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Distribution and Carcinogenicity of PCBs in Soil Contaminated with Transformer Oil in Selected Locations in Jos, Plateau State Nigeria

E. G. Ibrahim[1*], S. J. Salami[1], J. S. Gushit[2] and M. A. Gube-Ibrahim[3]

[1]Department Chemistry, University of Jos, P.M.B 2084 Jos, Nigeria.
[2]Department of Science Laboratory Technology, University of Jos, P.M.B 2084 Jos, Plateau State, Nigeria.
[3]Department of Chemistry, College of Education P. M. B 05 Akwanga, Nasarawa State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author EGI performed the experiment, wrote the manuscript and collected the samples. Author SJS designed the experiment. Author JSG analysed the data and contributed in provision of mateials and author MAG contributed reagents/analysis tools. All authors read and approved the final manuscript.

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ABSTRACT

Soil from the vicinity of transformers installation in different locations in Jos, Plateau State was investigated for Polychlorinated Biphenyls (PCBs). The assessment was carried out for both total PCBs and congeners using Agilent 6975 GC-MS in ten different locations. The soil samples were extracted with 1:1 hexane- acetone in an ultrasonic bath, concentrated and cleaned with column chromatography using silica gel and hexane as eluting solvent. The result shows five locations were polluted with PCBs that exceed the maximum limit of 2.0mg/kg as permitted by the United States Toxic Substance Control Act (TSCA) with the following values NGS 1 (14.25), NGS 3 (4.47), NGS 6 (9.48), NGS 9 (8.21) and NGS 10 (5.05) while the others have NGS 2 (0.64), NGS 4 (1.85), NGS 5 (0.83), NGS 7 (0.95) in mg/kg respectively, NGS 8 value was below the instrument detection limit (0.0012mg/kg). The order for the total PCBs concentration in these selected locations are NGS 1 > NGS 6 > NGS 9 > NGS 10 > NGS 3 > NGS 4 > NGS 7 > NGS 5 > NGS 2.

**Corresponding author: E-mail: ibrahime@unijos.edu.ng, ezekiel_ibrahim@yahoo.com;*

The carcinogenicity of the dioxin-like PCBs calculated as total toxicity equivalence concentration (TTEC) in these selected locations corresponds to NGS 1 (0.00001), NGS 2 (0.0000051), NGS 3 (0.0000054), NGS 4 (0.0000051), NGS 6 (0.0000063), NGS 7 (0.0000078), NGS 9 (0.0000051) and NGS 10 (0.0000051) respectively. The total cancer risk computed by addition of cancer risk due to ingestion, inhalation and dermal contact revealed that all the locations have very low to low cancer risk compared with the value recommended by the United State.

Keywords: Persistent; congener; assessment; risk and non-dioxin.

1. INTRODUCTION

PCBs are class of industrial chemical that are produced by partial or complete chlorination of biphenyl molecule with general formula of $C_{12}H_{10-n}Cl_n$ where n range from 1 to 10 [1]. They have been recognized among the twelve world most dangerous chemicals known to be detrimental health and the environment [2], there are 209 congeners of PCBs and their degree of chlorination have a significant impact on their exposure, metabolism and toxicity. Particularly PCBs are metabolized via hydroxylation by cytochlorine P450 enzymes. However, chlorine containing congeners (mono and disubstituted) have a higher propensity to be metabolized and excreted while higher chlorine containing congeners are less extensively metabolized and thus are more likely to be sequester and display toxicity [3].

PCBs are reported to caused wide range of illness which include skin acne and rashes, depression, irritation of the nose and lungs to more condition like gastrointestinal discomfort, changes in blood and liver and eventually long term exposure result to cancer [4]. Their exposure in humans is either occupational or accidental, however, the most relevant route of PCBs exposure today is through ingestion of PCBs contaminated food and water.

Chronic exposure to low concentration of PCBs results in inflammation and toxicity and this can progress to obesity, cardiovascular diseases, various cancer such as liver, stomach, intestinal and thyroid cancers, lymphoma and diabetes while acute toxicity has also been linked to skin lesions and immunocompromised which lead to immunosuppression.

PCBs application which includes their use as additives in plants, and as coolants and insulating liquid in power capacitors and transformer [5]. PCBs have also been used as pesticides extruders, hydraulic fluids, flame retardant, cutting oil in carbonless copy papers as stabilizing additives in PVC coating, adhesives, sealants, wood flour, finishes and casting agent [6].

PCBs properties such as high chemical and thermal stability, electrical resistance, low or no flammability, high permittivity make them to be persistence in the environment and to exhibit tendencies for bioaccumulation and biomagnification and long range transport and deposition in places far from emission sources [7].

PCBs are not produced in Nigeria but their presence has been reported in Nigeria soil [8], in street dust and sediment [2] and soil from transformer installation sites [7,9], this was due to contamination from transformer installation oil from power companies, application of pesticides for agricultural purposes and other industrial applications.

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

Soil samples were collected from different areas within Jos Metropolis. The soil samples were collected by scooping the soil at the topsoil depth between 10 – 15 cm using spade in each transformer site into an aluminum foil, sealed, labelled and placed in an Ice Chest cooler and transported to the laboratory where they were prepared and preserved appropriately before extracted.

10 g of the wet soil sample from the chest cooler was weighed into a 250 cm^3 conical flask and 10 g of anhydrous sodium sulphate was added and mixed thoroughly, this was transferred into 250 cm^3 beaker and added 40cm^3 of hexane: acetone (1:1) and placed on the Ultrasonic bath and sonicated for 20minutes, the mixture was allowed to settle and decanted the solvent layer, this was then concentrated to 2cm^3 using rotary evaporator and the extract was cleaned up by column chromatography using silica gel (150mm)

and hexane as eluting solvent [10] and the final extract was analyzed using Agilent 6975 GC-MS.

3. RESULTS AND DISCUSSION

The results of the GC-MS analysis of PCBs in soil samples from various locations within the transformer installation sites in Jos, Plateau State, Nigeria, the WHO toxicity equivalence factor (TET), the toxicity equivalence values for dioxin-like PCBs and carcinogenic potential due to dioxin-like PCBs inhalation, ingestion and dermal contact from these locations are shown in Table 1, 2, 3 and 4.

The carcinogenicity associated with the PCBs exposure were based on the deterministic approach from USEPAs assessment guidance [11]. The potential exposure to PCBs in topsoil of residential area was calculated by exposure route through ingestion, inhalation of particulate and dermal absorption as described in the USEPA screening level equation for preliminary remediation goals [12]. Residential land use was considered for carcinogenic in this case, the concentration of all individual PCBs was reported in mg/kg as indicated in Table 1. and the total lifetime cancer risk of the four dioxin-like PCBs are all reported in Table 4. The four dioxin-like PCBs (105, 118, 170 and 180) which were investigated with their oral slope factor and chronic inhalation unit risk (IUR) were already established by USEPA 2013, then the cancer risk of the PCBs was obtained respectively. The carcinogenic risk for ingestion, inhalation and dermal absorption were calculated using equation 1 – 3 below and results indicated in Table 4.

$$\text{TR ingestion} = \frac{Csoil \times IngR \times EF \times ED \times CF \times SForal}{BW \times AT} \quad \text{---------- (1)}$$

$$\text{TR dermal absorption} = \frac{Csoil \times SA \times AFsoil \times ABS \times EF \times ED \times CF \times SForal \times GIABS}{BW \times AT} \text{- - (2)}$$

$$\text{TR inhalation} = \frac{Csoil \times InHR \times AFinh \times ED \times EF \times IUR}{PEF \times AT} \quad \text{- - - - - - (3)}$$

TLCR = TR ingestion + TR dermal absorption + TR inhalation

Where TR ingestion, TR dermal absorption and TR inhalation stand for total cancer risk through ingestion, dermal absorption and inhalation.

SForal = Chronic oral slope factor (mg/kg/d), Cs = concentration of individual dioxin-like PCBs in soil (mg/kg), AT = average time (d/y), BW = body weight (kg), EF = exposure frequency (d/yrs.), IngR = residential soil ingestion rate, InHR = soil inhalation rate ED = exposure duration (yr.), AFsoil = soil exposure time, PEF = particulate emission factor (m3/kg), IUR = chronic inhalation unit risk $(mg/m^3)^{-1}$, ABsd = fraction contaminate absorbed dermally from the soil, SA = skin surface area, GIABs = fraction of contaminate absorbed in gastrointestinal tract, AFinh = absorption factor for lungs and TLCR is the total lifetime cancer risk which is obtained by combined total cancer risk through ingestion, inhalation and dermal absorption. BW = 65kg, CF = 1 x 10^{-6}, IngR = 100 for adult, SForal = 2, EF = 365 days/year, AT = ED x EF = 25,550 for adult, Ed = 70 for adult, SA = 3300cm^3, AFsoil = 0.2 $mgcm^{-2}$, InHR = 15.8 m^3d^{-1} for adult, ABS = 0.1, GIABS = 1, PEF = 1.36 x $10^9m^3kg^{-1}$, IUR = 5.7 x $10^{-1}\mu gm^{-3,}$ AFinh = 1 respectively.

According to human health evaluation manual [13] cancer risk can accelerate for the same individual by exposing in different exposure direction, however the estimation of total cancer risk through ingestion, dermal absorption and inhalation was calculated by the results of equation 1 – 3. The qualitative ranking of cancer risk estimates was used to classified the risk as very low (value ≤ 10^{-6}) and low (10^{-6} < value ≤ 10^{-4}) as indicated in Table 4. [14].

As indicated in Table 1. the total PCBs in site NGS 1, NGS 3, NGS 6, NGS 9 and NGS 10 have values more than 2.00mg/kg set by the United States Toxic Substance Control Act (TSCA) for remediation, hence these sites need cleaning up [15], NGS 1 have the highest concentration of total PCB with the value of 14.25mg/kg while in site NGS 8 the PCB was not detected probably the concentration is below the instrument detection limit of 0.0012mg/kg, other sites NGS 2, NGS 4, NGS 5 and NGS 7 have concentration of total PCBs less than 2.00mg/kg which does not need remediation, even though PCBs are known to be bioaccumulation and this need to be given attention. This study agreed with other findings which also report the concentration of total PCBs in soil from transformer Installation sites in University of Port Harcourt to be more than 2.00 mg/kg [9]. From Table 1. the results of individual congener revealed PCB 52 have the highest concentration with the value of 5.48mg/kg followed by PCB 137 (1.790), PCB 170 (1.590), PCB 153 (1.200) and least PCB 18 (0.010) mg/kg in site NGS 1.

Table 1. Concentration of PCBs in soil samples from various locations in Jos, Plateau State, Nigeria (mg/kg)

Congeners/Sites	NGS 1	NGS 2	NGS 3	NGS 4	NGS 5	NGS 6	NGS 7	NGS 8	NGS 9	NGS 10
PCB 18	0.010 ±0.001	BDL	0.000 ±0.000	BDL	BDL	0.050 ±0.002	BDL	BDL	0.000 ±0.000	0.000 ±0.000
PCB 20	0.470 ±0.010	BDL	0.390 ±0.130	0.270 ±0.002	BDL	0.860 ±0.210	BDL	BDL	0.350 ±0.020	0.700 ±0.030
PCB 28	0.370 ±0.010	BDL	0.340 ±0.020	0.280 ±0.010	BDL	0.390 ±0.010	BDL	BDL	0.330 ±0.010	0.290 ±0.010
PCB 29	0.370 ±0.020	BDL	0.340 ±0.010	0.280 ±0.020	BDL	0.390 ±0.020	BDL	BDL	0.330 ±0.020	0.290 ±0.001
PCB 44	0.340 ±0.020	BDL	0.220 ±0.010	0.170 ±0.010	BDL	0.540 ±0.120	0.150 ±0.010	BDL	0.290 ±0.010	0.330 ±0.020
PCB 52	5.840 ±1.100	0;090 ±0.010	1.160 ±0.200	0.250 ±0.020	BDL	3.860 ±0.250	BDL	BDL	3.070 ±0.210	1.640 ±0.150
PCB 101	0.890 ±0.2000	0.380 ±0.120	0.470 ±0.200	0.430 ±0.020	0.380 ±0.100	0.550 ±0.200	0.540 ±0.210	BDL	1.460 ±0.210	0.440 ±0.020
PCB 105	0.360 ±0.020	0.170 ±0.010	0.180 ±0.020	0.170 ±0.010	BDL	0.210 ±0.002	0.260 ±0.010	BDL	0.170 ±0.002	0.170 ±0.010
PCB 118	BDL	0.000 ±0.000	0.000 ±0.000	0.000 ±0.000	BDL	0.000 ±0.000	0.000 ±0.000	BDL	0.000 ±0.000	0.000 ±0.000
PCB 137	1.790 ±0.150	BDL	0.530 ±0.010	BDL	0.450 ±0.210	1.210 ±0.100	BDL	BDL	0.930 ±0.200	0.450 ±0.010
PCB 142	0.550 ±0.100	BDL	0.310 ±0.002	BDL	BDL	0.450 ±0.030	BDL	BDL	0.320 ±0.100	0.310 ±0.020
PCB 153	1.200 ±0.200	BDL	0.530 ±0.110	BDL	BDL	0.780 ±0.201	BDL	BDL	0.490 ±0.110	0.430 ±0.010
PCB 170	1.590 ±0.200	BDL	BDL	BDL	BDL	0.190 ±0.010	BDL	BDL	0.150 ±0.001	BDL
PCB 180	0.4790 ±0.020	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.000 ±0.000	BDL
PCB 194	BDL	BDL	0.000 ±0.000	BDL	BDL	BDL	0.000 ±0.000	BDL	0.320 ±0.010	BDL
TOTAL	14.250	0.640	4.470	1.850	0.830	9.480	0.950	NIL	8.210	5.050

Note: BDL is below the detection limit
BDL of the instrument used was 0.0012mg/kg

Table 2. WHO TEF for human health risk assessment

Dioxin-like PCB	TEF (1996)	TEF (2006)
PCB 77	0.0005	0.0001
PCB 105	0.0001	0.00001
PCB 114	0.0005	0.00003
PCB 118	0.0001	0.0001
PCB 123	0.0001	0.0003
PCB 126	0.1	0.1
PCB 156	0.0005	0.00003
PCB 157	0.0005	0.00003
PCB 167	0.00001	0.00003
PCB 169	0.01	0.03
PCB 170	0.0001	-
PCB 180	0.00001	-
PCB 189	0.0001	0.00003

Note: a = Vanden Berg et al.[16] and b = is Vanden Berg et al. [17]

Table 3. Total PCBs concentration and human risk assessment of soil from various locations in Jos, Plateau State, Nigeria

Sites	Total PCBs (mg/kg)	TEQ[a]	TEQ[b]
NGS 1	14.25	2.0×10^{-4}	1.0×10^{-5}
NGS 2	0.64	1.7×10^{-5}	5.1×10^{-6}
NGS 3	4.47	1.8×10^{-5}	5.4×10^{-6}
NGS 4	1.85	1.7×10^{-5}	5.1×10^{-6}
NGS 5	0.83	NIL	NIL
NGS 6	9.48	4.0×10^{-5}	6.3×10^{-6}
NGS 7	0.95	2.6×10^{-5}	7.8×10^{-6}
NGS 8	0.00	NIL	NIL
NGS 9	8.21	3.2×10^{-5}	5.1×10^{-6}
NGS 10	5.05	1.7×10^{-5}	5.1×10^{-6}

Table 4. Cancer risk from PCB exposure of soil from various locations in Jos, Plateau State.

Site	Cancer by ingestion	Cancer by dermal	Cancer by inhalation	Total	Remark
NGS 1	7.48×10^{-6}	4.93×10^{-6}	1.29×10^{-6}	1.36×10^{-6}	Low
NGS 2	5.23×10^{-7}	3.45×10^{-7}	9.00×10^{-8}	9.58×10^{-7}	Very low
NGS 3	5.53×10^{-7}	3.65×10^{-7}	9.50×10^{-8}	1.01×10^{-6}	Very low
NGS 4	5.23×10^{-7}	3.45×10^{-7}	9.00×10^{-8}	9.58×10^{-7}	Very low
NGS 5	NIL	NIL	NIL	NIL	-
NGS 6	1.23×10^{-6}	8.12×10^{-7}	2.11×10^{-7}	1.15×10^{-6}	Low
NGS 7	9.00×10^{-7}	5.29×10^{-7}	1.37×10^{-7}	6.75×10^{-7}	Very low
NGS 8	NIL	NIL	NIL	NIL	-
NGS 9	9.84×10^{-7}	6.49×10^{-7}	1.69×10^{-7}	1.80×10^{-6}	Low
NGS 10	5.23×10^{-7}	3.45×10^{-7}	9.00×10^{-8}	9.58×10^{-7}	Very low

Among the locations where this study was conducted site NGS 1, NGS 3, NGS 6, NGS 9 and NGS 10 were more contaminated with the fifteen congeners identified than NGS 2, NGS 4 and NGS 7, this can be seen in the total PCBs concentration computed and indicated in Table 1. The results of these findings when compared with other results across the globe, it show we have far less contamination to countries like China and US which are more industrialized [18,19,3].

From Fig. 1. Tri homologous series occurred most in the studied areas with 26.7%, followed by Penta and Hexa 20% each then Tetra and Hepta with 13.3% each and least is the Octa with 6.7% respectively.

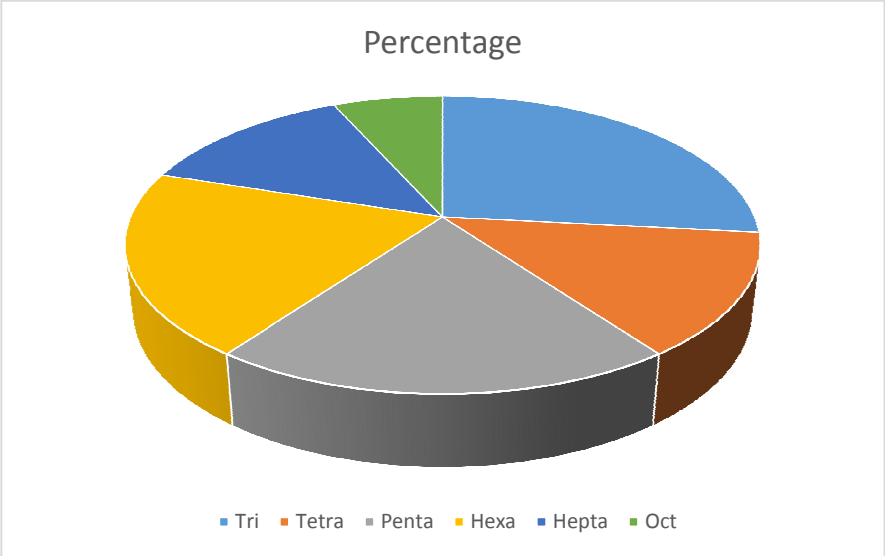

Fig. 1. The distribution of PCBs homologue in the study areas

4. CONCLUSION

The soil samples from transformer installation sites in Jos, Plateau State, Nigeria was investigated for polychlorinated biphenyls distributions and carcinogenicity and it was discovered that the soil was polluted above the 2.00mg/kg value set by the United States Toxic Substance Control Act (TSCA) in sites NGS 1, NGS 3, NGS 6, NGS 9 and NGS 10 out of the ten sites studied, these possibly required clean up. The human health risk assessment of carcinogenicity revealed very low to low cancer risk in adult of this residential area. The concentrations of individual congeners are far below Basel convention guideline value of 50mg/kg generally accepted as the limit for waste classification in the POPs regulation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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