

Spatial and Temporal Distribution of Polychlorinated Biphenyl Residues in Tropical Soils

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Abstract

Polychlorinated biphenyls (PCBs) in tropical soil samples from the Central Region of Ghana, and their variation with the soil characteristics were assessed. The soil characteristics of seventy eight samples were first determined. The PCBs was extracted with (1:1) hexane:acetone mixture, and then the extract treated with concentrated H₂SO₄, 5% KMnO₄ and copper. The extract was finally eluted from a silica gel column with hexane:dichloromethane (97:3 v/v), and the PCBs analyzed using a gas chromatograph equipped with ⁶³Ni electron capture detector (GC-ECD model CP 3800). The composition of PCBs homologous in the soils followed the order: hexa-PCBs (31.89%) > penta-PCBs (23.98%) > tri-PCBs (18.47%) > tetra-PCBs (13.67%) > hepta-PCBs (11.99%). The PCB congener profile in the study area was PCB 28 > PCB 153 > PCB 138 > PCB 52 > PCB 101 > PCB 180 > PCB 118. The mean concentration of the PCB congeners (dry matter basis) was PCB 28, 2.27 ± 2.436; PCB 52, 1.84 ± 2.27; PCB 101, 2.17 ± 2.52 µg/kg; PCB 118, 0.83 ± 0.89 µg/kg; PCB 138, 0.99 + 0.91 µg/kg; PCB 153, 1.18 ± 1.11 µg/kg and PCB 180, 1.18 ± 1.19 µg/kg. The mean concentrations of ΣPCBs were 9.15 ± 0.52 µg/kg for the surface soils (0 - 10 cm), 7.55 ± 0.56 µg/kg and 7.82 ± 0.55 µg/kg for the 10 - 20 cm and 20 - 30 cm sub-surface soils respectively. Significant but weak correlations were observed between PCBs and the soil pH, moisture, and exchangeable base. The coefficient of determination for all significant correlations was between 6.6% and 18.75%.

Keywords

Polychlorinated Biphenyls, Soil Properties, Principal Component Analysis, Contamination

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1. Introduction

Polychlorinated biphenyls (PCBs) are among the widespread pollutants in the global ecosystem and have been identified in the air, water, soils and sediments, fish, wildlife, plants, domestic animals, and human adipose tissue, blood and milk [1]-[6]. PCBs are naturally persistent, toxic and bioaccumulative in living organisms [7]-[9]. A large proportion of PCBs remains in transformers and capacitors in most developing countries [10] [11]. Sediments from the tropics have been found to contain relatively low concentrations of total PCBs.

The most polluted tropical site in the tropics has been found in India, which had sediment concentrations up to 2330 $\mu\text{g/g}$ dw attributed to industrialization and pollution. Sediments from pristine areas were unquantifiable at levels below the detection limits [12]. It has been reported that surface sediments were from the highly developed areas of West Bengal, India, and found that the total PCB concentrations from ten sites averaged 750 ng/g dw, with a maximum detection of 2330 ng/g dw, and the PCBs were dominated by congeners with four to six chlorines [13]. Large variation in total PCBs from sediments around Singapore, ranging from 1.4 to 329.6 ng/g dw (average = 73.9 ng/g dw) has been found [14]. Other literature reports indicate that in 2005, information on polychlorinated biphenyls (PCBs) in environmental media in Africa was limited [15]. High concentrations of PCBs have been found in some countries in West Africa, such as the Gambia and Ivory Coast and Ghana, and all along this coast. They also gathered samples from land-based stations (Gambia, Sierra Leone, Ivory Coast and Ghana), and used particle dispersion models to seek the possible sources of the contamination [16]. Illegal dumping of waste containing these compounds—old electrical waste such as capacitors and other PCB-containing products was the likely sources of the pollution.

Developing countries take large amounts of waste from Western nations and break them down or dispose of them, often with little regard for safety or pollution. High levels of PCBs are released through volatilization, as well as the storage and scrapping of old ships. Another probable source of the PCBs is one of the world's largest ships' graveyards, just in the south of Nouadhibou in Mauritania, off the West African coast, where hundreds of wrecks have been grounded in shallow water. This break-up probably releases PCBs [16]. Polychlorinated biphenyl (PCB) concentrations in air and soil have been measured by various research groups from around the world. The average soil concentrations (pg/g dry weight) for Sigma PCB at background sites were 7500 (47 - 97,000) for Europe, 4300 (110 - 25,000) for North America, 1400 (61 - 9500) for South America, 580 (120 - 2900) for Asia, 390 (94 - 620) for Africa, and 280 (140 - 540) for Australia [17]. In Ghana, PCB concentrations ranged between 0.357 and 20.721 mg/kg have been found in soils in the Electricity Company of Ghana compound in Accra.

Investigation of the soil profile of this site revealed very high levels of PCBs, between 82.3 mg/kg and 129.96 mg/kg. Analysis of underground water indicated that the levels of PCBs in the water were 0.059 mg/L and 0.071 mg/L, which were higher than the recommended level of 0.0094 mg/L [18]. PCBs have been detected in human breast milk and some environment samples in Ghana [19] [20]. Even though importation of PCB-containing transformers and capacitors for use in Ghana ceased in 1972, it has been established that 455 pre-1972 possible PCB-containing transformers could be found countrywide.

Multivariate analysis has been used to assess the source of the PCBs and heavy metals in the soils from the study sites in the central region of Ghana [21]. This paper is aimed at assessing the temporal and spatial distribution of PCBs in the tropical soils from the central region of Ghana, and the variation of the extracted PCB residues with the soil properties.

2. Experimental

2.1. Study Area

The study areas (**Figure 1**) [21], is along the coast of the Central region in the southern part of Ghana. Four of the study areas, districts/metropolis, Efutu-Awutu-Senya and Appam, Mfantiman, Cape Coast and Komenda-Edna-Eguaful-Abrim are bounded on the south by the gulf of guinea. The fifth study area, Agona district, is bounded on the south by Efutu-Awutu-Senya district. The areas are predominantly urban and coastal in nature with a varied, high density housing stock, but also substantial areas of open space and with very few manufacturing industry.

2.2. Sampling

Seventy eight composite soil samples were collected from the immediate surroundings of Electricity Corporation

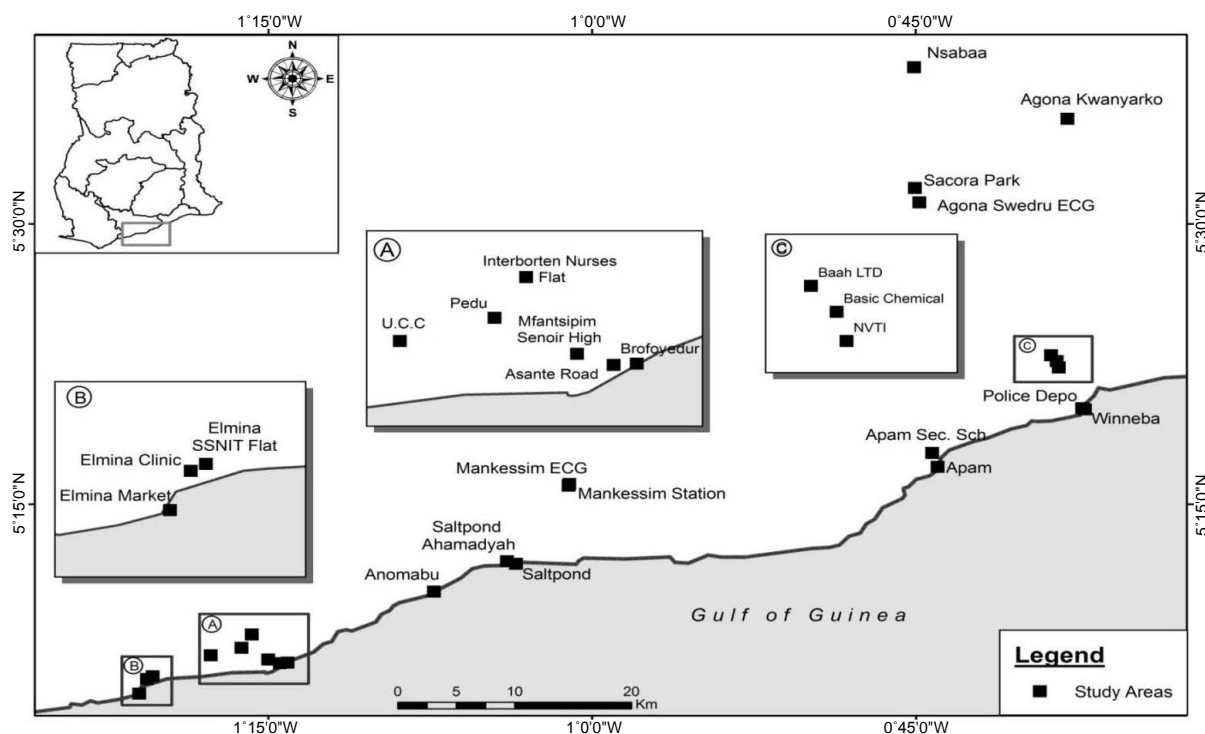


Figure 1. Map showing sampling sites in the central region [21].

Ghana (ECG) transformers at selected sites in the Central Region of Ghana at depth of 0 - 10 cm, 10 - 20 cm and 20 - 30 cm. The samples were placed in labeled polythene bags and sent to the laboratory. They were air dried, and each sample was sieved using 250 μm mesh sieve.

2.3. Measurements of Soil Properties

Standard procedure was used for the soils analysis. The following properties moisture, pH, exchangeable acidity, exchangeable base and Effective Cation Exchange Capacity (ECEC), sand, silt, clay, moisture content and Soil Organic Matter [22]-[25].

2.4. Analysis of PCBs

For the PCBs analysis, a modified analytical procedures reported by Bentum in 2012 [26] were employed. Ten grams of air-dried soil was extracted with 100 ml of hexane-acetone mixture (1:1 v/v) for 16 hours using an automated soxhlet apparatus, and then concentrated to 10 ml. Hexane was added and concentrated to remove the acetone, after which it was dried with sodium sulphate and concentrated. 10 ml of concentrated extract was transferred, with three 5 ml hexane rinse of the flask into a separatory funnel for clean up. 10 ml of the extract was cleaned up with sulphuric acid (1 + 1), followed by clean up with 5 ml 5% (w/v) KMnO_4 in order to decompose other organic compounds in the extract since PCBs are not affected by strong acids and oxidizing agents. Clean up with copper granules was to precipitate sulphur in the extract that might interfere with the gas chromatographic analysis; and finally with silica gel, and the column eluted with 100 ml of hexane: dichloromethane (97:3 v/v). 1 ml of the clean 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 and analyzed for PCBs using a gas chromatograph equipped with ^{63}Ni electron capture detector GC-ECD model CP 3800.

The capillary column used was VF 5 ms 30 m \times 0.25 mm id \times 0.25 μm film thickness. The GC conditions were as follows: injection point temperature: 270°C; oven temperature programme: 70°C (hold 2 min) to 180°C at a rate of 25°C/min (hold 1 min) to 300°C at a rate of 5°C/min. Temperature of detector was 300°C; carrier gas-nitrogen at flow rate: 1.0 ml/min; make-up gas flow rate: 29.0 ml/min. The total runtime was 31.368 min. The PCB congeners were identified qualitatively using their retention times, and their concentrations calculated

on dry weight basis.

2.5. Performance Validation and Reproducibility

Two recovery study procedures were conducted for the performance validation (to assess the ability to achieved acceptable recovery) as well as the reproducibility of GC/ECD analysis. The first recovery study involved random spiking of duplicate soil samples with 0.02 ppm PCB mix standards, containing PCB# 28, 52, 101, 118, 138, 153 and 180, before extraction. The recovery of 0.2 ppm mix standards from the spiked duplicate soil samples was 89%. The second recovery study involved the use of PCBs certified reference materials from the National Institute of Standards and Technology (NIST, USA). These samples were extracted and cleaned as described for the samples; the extracted samples were analyzed and the recoveries calculated. The percentage recovery of PCBs from the referenced standard reference material was 79%. All the recoveries were within the acceptable criteria ($100\% \pm 25\%$).

For the reproducibility, repeat analysis, of 0.02 ppm PCB mix standards containing PCB# 28, 52, 101, 118, 138, 153 and 180 was used and the Relative Percent Difference (%RPD) between duplicates calculated based on the peak areas (concentrations) of congeners with identical retention times. The %RPD was within the acceptable range of $\pm 15\%$.

2.6. Statistical Analysis

In order to explain the data generated, which are difficult to analyze and interpret because the complex relationships among the variables, the Kolmogorov-Smirnov test and Shapiro-Wilk test of normality, Pearson's regression and correlation, Multivariate analysis, Post Hoc test, principal component analysis (PCA) and cluster analysis (CA) were used to support the interpretation of complex data and extract meaningful information from the data [27]-[30]. Microsoft Excel 2010 and SPSS (version 16) were used for the calculations and statistical analysis.

2.7. Multivariate Analysis

Multivariate analysis, principal component analysis (PCA) and cluster analysis (CA) and correlation matrix were used in the study to provide a better insight and understanding of the dynamics of the PCBs in the top surface and subsurface soils, and source of variation in the data. PCA was applied on the logarithmic form of investigated PCB congeners data and Varimax with Kaiser Normalization rotation method used to maximize the sum of the variance of the factor coefficient, highly correlated variables or factors (with sum of squared loadings >0.3) were grouped into one component. The number of components indicated the total number of possible sources of variation in the data. For the cluster analysis hierarchical agglomerative clustering by the Ward's method was selected for sample classification because it possesses a small space distorting effect, uses more information on cluster contents than other methods, and has been proved to be an extremely powerful grouping mechanism [31]. The method was applied to normalized data using squared Euclidean distances as a measure of similarity [32].

3. Result and Discussion

3.1. Results of Precision and Reproducibility of Analysis

The recovery of 0.2 ppm mix standards from the spiked duplicate soil samples indicated 89% recovery, which was within the $100\% \pm 25\%$ acceptable criteria. The precision of the analysis calculated as the relative percent difference (%RPD) was 8% and was within the acceptable range of $\pm 15\%$. The mean percentage recovery of PCB# from the referenced standard reference material was 79%.

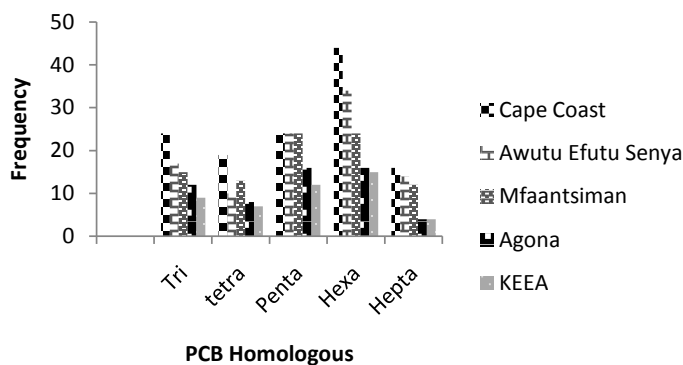
3.2. PCB Homologous

The results of the analyses of soil PCBs from the Central Region are shown in **Table 1**. All the seven PCB congeners analyzed were detected in soils from all the study areas. **Figure 2** shows the types and numbers of polychlorinated homologous detected in the samples from the various study areas. Generally, all these PCB homologous were found to be dominant in the Cape Coast Metropolis and least in the KEEA district. All the sites had

Table 1. Mean of soil characteristics and polychlorinated biphenyls in soils from the central region of Ghana.

	PCB Congener ($\mu\text{g}/\text{kg}$)							ΣPCB
	28	52	101	118	138	153	180	
Mean	2.26	1.84	2.17	0.83	0.95	1.14	1.23	7.99
Stdev	1.83	2.45	1.69	0.63	0.67	0.69	0.81	3.04
CV	81	133	83	79	71	63	65	38
Max	6.56	3.82	6.52	2.5	2.86	2.76	3.75	12.94
Min	0.33	nd	nd	nd	0.14	nd	nd	1.32

nd: not detected.

**Figure 2.** PCB homologous detected in soils from the study areas.

similar PCB composition.

The composition of PCB homologous in the soils was dominated by hexa-PCBs. The percentage composition of the homologous followed the order hexa-PCBs (31.89%) > penta-PCBs (23.98%) > tri-PCBs (18.47%) > tetra-PCBs (13.67%) > hepta-PCBs (11.99%), followed by the penta-PCBs. Tetra-, penta-, and hexa-chlorinated biphenyls have been found as dominant species in some agricultural soils from Southern Jiangsu, China [33]. All the sites had similar PCB composition. This suggest the soils were probably contaminated from similar sources, most likely from transformer oils containing PCB Aroclor such as 1016, 1242, 1254 and 1260 [34].

3.3. PCB Levels, Distribution and Congener Profile

The concentration of the sum of the seven key PCBs (IUPAC No. PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153 and PCB 180) for 78 samples of soils from 26 sites are also shown (Figure 3). The concentration (mean \pm CV) of PCBs in soils was $7.99 \pm 38 \mu\text{g}/\text{kg}$ and ranged from 1.32 - 12.94 $\mu\text{g}/\text{kg}$. The highest concentrations of PCBs were found at two sites, Winneba (WPD) 12.72 $\mu\text{g}/\text{kg}$ and Saltpond (SAH), 12.94 $\mu\text{g}/\text{kg}$ and the least found in soils from Agona Nsaba (ANP) at the Agona district. The soils from SAH are sandy loams with higher organic carbon 0.39% and the other WPD is sandy soils, with lower organic carbon content 0.15%. The observation is similar to those found in soils in the west coast of southern Sweden [35], where the highest concentrations were found at two sites with sandy soils, one with extremely high organic carbon.

Relatively high levels of PCBs were found in soil samples from the University of Cape Coast, Salt Pond and Winneba (WPD); and very low levels found in samples from Salt POUND ECG and Agona Nsaba. PCB concentrations in the soils showed a large variation between sampling-areas.

The highest concentrations were found at three sites; Winneba Police Depo (WPD), Apam Manfam (AM) and the University of Cape Coast (AU) with sandy soils, and one, WPD. Differences in PCB profiles were observed among districts, probably due to the combined number of transformers at the selected areas, effects of environmental conditions, and magnitude and age of the contamination, which determines the time available for volatilization and degradation, and differences in rainfall, which influence volatilization and deposition.

The spatial patterns of PCBs in the Central Region indicate that PCB concentrations ($\geq 4.62 \mu\text{g}/\text{kg}$) cover almost the entire costal area of the region. The mean ΣPCB for the Agona district was $4.62 \pm 0.06 \mu\text{g}/\text{kg}$, lower than the overall regional average of $7.99 \pm 38 \mu\text{g}/\text{kg}$ (Figure 3). The mean ΣPCB for the other areas were higher than the

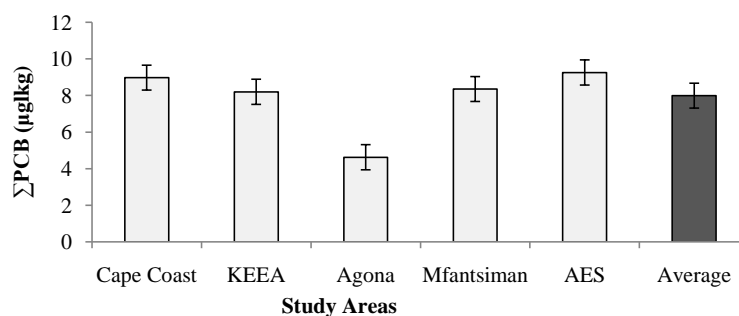


Figure 3. Mean concentrations of PCBs at the study areas.

regional average, and follow the order: Agona ($4.62 \pm 0.06 \mu\text{g/kg}$) < KEEA ($8.20 \pm 0.04 \mu\text{g/kg}$) < Cape Coast ($8.24 \pm 0.06 \mu\text{g/kg}$) < Awutu-Efutu Senya (AES) ($9.28 \pm 0.53 \mu\text{g/kg}$) < Mfantisman (ASM) ($9.56 \pm 0.38 \mu\text{g/kg}$). The means and ranges of the congener concentration and ΣPCB for 0 - 30 cm samples from the selected districts and metropolis (Table 2).

The concentration (mean \pm CV) of PCB congeners found in the soils, 0 - 30 cm, from all the five selected areas in the Central region (Table 2) were as follows: PCB-28, $2.26 \pm 81 \mu\text{g/g}$; PCB-52, $1.84 \pm 133 \mu\text{g/kg}$; PCB-101, $2.17 \pm 83 \mu\text{g/kg}$; PCB-118, $0.83 \pm 79 \mu\text{g/kg}$; PCB-138, $0.95 \pm 71 \mu\text{g/kg}$; PCB-153 $1.14 \pm 63 \mu\text{g/kg}$ and PCB-180 $1.23 \pm 65 \mu\text{g/kg}$. There were variation in the levels of the congeners, PCB-52 showed the greatest variation of 123% and PCB-153 the least 63%. The variation, as revealed by the percent relative standard deviation, increase in the order PCB-153 < PCB-180 < PCB-138, PCB-118 < PCB-28 < PCB-101 < PCB-52. Figure 4 shows the distribution profile of the PCB congeners in soils from the study areas.

The highest concentrations of PCB 28, 153 and 180 were found in the Awutu-Eufutu-Senya district (AES) (Figure 4); PCB 101, 118 and 138 were found highest at Elmina in the Komenda-Edna-Eguaful-Abrem district (KEEA); and PCB 52 found highest at Anomabo (ANO), Salt-Pond, Mankesim area in the Mfants man district (ASM).

The presence of PCBs in the soils is not strange as observed much higher concentrations of PCBs in soil at different sites in an assessment of Persistence Organic Pollutants (POPs) contamination sites in the transformer servicing center of the Electricity Company of Ghana in Accra [36]. The levels of PCBs (ΣPCB) in the study areas were about one-thousandth of the levels found in soils in the transformer servicing center of the Electricity Company of Ghana in Accra, which were between 0.357 mg/kg and 20.721 mg/kg. The levels of PCBs contamination in the soils studied were much lower than the recommended limits of 25 mg/kg and 33 mg/kg set by the Canadian Soil guide [37], and the US EPA [38], respectively. The levels were comparable to levels detected in soils in Linfen city, China [39], lower than those found in soils elsewhere in Bahrain [40], Moscow region [41], Switzerland [42], Belarus [43], New York [44], Shanghai [45], but higher than those found in Poland [46].

3.4. Vertical Distribution of PCBs in the Soils

The box-and-whisker plots of total PCBs (ΣPCB) in the top and sub-surface soils from all sampling sites (Figure 5) were examined. The mean levels of ΣPCBs (based on dry weight) was $9.15 \pm 0.53 \mu\text{g/kg}$ for the top surface soils and $7.55 \pm 0.56 \mu\text{g/kg}$ and $7.82 \pm 0.55 \mu\text{g/kg}$ for the 10 - 20 cm and 20 - 30 cm subsurface soils respectively. The box plots for the PCBs relates to the levels of PCB contamination of the soils. In general the surface soils, 0 - 10 cm, had the highest levels of PCBs (ΣPCB), suggesting that the topmost soils are the most contaminated, and the 10 - 20 cm subsurface soils the least. Figure 6 show the levels and the distributions of PCBs in the different depth of the soils at the sampling sites.

3.5. Relationship between soil PCB Concentration and Soils Parameters

Regression analysis among the seven congeners revealed that only PCB 138 and 153 correlated significantly at the 5% level of significance. However, the correlation was weak ($r = 0.30$, $p = 0.5$). Regression analyses revealed some significant relationships between the soil characteristics and the PCB content of the soils. The coefficient of determination, which is an expressed variation in the PCB levels due to variation in the soil characteristics was determined by squaring the correlation coefficient, and multiplying by 100. It gave an indication

Table 2. Means concentration PCB congeners and Σ PCB for 0 - 30 cm soil samples.

Sampling Area	(n)	Mean PCB Congeners ($\mu\text{g}/\text{kg}$)							Σ PCB ($\mu\text{g}/\text{kg}$)	
		28	52	101	118	138	153	180	Mean	range
Cape Coast	24	2.16	1.79	2.53	0.83	1.12	1.22	1.27	8.24 ± 0.01	3.58 - 12.21
KEEA	9	1.99	1.22	2.68	1.62	1.49	0.64	0.56	8.20 ± 0.04	6.81 - 9.50
AES	18	3.05	1.67	2.49	0.8	0.94	1.45	1.57	9.28 ± 0.53	4.46 - 12.72
ASM	15	2.68	2.48	1.65	0.64	0.86	1.35	1.47	9.56 ± 0.38	3.22 - 12.94
Agona	12	1.06	1.72	1.56	0.664	0.411	0.50	0.72	4.62 ± 0.06	1.32 - 6.97

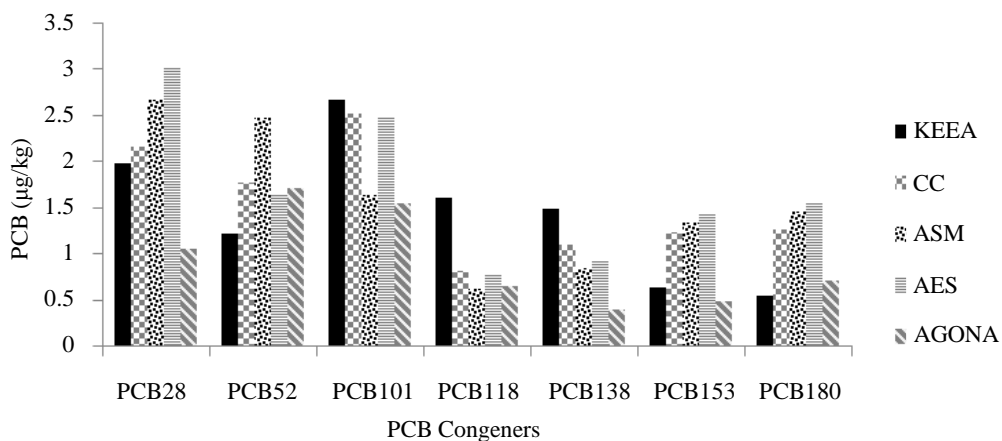


Figure 4. Mean concentration of PCB congeners in soils from the study sites.

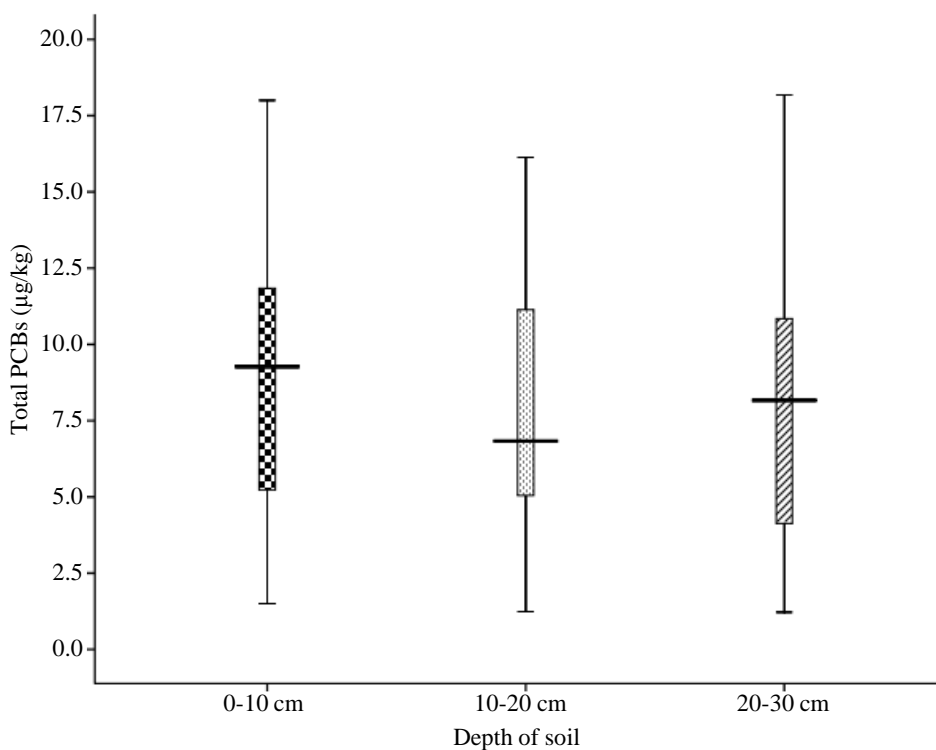


Figure 5. Box-and-whisker plots of Σ PCB in top surface and subsurface soils.

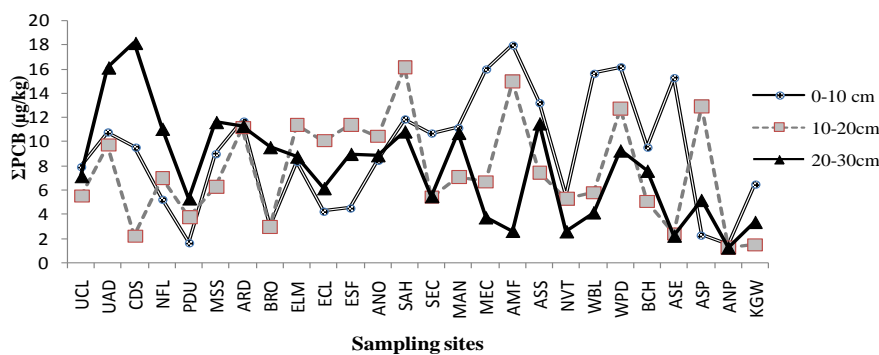


Figure 6. Profiles of PCBs at different depth of topsoils.

of the contribution of the characteristics to the varied levels of PCB residue. The characteristics of the soils (**Table 3**) indicate pH range of 6.07 - 7.4. The soils were characterized by relatively low organic carbon (organic matter) low moisture, low effective cation exchange capacity (ECEC) and high sand content. The moisture contents showed the greatest variation, 78% and pH the least, 7%.

The pH of the surface soils correlated positively with PCBs content in the 10 - 20 cm sub-surface soils with $r = 0.535$ ($p < 0.01$), but the correlations between pH and PCBs content in the 0 - 10 cm and 20 - 30 cm sub-surface soils were not significant. The PCB# 138 and 180 correlated positively with pH at the 0.01 confidence levels; and the respective coefficients values of were 0.257 and 0.346. Even though pH does not have direct effect on the degradation of PCBs, the coefficient of determination or explained variation as a percentage of total variation in the levels of PCB# 138 and 180 in the soils that are accounted for by the variations in the soil pH, were respectively 6.6% and 12.47%.

With moisture content, a significant negative correlation was observed between the moisture and PCBs in the 20 - 30 cm sub-surface soils at 0.05 level, $r = -0.414$. The coefficient of determination is 17.14%. The soil organic carbon (organic matter) content showed only a weak correlation with the PCBs. However, the correlation was not significant.

Weak and insignificant correlation was between organic carbon and the PCBs. Similar observation has been reported [47]. The weak and statistically insignificant correlation observed between the PCBs and the soil organic carbon (organic matter) at the study sites might be due to decreased in sorption strength of the PCBs onto the soil organic matter with increasing residence time of the compound in soil, and the higher temperature of the prevailing tropical environment compared to the temperate region, resulting in desorption of the PCBs. The desorbed PCBs might have been co-evaporated with water, or volatilized from the soils. Sorption of organic compounds such as mono-ortho-polychlorinated biphenyls (PCBs) in soils and sediment in the temperate regions has been reported to be higher than could be anticipated based on the compounds' hydrophobicities [48]-[51]. Other soil properties, besides organic carbon (organic matter) might have been responsible for adsorption [52].

A significant negative correlation was observed between the exchangeable bases and the PCBs in the top surface and 10 - 20 cm sub-surface soils with respective correlation coefficients $r = -0.394$ and ($r = -0.433$, $p < 0.05$). Thus the exchangeable bases accounts for 15.6% and 18.75% of the variations in PCBs in the top surface and 10 - 20 cm sub-surface soils respectively. PCB 101 correlated with exchangeable base ($r = 0.299$, $p < 0.05$); with coefficient of determination of 8.9%. Only, PCB 118, the mono-ortho-polychlorinated biphenyls in the PCB indicator used, correlated significantly with the exchangeable acidity, with $r = 0.367$ ($p < 0.05$). The coefficient of determination was 13.5%.

The positive correlation is an indication that these PCBs were from the similar sources, probably Aroclor 1254 and 1260, which contain PCB 138, 153 and 180 [34] [53]. Even though the three PCB congeners are suspected to be from the similar source, no significant correlation was observed between PCB 180 and any of the other two. This could be due the degradation of PCB 180 (2, 2', 3, 4, 4', 5, 5' heptachlorobiphenyl) via removal of meta-chlorine from single chlorobiphenyl group to give either PCB 138 (2,2',3,4,4',5' hexachlorobiphenyl) or PCB 153 (2,2',4,4',5,5' hexachlorobiphenyl) as has been reported [54].

3.6. Multivariate Analysis and Patterns in Soil PCB Congeners Distribution

Kolmogorov-Smirnov test and Shapiro-Wilk test of normality data at 0.05 significance level showed that the

three sets of PCB data were normally distributed and come from the same population. The F-statistic of the Analysis of variance (ANOVA) results showed that there were significant differences between the three sets (0 - 10, 10 - 20 and 20 - 30 cm) of soil PCB data at 0.05 level ($F = 0.975$, $df = 2$, $p\text{-value} = 0.382$). Multiple comparisons among the three sets (Post Hoc test) performed in order to assess whether the variation as revealed by ANOVA was significantly high, showed that the variation was the highest for the 0 - 10 cm top surface soils with mean Σ PCBs ($9.15 \pm 0.53 \mu\text{g/kg}$).

The results of the principal component analysis are shown in **Tables 4-6**. PCB congeners that showed moderate to high factor loading the values in bold. Three (3) principal components (PCs) with eigenvalues greater than one (1) were extracted. Three components identified for the surface soil (0 - 10 cm); three (3), and four (4) components were extracted for the 10 - 20 and 20 - 30 cm subsurface soils respectively. Thus the initial dimension of the three sets of data are reduced to three (3), three (3) and four (4), which cumulatively accounted for 72.81%, 64.99% and 78.82% of the total variability in the original PCB data of the study area respectively. Among them, three groups A1, A2 and A3 were identified in the top soils (**Table 4**).

Table 3. Mean of soil characteristics and polychlorinated biphenyls in soils from the central region of Ghana.

	Soil Characteristics								
	pH	Moisture %	exA	exB	ECEC	OC %	Sand %	Silt %	Clay %
Mean	7.4	2.06	0.33	1.91	7.5	0.33	68.17	22.82	9.28
Stdev	0.47	1.60	0.12	1.42	3.85	0.15	12.92	10.44	4.86
CV	7.0	78.0	35.0	74.0	51.0	46.0	19.0	46.0	52.0
Max	7.83	7.06	0.65	7.71	19.46	0.77	94	46.28	24
Min	6.07	0.31	0.23	0.78	3.24	0.15	29.72	2.78	3.2

exA: exchangeable acid; exB: exchangeable base.

Table 4. Component matrix showing factor loadings for PCB congeners in 0 - 10 cm top surface soils.

	Component		
	A1	A2	A3
PCB 28	0.726	0.253	-0.461
PCB 52	-0.774	-0.145	-0.443
PCB 101	-0.029	0.759	0.206
PCB 118	-0.401	-0.031	0.68
PCB 138	0.691	0.14	0.341
PCB 153	0.226	-0.696	0.527
PCB 180	-0.283	0.799	0.295

Table 5. Component matrix showing factor loadings for PCB congeners in 10 - 20 cm sub-surface soils.

	Component		
	B1	B2	B3
PCB 28	0.689	0.363	-0.234
PCB 52	0.651	-0.408	0.037
PCB 101	0.239	0.597	0.434
PCB 118	-0.065	-0.711	0.079
PCB 138	0.821	0.023	-0.242
PCB 153	-0.43	0.451	-0.529
PCB 180	0.011	0.163	0.866

Significant correlations with factor loadings >0.3 have been made bold.

Table 6. Component matrix showing Factor loadings for PCB congeners in 20 - 30 cm sub-surface soils.

	Component			
	C1	C2	C3	C4
PCB 28	0.365	0.836	0.209	-0.034
PCB 52	-0.099	0.248	0.905	-0.203
PCB 101	0.445	-0.524	0.137	0.264
PCB 118	0.276	0.294	-0.055	0.828
PCB 138	0.808	0.302	-0.081	-0.173
PCB 153	0.621	-0.179	0.235	-0.485
PCB 180	-0.613	0.428	0.477	-0.142

Significant correlations with factor loadings >0.3 have been made bold.

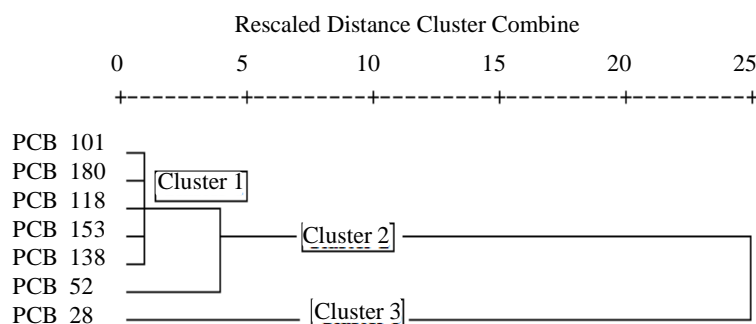


Figure 7. A dendrogram obtained by hierarchical clustering analysis for PCB congeners in surface soils (0 - 10 cm).

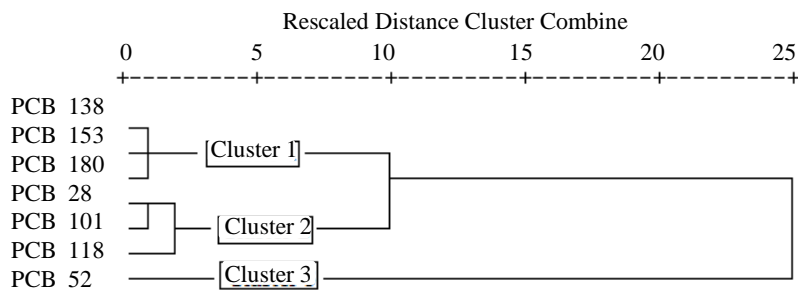


Figure 8. A dendrogram obtained by hierarchical clustering analysis for PCB congeners in sub-surface soils (10 - 20 cm).

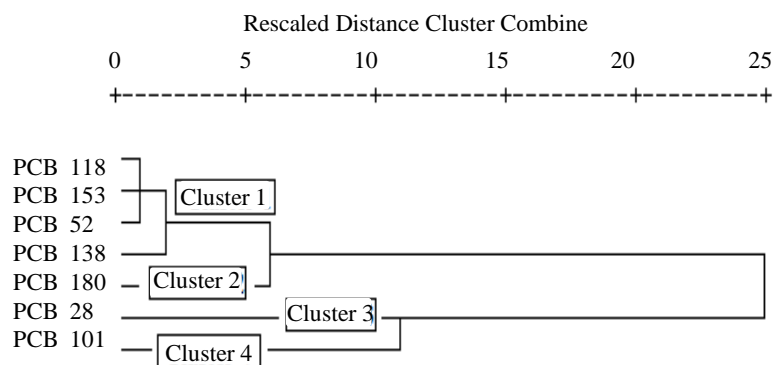


Figure 9. A dendrogram obtained by hierarchical clustering analysis for PCB congeners in sub-surface soils (20 - 30 cm).

The first groups A1 was positively and moderately loaded with PCBs 28, and 138, but negatively loaded with PCB 52 and 118 respectively (A1: accounting for 25.76% of variance); the second group A2 was positively loaded with PCBs 101 and 180, and negatively loaded with 153. A2 accounted for 24.945% variance and the third group A3, positively loaded with PCBs 118, 138, and 153; and negatively loaded with PCB28 and 52 into (A3: 22.11% of variance). This imply in the topmost layer, the first, second and third principal components are strongly correlated with four, three, five of the original variables.

The subsurface soils (10 - 20 cm), showed Three groupings (Table 5), with the first component, B1 positively loaded with PCBs 28, 52 and, 138 and negatively loaded with PCB 153. B1, which account for 24.776% of variance. The second group B2, was positively loaded with PCBs 28, 101 and 153, and negatively loaded with PCB 52 and 118 into the accounting for 20.673% of variance. The third component B3 had positively loading PCBs 101 and 180 and negative loading of 153 in the grouped: accounting for 19.537% of variance. The first, second and third principal components of the 10 - 20 cm layer strongly correlated with four, four, and three of the original variables.

The subsurface soils (20 - 30 cm) had four components (Table 6), (C1: 26.165% of variance) containing PCBs 28,101, moderately and highly loadings for PBC 153 and138 respectively, and negatively and moderately loading for PCB 180. The second component C2 (C2: 20.397% of variance) containing 28, 138 and 180 and negative loadings for PCB 101 (C3: 16.768% variance) and (C4: 15.489% variance) are respectively characterized by PCBs 180 and 52, and PCBs 118 and 153. In the 20 - 30 cm layer, the four principal components significantly correlated with five, three, two and two of the original variables.

The results of PCA analysis suggest that soils with high Factor loadings values would tend to have a lot of the PCB congeners available. Whereas soil with small values would have very few of these congeners. Thus the dominant congeners in the 0 - 10 cm soils was PCB 180 with a factor loading of 0.799. The 10 - 20 cm and 20 - 30 cm soils were dominated respectively by PCB 180 with a factor loading 0.866 and PCB 52 with factor loading 0.905.

Based on the information obtained from the PCA, hierarchical cluster analysis (CA) was performed on the PCB congeners with Ward's method and the squared Euclidean distance as similarity measured (Figures 7-9). Factors having strong correlation form cluster. The same number of groupings, three (3), three (3) and four (4) were obtained for the top surface (0 - 10 cm), 10 - 20 cm, and 20 - 30 cm subsurface soils respectively by the cluster analysis. For the 0 - 10 cm soils cluster 1 included PCB# 101, 118, 138, 153 and 180; cluster 2 contained PCB# 52 and cluster 3 contained PCB 28 (Figure 7). The subsurface soils (10 - 20 cm) is characterized by PCB# 138, 153 and 180 in cluster1; PCB# 28, 101 and 118 in cluser 2 and PCB 52 in cluster 3 (Figure 8). The first cluster of PCBs in the subsurface soils (20 - 30 cm) included PCB# 52, 118, 138 and 153; the second, contained PCB 180; the third and fourth were characterized by PCB# 28 and 101 respectively (Figure 9).

4. Conclusion

The study revealed that among seven indicator PCBs which were found in soils samples from all the study areas, hexa-PCBs was the dominant of the PCB homologous. Generally the top surface soils had the highest concentrations of PCBs. The mean \sum PCB (0 - 30 cm soil) for the Agona district was $4.62 \pm 0.06 \mu\text{g/kg}$, lower than the overall regional average of $7.99 \pm 38 \mu\text{g/kg}$. It followed the order: Agona ($4.62 \pm 0.06 \mu\text{g/kg}$) < KEEA ($8.20 \pm 0.04 \mu\text{g/kg}$) < Cape Coast ($8.24 \pm 0.06 \mu\text{g/kg}$) < Awutu-Efutu Senya ($9.28 \pm 0.53 \mu\text{g/kg}$) < Mfantisman ($9.56 \pm 0.38 \mu\text{g/kg}$). The variations in the concentrations of the congeners increased in the order: PCB-153 < PCB-180 < PCB-138, PCB-118 < PCB-28 < PCB-101 < PCB-52. Significant but weak correlations were observed between PCBs and the soil pH, moisture and exchangeable base. Even though the soils examined were contaminated with PCBs, they were not polluted and can be classified as clean. However, the presences of these toxic compounds in the environment raise concerns because of their toxicity and potential to bio-accumulate.

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