg/kg) in earthworms from Okhun Village were 0.001 (PCB28), 0.001 (PCB52), 0.002 (PCB60), 0.001 (PCB77), 0.001 (PCB101), 0.002 (PCB105), 0.001 (PCB123), 0.001 (PCB180), 0.001 (PCB195) (Figure 8). From results, PCB60 and PCB105 had the highest mean levels of 0.002 µg/kg. Tissues of earthworms from EPS Sapele Road showed the presence of 14 PCBs congeners. Mean levels (µg/kg) of these congeners include: 0.001 (PCB7), 0.001 (PCB18), 0.001 (PCB28), 0.001 (PCB43), 0.001 (PCB52), 0.003 (PCB60), 0.001 (PCB77), 0.001 (PCB101), 0.001 (PCB105), 0.002 (PCB123), 0.001 (PCB126), 0.001 (PCB128), 0.001 (PCB154), 0.002 (PCB200). PCB60 had the highest mean level (0.003 µg/kg) (Figure 9). Ten (10) congeners were detected in all soil samples obtained from EPS Ugbowo: 0.001 (PCB7), 0.002 (PCB18), 0.001 (PCB28), 0.001 (PCB43), 0.001 (PCB52), 0.003 (PCB60), 0.001 (PCB77), 0.002 (PCB105), 0.001 (PCB180) and 0.001 (PCB185) µg/kg. Figure 10 showed that PCB60 had the highest mean level of 0.003 µg/kg. PCBs have been shown to affect earthworm health, enzymatic and physiological conditions. Duan et al., 2017) studied the Physiological and molecular responses of the earthworm, *Eisenia fetida* to PCBs contamination in soil. Reports from their study indicated that Earthworms had significantly lower weights in red soil and fluvo-aquic soils after PCB exposure. PCBs significantly increased catalase (CAT), superoxide dismutase (SOD), and guaiacol peroxidase (POD) activity in earthworms exposed to either soil type for 7 or 14 days and decreased the malondialdehyde (MDA) content in earthworms exposed to red soil for 14 days.

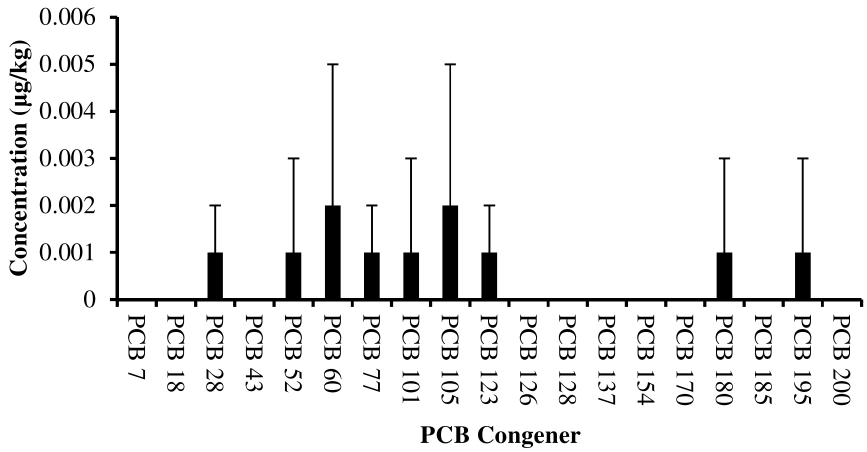

Figure 8: Mean distribution of PCBs in earthworm from Okhun

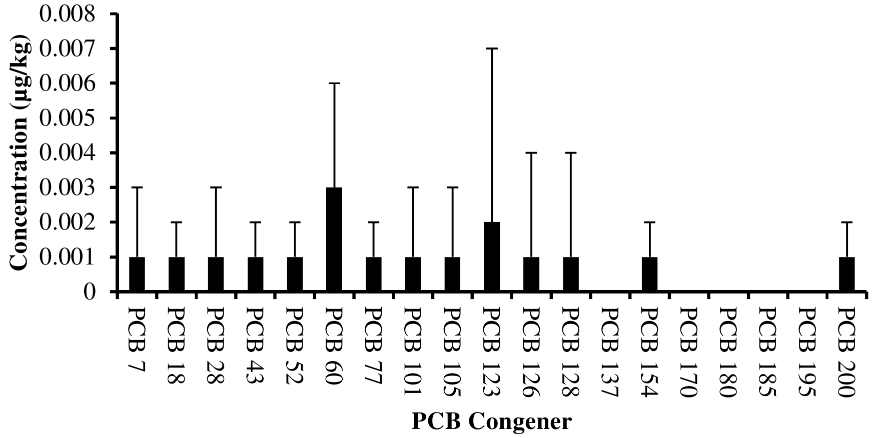

Figure 9: Mean distribution of PCBs in earthworm from EPS Sapele road

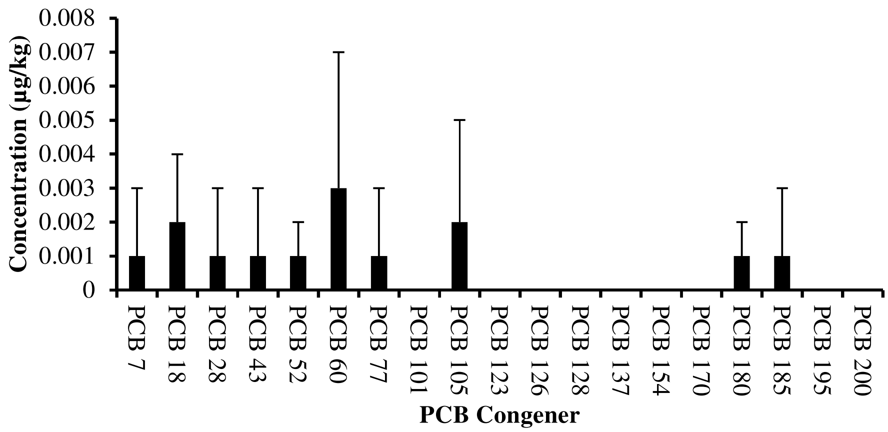

Figure 10: Mean distribution of PCBs in earthworm from EPS Ugbowo

3.4. Differential Distribution of PCBs Congeners Levels between Soil and Earthworm

Results showed that levels of PCBs congeners in samples analyzed from EPS Sapele Road, EPS Ugbowo and Okhun Village showed that the levels of PCBs in soil was significantly higher ($P<0.05$) compared to levels in earthworm (Figure 11). Accumulation of PCBs have been reported to be species specific in earthworms. Rodriguez *et al.* (1989) showed that *E. fetida* was four times more resistant to PCB than *L. terrestris*. The higher PCBs levels in EPS Sapele Road and Ugbowo ($P < 0.005$) compared to Okhun village is probably because EPS Sapele Road and Ugbowo are areas with high-to-medium voltage transformer stations and numerous medium-to-low voltage transformer substations for supply of electricity to households and industries. Similarly, Khomich *et al.* (2008) reported that high concentrations of PCBs (2–21 g/kg) were tracked in the soil near destroyed capacitors and transformers as a consequence of PCB leakage. Mamontova *et al.* (2013) reported the occurrence of higher PCB levels in soil from urban settlements in Mongolia than those in rural soil.

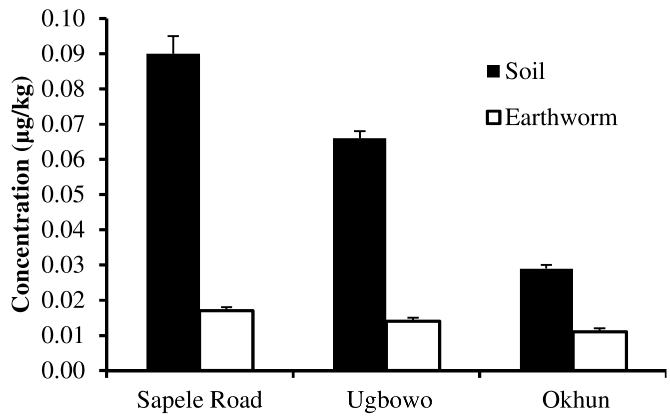

Figure 11: Differential distribution of PCBs in soil and Earthworm

3.5. Temporal Variations

3.5.1. Monthly distribution of PCBs residues in Soil Samples from sampled locations

The distribution of PCBs residues in soil samples from EPS Okhun Village showed that the peak levels (0.060 µg/kg) of PCBs residues were recorded in April. There was significant difference ($P<0.05$, $F = 6.447$) in the levels of PCBs for the months compared. In EPS Sapele Road, the peak PCBs level of 0.35µg/kg was recorded in February. There was significant difference ($P < 0.05$, $F = 9.530$) in the levels of PCBs between the months. In EPS Ugbowo, the peak level (0.024 µg/kg) of PCBs residues was also recorded in April. There was significant difference ($P < 0.05$, $F = 3.206$) in the level of PCBs between the months.

3.5.2. Monthly Distribution of PCBs Residues in Earthworm Samples

In EPS Sapele Road the peak level (0.046µg/kg) of PCBs residues was recorded in June. A significant difference ($P < 0.05$, $F = 13.673$) occurred in the levels of PCBs between the months. In EPS Ugbowo, the peak level (0.230 µg/kg) of PCBs residues was recorded in February. There was also a significant difference ($P < 0.05$, $F = 15.419$) in the level of PCBs between each month. In EPS Ugbowo, the peak level (0.030 µg/kg) of PCBs residues was recorded in the month of June. There was significant difference ($P < 0.05$, $F = 3.370$) in the level of PCBs between the months. The peak level of PCBs residues was recorded in February for soil samples from EPS Sapele Road (0.35 µg/kg) and EPS Ugbowo (0.230 µg/kg). This was probably because of higher temperature as a result of absence of precipitation within February. Danielovic *et al.* (2014) has reported higher levels of PCBs during seasons with higher temperature compared to lower temperature. A progressive decrease in the levels of PCBs was observed from March down to June. This is may be attributed to increasing level of precipitation. Fu and Wu (2006) studied the effect of precipitation on PCB levels in the Er-Jen River in Taiwan. They found that PCB levels increased in warmer weather due to higher water temperatures. The peak levels (0.06 µg/kg) of PCBs residues in soil samples from Okhun Village was however recorded in April. This could be because PCBs are disposed to long-range transportation from the original source to other areas. The main contributors to the total dioxin-like PCBs (dl-PCB) levels was PCB 105 accounting for 53% in EPS Sapele Road, 47% in EPS Ugbowo and 33% in Okhun Village of the total PCBs levels in each station. Commercial PCBs mixtures have been known to generally contain a high proportion of PCB 105. The high contributions of PCB 105 in the soil samples from three stations suggest that PCB emissions from old PCBs containing materials strongly influenced PCBs levels in the soil. This report is in line with the findings of Yajun *et al.* (2016) who assessed dioxin-like polychlorinated biphenyl (dl-PCB) levels in ambient air and soil in Shanghai, China and showed that the major contributors to the total dl-PCB in soil samples were PCB-118, -105, and -77 respectively.

In this study, PCBs levels in the earthworm samples were significantly lower than the levels in soil ($P<005$, $F = 20.166$). This is probably because the PCBs in the three stations sampled were dominated by congeners with less chlorination. PCBs with low chlorination are more readily metabolized and eliminated and so do not tend to bioaccumulate as much (Hutzinger *et al.*, 1974). Furthermore, bioavailability of chemical contaminants is dependent on soil properties including clay content, organic matter content, and soil sorption and desorption processes. The profiles for congeners of PCBs in earthworm in this study were similar to that of soil, implying that the congener profiles of the earthworms reflected the profiles of the habitat soil. Of all the congeners sampled, PCB60 was the dominant congener across the three sampling stations (EPS Sapele road, EPS Ugbowo and Okhun Village). Also, the profile of PCB homologues comprised dichlorinated to octochlorinated biphenyls within the three stations studied. The dominant homologues were tetrachlorinated across the three stations. This observation is similar to a study by Spongberg (2006) on PCBs in 27 sipunculan worm samples from the west coast of Costa Rica. In all cases the congeners profiles were dominated by tetrachlorinated bipheyls. Bioaccumulation of PCBs in fatty tissues of animals and in soils, may result in chronic exposure of humans to these substances as they get transferred up the food chain. Hens and Hens (2017) advocated that the impact of the different PCB congeners on human health should not be underestimated, as they are ubiquitous, stable molecules and reactive in biological tissues, leading to neurological, endocrine, genetic, and systemic adverse effects in the human body.

4. CONCLUSION

The occurrence of several PCBs congener residues in top soil and earthworm samples (*A. longa*) from electric power substations in Benin City has been demonstrated in this study. A seemingly pristine village (Okhun) also showed the presence of these congeners. Findings from this study demonstrate the continuing role of urban areas as emission sources of PCBs as revealed by a higher level in EPS Sapele Road and Ugbowo with high numbers of electrical transformers. The source of PCBs transfer to the sampled areas in this study is believed to be emission from PCB-containing equipment such as old electrical transformers in power stations which abound in the municipality studied. Dioxin-like PCBs were detected in soils and earthworms of all sampled sites. A higher level of PCBs occurred in soil compared to earthworm ($P<0.05$) with a significant positive correlation ($p<0.05$, $R = 0.829$). This is largely because the PCBs in the three areas sampled were dominated by congeners with less chlorination, which are more readily metabolized and eliminated and so do not tend to bioaccumulate as much. In this study, *A. longa* has been proven to be an excellent candidate sentinel for PCBs contamination as PCBs levels found in earthworms were lower than levels detected in soil. The observed levels in soil samples were generally below the ecological benchmark of 0.3mg/kg. Nevertheless, the occurrence of these toxic compounds in the environment raises concerns because of their persistence and toxic potentials. Alternative energy sources with less environmental effects should be sought and deployed to access the enormous benefits of a green economy and sustainable healthy ecosystem.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Bentum, J.K., Dodoo, D.K. and Kwakye, P.K. (2012). Accumulation of Metals and Polychlorinated Biphenyls (PCBs) in Soils around Electric Transformers in the Central Region of Ghana. *Advances in Applied Science Research*, 3 (2), pp. 634-643.

Bentum, J.K., Dodoo, D.K., Kwakye, P.K., Essumang, D.K. and Adjei, G.A. (2016). Spatial and Temporal Distribution of Polychlorinated Biphenyl Residues in Tropical Soils. *Open Journal of Applied Sciences*, 6, pp. 234-247.

Bi, X., Chu, S., Meng, Q. and Xu, X. (2002). Movement and retention of polychlorinated biphenyls in a paddy feld of WenTai area in China. *Agriculture, Ecosystems and Environment*, 89, pp. 241–252.

Blais, J.M., Froese, K.L., Kimpe, L.E., Muir, D.C.G., Backus, S., Comba, M. and Schindler, D.N. (2003) Assessment and characterization of polychlorinated biphenyls near a hazardous waste incinerator analysis of vegetation, snow and sediments. *Environmental Toxicology and Chemistry*, 22(1), pp. 126–133.

Breivik, K., Sweetman, A., Pacyna, J.M. and Jones, K.C. (2007). Towards a Global Historical Emission Inventory for Selected PCB Congeners – A Mass Balance Approach: 3. An Update. *Science of the Total Environment*, 377 (2 – 3), pp. 296-307.

Chekol, T., Vough, L.R. and Chaney, R.L. (2004). Phytoremediation of polychlorinated biphenyl-contaminated soils: the rhizosphere effect. *Environment International,* 30, pp. 799–804.

Chen, D. and Hale, R.C. (2010). A global review of polybrominated diphenyl ether flame retardant contamination in birds. *Environment International*, 36, 800e811.

Dalla, V.M., Jurado, E., Dachs, J., Sweetman, A.J. and Jones, K.C. (2004). The maximum reservoir capacity of soils for persistent organic pollutants: implications for global cycling. *Environmental Pollution*, 134, pp. 153–164.

Danielovic, I., Hecl, J. and Danilovic, M. (2014). Soil Contamination by PCBs on a Regional Scale the Case of Strážske, Slovakia. Polish Journal of Environmental Studies, 23(5), pp. 1547-1554.

Danse, I.R., Jaeger, R.J., Kava, R., Kroger, M., London, W.M., Lu, F.C., Maickel, R.P., McKetta, J.J., Newwell, G.W., Shindell, S., Stare, F.J. and Whelan, E.M. (1997). Position paper of the American Council on Science and Health: Public health concerns about environmental polychlorinated biphenyls (PCBs). *Ecotoxicology and Environmental Safety*, 38, pp. 71–84.

Duan, X., Fu, X., Song, J., Li, H., Su, M,, Hu, F., Xu, L. and Jiao, J. (2017). Physiological and molecular responses of the earthworm Eisenia fetida to polychlorinated biphenyl contamination in soil. *Environmental Science and Pollution Research International*, 24(22), pp. 18096-18105.

Ezemonye, L.I.N. (2005). Polychlorinated biphenyls (PCBs) levels and distribution in Ethiope and Benin Rivers of the Niger Delta, Nigeria: surface water and sediments. *International Journal of Environmental Studies*, 62(5), pp. 491-504.

Fagbote, E.O and Olanipekun, E.O (2010). Levels of polycyclic aromatic hydrocarbons and polychlorinated biphenyls in sediment of bitumen deposit impacted area. *International Journal of Environmental Science and Technology*, 7(3), pp. 561-570.

Fayiga, A.O., Ipinmoroti, M.O and Chirenje, T. (2018). Environmental pollution in Africa. *Development and Sustainability*, 20(1), pp. 41-73.

Federal Ministry of Environment (FMEnv.) (2009). National lmplementation Plan for the Stockholm Convention on Persistent Organic Pollutants (POPS). Final Report. National Implementation Plan for Stockholm Convention. p. 282

Fu, C.T. and Wu, S.C. (2006) Seasonal variation of the distribution of PCBs in sediments and biota in a PCB contaminated estuary. *Chemosphere*, 62, pp. 1786-1794.

Gioia, R., Nizzetto, L., Lohmann, R., Dachs, J. and Jones, K.C. (2008) Polychlorinated biphenyls (PCBs) in air and seawater of the Atlantic Ocean: Sources, trends and processes. *Environmental Science and Technology*, 42, pp. 1416–1422.

Gioia, R., Akindele, A.J, Adebusoye, S.A., Tanabe, S., Buekens, A and Sasco, A.J. (2014). Polychlorinated biphenyls (PCBs) in Africa: a review of environmental levels. *Environmental Science and Pollution Research*, 21(10), pp. 6278-89

Hansen, L.G. and O'Keefe, P.W. (1996). Polychlorinated dibenzofurans and dibenzo-p-dioxins in subsurface soil, superficial dust, and air extracts from a contaminated landfill. Archives of Environmental Contamination and Toxicology, 31, pp. 271-276.

Hens, B. and Hens, L. (2017). Persistent Threats by Persistent Pollutants: Chemical Nature, Concerns and Future Policy Regarding PCBs—What Are We Heading For. *Toxics* 6, pp. 1-12.

Holt, E., Kocan, A., Klanova, J., Assefa, A. and Wiberg, K. (2016). Spatiotemporal patterns and potential sources of polychlorinated biphenyl (PCB) contamination in Scots pine (Pinus sylvestris) needles from Europe. *Environmental Science and Pollution Research* 23, pp. 19602–19612.

Hutzinger, O., Safe, S. and Zitko, V. (1974). *The Chemistry of PCBs*. CRC Press: Cleveland, OH, Chemical Rubber Co; pp. 1-269.

Kammenga, J.E., Dallinger, R., Donker, M.H., Köhler, H.R., Simonsen, V., Triebskorn, R. and Weeks, J.M. (2000). Biomarkers in terrestrial invertebrates for ecotoxicological soil risk assessment. *Reviews of Environmental Contamination and Toxicology*, 164, pp. 93–147.

Kim, L., Jeon, J., Son, J., Park, M., Kim, C. and Jeon, H. (2017). Monitoring and risk assessment of polychlorinated biphenyls (PCBs) in agricultural soil from two industrialized areas. *Environmental and Geochemical Health*, 39(2), pp. 279-291.

Khomich, V., Kukharchyk, T. and Kakareka, S. (2008). Urban Soils Pollution in Belarus: Priority Pollutants and Levels. *Soil Chemical Pollution, Risk Assessment, Remediation and Security*. pp. 209-215.

Klanova, J., Cupr, P., Holoubek, J., Boruvkova, J., Pribylova, P., Kares, R., Tomsej, T. and Ocelka, T.J. (2009). Monitoring persistent organic pollutants in Africa. Part 1: Passive air sampling across the continent in 2008. *Environmental Monitoring*, 11, pp. 1952–1963.

Loganathan, B.G., Kannan, K., Watanabe, I., Kawano, M., Irvine, K., Kumar, S. and Sikka, H.C. (1995). Isomer-specific determination and toxic evaluation of polychlorinated biphenyls (PCBs), polychlorinated/brominated dibenzo-pdioxins (PCDDs/PBDDs), dibenzofurans (PCDFs/PBDFs), polybrominated diphenyl ethers (PBDEs) and extractable organohalogens (EOX) in carp from the Buffalo River, New York. *Environmental Science Technology,* 29, pp. 1832–1838.

Mac Donald, R.W., Barrie, L.A, Bidleman, T.F, Diamond, M.L., Gregor, D.J., Semkin, R.G., Strachan, W.M.J., Li Y.F., Wania, F., Alaee, M., Alexeeva, L.B., Backus, S.M., Bailey, R., Bewers, J.M., Gobeil, C., Halsall, C.J, Harner, T., Hoff, J.T., Jantunen, L.M.M., Lockhart, W.L., Mackay, D., Muir, D.C.G., Pudykiewic, J., Reimer, K.J., Smith, J.N., Stern, G.A., Schroeder, W.H., Wagemann, R. and Yunker, M.B. (2000). Contaminants in the Canadian Arctic: 5 years of progress in understanding sources, occurrence and pathways. *The Science of the Total Environment* 2-3, pp. 93-234.

Mamontova, E., Mamontov, A., Tarasova, E., Kuzmin, M., Ganchimeg, D., Khomutova, M., Gombosuren, O. and Ganjuurav, E. (2013). Polychlorinated biphenyls in surface soil in urban and background areas of Mongolia. *Environmental Pollution*, 182C, pp. 424-429.

Nature Watch (2003). Earthworms Identification, http//www.naturewatch.ca/English/wormwatch/index.htmls

Nizzetto, L., Lohmann, R., Gioia, R., Jahnke, A., Temme, C., Di Guardo, A. and Jones, K.C. (2008) PAHs in air and seawater along a North- South Atlantic transect: Trends and controlling processes. *Environmental Science and Technology*, 42, pp. 1580–1585.

Okoh, M.P. (2015) Exposure to Organo-Chlorinated Compound, Polychlorinated Biphenyl (PCB), environmental and public health Implications: A Nigeria Case study. IJCS, 2(6), pp. 14-21.

Ontario Ministry of Environment and Energy (OMEE). (1994). Ontario typical range of chemical parameters in soil, vegetation, moss bags and snow. Version 1.0a. PIBS 2792. Standards Development Branch, Phytotoxicology Section, Toronto.

Owa, S.O., Olowoparija, S.B., Aladesida, A. and Dedeke, G.A. (2013). Enteric bacteria and fungi of the Eudrilid earthworm *Libyodrilus violaceus*. *African Journal of Agricultural Research*, 8 (17), 1760-1766.

Rodriguez, J., Venables, B.J., Fitzpatrick, L.C., Goven, A.J. and Cooper, E.L. (1989). Suppression of secretory rosette formation by PCBs in Lumbricus terrestris: an earthworm immunoassay for humoral immunotoxicity of xenobiotics. *Environmental Toxicology and Chemistry*, 8, pp. 1201-7.

Sandu, M.A., Bica, I., Virsta, A., Preda, M. and Stan, V.S. (2013). Persistent Organic Contaminants in the urban and peri-urban area of Ploiesti city. *Agro Life Scientific Journal*, 1(1), pp. 143-150.

Sims, R.W. and Gerrard, B.M. (1985) Earthworms. Synopsis Bristish Fauna (New Series), AJ Brill and Dr W. Backhuys, London. 31, pp. 1-171.

Spongberg, A.L. (2006). PCB concentrations in intertidal sipunculan (Phylum Sipuncula) marine worms from the Pacific coast of Costa Rica. Rev. Biol. Trop., 54(1), pp. 27-33.

Stojić, N., Pucarević, M., Mrkajić, D. and Kecojević, I. (2014). Transformers as a potential for soil contamination. *Metalurgija*, 53 (4), pp. 689-692.

Taru, L., Anu, M., Bergur, S., Kristin, O., Kristin, V.R. and Rannveig, G. (2014) Bioremediation trial on aged PCB-polluted soils—a bench study in Iceland. *Environmental Science and Pollution Research*, 21(3), pp. 1759–1768.

Tillmann, S., Strompl, C., Timmis, K.N. and Abraham, W.R. (2005). Stable isotope probing reveals the dominant role of *Burkholderia* species in aerobic degradation of PCBs. *FEMS Microbial Ecology*, 52, pp. 207–217.

Tu, C., Teng, Y., Luo, Y., Li, X., Su, X., Li, Z., Liu, W. and Cristie, P. (2011). Potential for biodegradation of polychlorinated biphenyls (PCBs) by Sinorhizobium meliloti. *Journal of Hazardous Materials*, 186(2-3), pp. 1438-44.

USEPA (2011). PCB TMDL Handbook. Office of Wetlands, Oceans and Watersheds. EPA 841-R-11-006.

Van den Berg, M., Birnbaum L.S., Denison, M., De Vito, M., Farland W and Feeley M. (2006). The 2005 World Health Organization reevaluation of human and Mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological Sciences,* 93(2), pp. 223–41.

Vasilyeva, G.K. and Strijakova, E.R. (2007) Bioremediation of Soils and Sediments Contaminated by Polychlorinated Biphenyls. *Microbiology*, 76, pp. 639-653.

Voorspoels, S., Covaci, A., Maervoet, J., De Meester, I. and Schepens, P. (2004). Levels and profiles of PCBs and OCPs in marine benthic species from the Belgian North Sea and the Western Scheldt Estuary. *Marine Pollution Bulletin*, 49, pp. 393–404.

Yajun, T., Zhiqiang, N., Jie, H., Qingqi, D., Yanyan, F., Feng, L., Yufei, Y., Xingbao, G. and Qifei, H. (2016). Seasonal variations in concentrations, distributions, and air–soil exchange fluxes of dioxin-like polychlorinated biphenyls in Shanghai, China. *Environmental Science and Pollution Research*, 23, pp. 3376–3384.

Zaborski, A., Carroll, J., Pazdro, K. and Pemkowiak, J. (2011) Spatio-temporal patterns of PAHs and PCBs and HCBs in sediments of the Western Barents Sea. *Oceanologia*, 53(4), pp. 1005 – 1026.

Zani, C., Toninelli, G., Filisetti, B. and Donato, F. (2013) Polychlorinated Biphenyls and Cancer: An Epidemiological Assessment. *Journal of Environmental Science and Health, Part C. Environmental Carcinogenesis and Ecotoxicology Reviews*, 31(2), pp. 99-144.