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Ecological Risk of Polychlorinated Biphenyls in Soil from Selected Residential Dumpsites in Delta State, Nigeria

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ABSTRACT

This study investigated the compositional patterns and ecological risks of polychlorinated biphenyls (PCBs) in soils from selected residential dumpsites in Delta State, Nigeria. Five soil samples were analyzed for 28 PCB congeners using gas chromatography–mass spectrometry (GC–MS) after Soxhlet extraction and clean-up with florisil and silica gel. The concentrations of ∑28 PCBs ranged from 6.88 to 21.25 ng/g, indicating contamination mainly associated with anthropogenic activities. The PCB profiles were dominated by penta-, tetra-, and hepta-chlorinated biphenyls, suggesting contributions from mixed waste sources such as domestic, industrial, electrical, and commercial materials. Ecological risk assessment based on Hakanson's ecological risk index revealed varying degrees of environmental risk among the dumpsites. Dumpsite A showed low ecological risk, whereas dumpsites C and D exhibited considerable ecological risk levels. The toxic equivalency (TEQ) values of dioxin-like PCBs ranged from 0.007 to 0.104 ng TEQ/g and were below international guideline values, including the Threshold Effect Level (TEL), Probable Effect Level (PEL), and Effect Range Medium (ERM), indicating limited ecological effects. The study highlights the influence of poor waste management practices on PCB contamination and recommends regular monitoring, public awareness, and improved waste disposal measures to minimize environmental and psychological health in the affected communities.

Keywords: PCBs, Soil, Dumpsite, Ecological Risk

INTRODUCTION

Polychlorinated biphenyls (PCBs) are highly persistent environmental pollutants consisting of 209 different congeners and are recognized among the twelve most hazardous chemical groups because of their adverse effects on ecosystems and human health (UNEP, 2009). PCBs are classified as persistent organic pollutants (POPs) due to their resistance to degradation and their ability to remain in the environment for extended periods after use (Igbo et al., 2018). Dump sites serve as repositories for waste disposal and have become important sources of environmental contamination, affecting soils as well as surface and groundwater systems (Abdus-Salam et al., 2011). In Nigeria, where waste segregation practices are generally inadequate, most dump sites contain mixed categories of waste materials. Improper handling of damaged electrical equipment and indiscriminate disposal of PCB-containing materials have been identified as significant sources of PCB contamination in the environment (Sohail et al., 2017). Consequently, individuals residing near PCB-contaminated dump sites are at a greater risk of exposure compared with populations living farther away.

Several studies have investigated the concentrations of metals and PAHs in soils surrounding dumpsites (Adeyi and Oyeleke, 2017; Tesi and Iniaghe, 2020). However, limited information is available regarding the concentrations, compositional patterns, and ecological risks of PCBs in soils around solid waste dumpsites in Ika South and Aniocha South Local Government Areas of Delta State, Nigeria. Several studies have investigated the concentration of PCBs in dumpsite but to my knowledge no or limited work has been done on PCBs in residential dumpsite in Ika South and Aniocha South. Therefore, this study aimed to determine the concentrations of PCBs in selected dumpsite soils from Ika South and Aniocha South Local Government Areas of Delta State, Nigeria.

Psychological Effects of PCB's

There are evidences on devastating psychological problems which results from PCB's exposure that people ordinarily have not paid attention to. This should be considered as most of the problems of the contemporarily generation is behavioural.

Pessah et al. (2019) reported the issue of cognitive impairments noting that PCB's can damage the hippocampus, a brain region that is crucial for memory formation. This can lead to difficulties in learning new information and recalling memories. Pesovski et al., (2023) however have reported intelligence quotient (IQ) depreciation in Jenzee generation which could be connected to PCB exposure. Jacobson and Jacobson (2003) have initially linked Attention Deficits which include decreased attention span and focus to PCB's exposure. It is quite obvious that the Jenzee generation show difficulty in concentrating or staying on important tasks than those other generations. High levels of PCB's exposure, especially prenatally has been linked to intelligent quotient reduction due to disrupted brain development (Stewart et al., 2008).

Another significant psychological effect of PCB does include Mood and Emotional changes (Faroon, Jones, & Derosa, 2000). PCB's can affect neurotransmitter systems such as serotonin and dopamine involved in mood regulation. Consequently, this might result to depressive symptoms like low mood, or changes in appetite or sleep. Exposure to PCB does disrupt stress response system consequently linked to increased anxiety symptoms (Schantz et al., 2003). Some studies suggest that PCB's exposure might lead to increased irritability and mood instability (Perper et al., 2005). These are psychological problems people take for granted by ignoring it existence in their lives, or by managing it wrongly.

MATERIALS AND METHODS

Study Area

The study area is situated in Delta State, Nigeria (Figure 1), and lies approximately between latitudes 5°00′–6°30′ North and longitudes 5°00′–6°45′ east. Delta State has an estimated population of over 7.8 million people as of 2024. The region experiences a tropical equatorial climate with two major seasons: the dry season, which extends from November to March, and the wet season, which occurs between April and October.

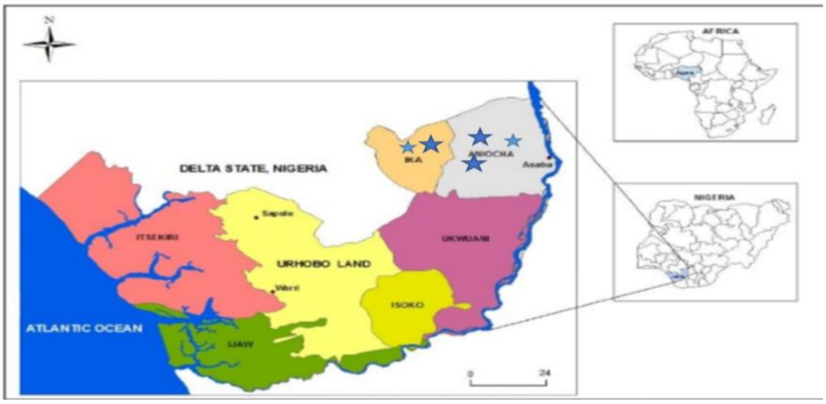

Figure 1: Map of Delta State, Nigeria, Showing the Locations of the Study Areas Indicated By Stars. The Inset Map Illustrates The Position Of Delta State Within Nigeria. Adapted and Modified From Odemerho (2008)

Sampling Collection

Five soil samples (10 g) were collected from five different dumpsites using a hand trowel and placed in aluminium foil paper, using a random sampling technique. The samples were subsequently wrapped in black polyethylene bags, properly labeled, and transported to the laboratory in an ice-cooled container. In the laboratory, the soil samples were air-dried, sieved through a 2 mm mesh sieve, and stored in a refrigerator at 4 °C prior to analysis.

Sampling Location and Site

The study sites consisted of dumpsites situated within residential and commercial areas of Delta State, Nigeria. Site A was located opposite NDDC Road, Alihame, Agbor, at coordinates 6.253188° N and 6.177140° E. Site B was situated at the University back gate, Alihame, Agbor, with coordinates 6.251077° N and 6.175803° E. Site C was located at Isah Ogwashi along Ubulu-Uku Road, with coordinates 6.206687° N and 6.506758° E. Site D was situated at Ogwashi-Uku Main Market, located at coordinates 6.185197° N and 6.526638° E, while Site E was located on Okocha Street, Ogwashi-Uku, at coordinates 6.184657° N and 6.522430° E.

Sample Extraction and Clean up

The extraction of PCBs from the soil samples was carried out according to the USEPA Method 3540C (USEPA, 1996) as described by Irerhievwie et al. (2020). Approximately 5.0 g of dried soil sample was spiked with a mixed standard solution containing isotopically labeled PCB congeners and extracted using a Soxhlet apparatus with 150 mL of an acetone/dichloromethane/n-hexane solvent mixture (1:1:1, v/v/v) in a water bath maintained at 65 °C for 18 h. To remove sulfur and residual moisture, 1 g of activated copper granules and 3 g of anhydrous Na_2SO_4 were added, respectively.

The resulting extract was concentrated to approximately 2 mL using a rotary evaporator and subsequently purified using a multilayer alumina–silica gel column. The column was packed sequentially from bottom to top with 4 g of neutral silica gel (5% deactivated), 2 g of neutral alumina (6% deactivated), and 5 g of anhydrous Na_2SO_4. Elution of the PCBs was achieved using 40 mL of an n-hexane/dichloromethane mixture (3:1, v/v). The cleaned eluate was then concentrated to approximately 2 mL under a gentle stream of nitrogen gas.

The separation, detection, and quantification of PCB congeners in the samples were performed using an Agilent 7890A gas chromatograph coupled with an Agilent 5975C mass selective detector (Palo Alto, CA, USA).

Quality Control/Assurance Measures

Before analysis, all glassware was subjected to a rigorous cleaning procedure involving washing with detergent, rinsing thoroughly with distilled water and acetone, and subsequent heating in an oven at 450 °C for 4 h. The reliability and accuracy of the analytical procedure were evaluated using the method blank approach.

Statistical Analysis

The Tukey test was employed to compare the mean concentrations of PCBs in the soil samples. All statistical analyses were carried out using the Statistical Package for the Social Sciences (SPSS) version 19.0.

Ecological Risk Assessment of PCBs

The ecological risks associated with PCBs in the samples were evaluated using the potential ecological risk index proposed by Hakanson (1980), as expressed in Equation 1.

$$ERI = \sum_{i=1}^{n} E_r^i \tag{1}$$

Where, $E_r^i = T_f^i \times C_f^i$ and (2)

$$C_f^i = \frac{C_s^i}{C_r^i} \tag{3}$$

Where; ERI is the ecological risk index, C_f^i is the contamination factor, C_r^i and C_s^i are the background and sample concentrations of PCBs respectively. E_r^i Is the ecological risk factor, T_f^i is the toxic response factor = 40 for PCBs (Hakanson, 1980). The background concentration of 10 ng/g PCBs in soil will be used based on Hakanson (1980). According to Hakanson (1980), $E_r < 40$ = low risk, $40 \le E_r < 80$ = moderate risk, $80 \le E_r < 160$ = considerable risk, $160 \le E_r < 320$ = high risk and $E_r \ge 320$ = very high risk.

Estimation of toxic equivalent of dl-PCBs in soil

The toxic effects of dioxin-like PCBs (dl-PCBs) were assessed using the toxic equivalency (TEQ) approach. The

TEQ concentrations of dl-PCBs were calculated relative to 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), which was used as the reference compound, according to the equation described by Van den Berg et al. (2006) and Tesi and Iniaghe (2020).

$$TEQ = \sum TEF_i \times C_i \quad (5)$$

Where C_i is the concentrations of the *dl*-PCB congeners in soils and TEF_i is the toxic equivalency factor of the *dl*-PCB congener. The TEF values of the dl-PCB congeners used are 1×10^{-4} for PCB77, 3×10^{-4} for PCB81, 3×10^{-5} for PCB105, 3×10^{-5} for PCB114, 3×10^{-5} for PCB118, 3×10^{-5} for PCB123, 1×10^{-1} for PCB126, 3×10^{-5} for PCB156, 3×10^{-5} for PCB157, 3×10^{-5} for PCB167, 3×10^{-2} for PCB169 and 3×10^{-5} for PCB189 (Van den Berg *et al.,* 2006).

RESULTS AND DISCUSSION

PCBs Concentrations in Soils

The summary statistics for PCBs in the soil samples are presented in Table 4.1. The concentrations of ∑28 PCBs in the dumpsite soils ranged from 6.88 to 21.25 ng g^{-1}. The compositional distribution of PCB congeners in the study area followed the order: penta-PCBs > tetra-PCBs > hepta-PCBs > hexa-PCBs > octa-PCBs > deca-PCBs > di-PCBs > mono-PCBs. The relatively high concentration of PCBs observed at Dumpsite C may be attributed to increased population density and industrial activities within the area (Iwegbue et al., 2020). Lower chlorinated PCB congeners are often formed through dechlorination processes and cannot undergo further chlorination (Iwegbue et al., 2020). In some countries, including China, lower chlorinated PCBs have been widely used in industrial and electrical applications (Yadav et al., 2017). The recommended Ecological Assessment Criteria (EAC) for indicator PCBs established by the OSPAR Commission (2000) range from 1.0 to 10 ng g^{-1}. The concentrations of indicator PCBs detected in the study area were within these guideline values, suggesting minimal adverse ecological effects (Iwegbue et al., 2020).

The concentrations of non-ortho dioxin-like PCBs (dl-PCBs) detected in the soil samples were lower than those of mono-ortho dl-PCBs within the study area. The relatively low levels of non-ortho dl-PCBs in the soils may be of less environmental concern because these congeners possess less similarity in carcinogenic characteristics to tetrachlorodibenzo-p-dioxin (TCDD) (Baqar et al., 2017).

A comparison of the ∑28 PCB concentrations obtained in this study with values previously reported in the literature is presented in Table 4.2. The PCB concentrations recorded in the present study were higher than those reported for soils from Kotobe, Addis Ababa (Dedela et al., 2020), Plateau State, Nigeria (Ibrahim et al., 2018), Choba in Port Harcourt, Nigeria (Adetutu et al., 2020), the Niger Delta region of Nigeria (Aganbi et al., 2019), Mai Mahiu, Kenya (Sun et al., 2015), and Narok, Kenya (Sun et al., 2015). However, the concentrations were lower than those reported for Mount Suswa Conservancy, Kenya (Sun et al., 2015), Agbogbloshie, Ghana (Moeckel et al., 2020), Yaba, Lagos, Nigeria (Fatusin et al., 2019), Kingtom, Sierra Leone (Moeckel et al., 2020), and Korba, India (Kumar et al., 2014). In addition, the concentrations observed in this study were comparable to values reported for suburban soils, but higher than those reported for rural and urban soils in Lagos, Nigeria (Folarin et al., 2018), as well as soils from Juja, Kenya (Sun et al., 2015).

Table 1: Summary Statistics of PCBs Concentrations (ng/g) in Soils of Dumpsites

	MEAN	SD	MEDIAN	MIN	MAX	CV%
PCB8	0.37	0.41	0.4	0	1.01	111
PCB18	0.48	0.46	0.31	0.02	1.16	96
PCB28	0.73	0.40	0.83	0.03	1.01	56
PCB44	0.28	0.45	0.15	0.01	1.08	159
PCB52	0.44	0.43	0.4	0.04	1.12	98
PCB66	0.63	0.56	0.49	0.08	1.36	88
PCB77	0.70	0.56	0.73	0.03	1.32	80
PCB81	0.82	0.56	0.94	0.02	1.49	67
PCB101	0.56	0.28	0.65	0.09	0.84	50
PCB105	0.37	0.35	0.27	0.06	0.98	95
PCB114	0.52	0.49	0.64	0.01	1.16	96
PCB118	0.58	0.51	0.85	0.02	1.09	88
PCB123	0.58	0.52	0.34	0.05	1.32	89
PCB126	0.29	0.40	0.21	0.01	0.97	138
PCB128	0.83	0.44	0.9	0.32	1.32	53
PCB138	0.63	0.56	0.87	0.02	1.16	88
PCB153	0.48	0.44	0.46	0.11	1.21	92
PCB156	0.36	0.33	0.35	0.01	0.78	93
PCB157	0.57	0.35	0.69	0.05	0.96	61
PCB167	0.18	0.18	0.13	0.02	0.47	99
PCB169	0.38	0.46	0.21	0.02	1.19	120
PCB170	0.46	0.49	0.17	0.04	1.08	107
PCB180	0.61	0.36	0.72	0.22	0.96	58
PCB187	1.00	0.68	1.01	0.02	1.95	68
PCB189	0.49	0.42	0.44	0.11	1.16	85
PCB195	0.36	0.21	0.39	0.06	0.64	58
PCB206	0.54	0.44	0.45	0.11	1.23	81
PCB209	0.94	0.62	0.77	0.39	1.95	66

SUM	15.20	5.87	17.2	6.88	21.25	39
Mono-PCBs	0.37	0.41	0.4	0	1.01	111
Di-PCBs	0.48	0.46	0.31	0.02	1.16	95
Tetra-PCBs	2.79	1.77	2.51	0.4	5.02	63
Penta-PCBs	4.55	1.00	4.64	3.14	5.84	22
Hexa-PCBs	2.04	1.25	2.22	0.57	3.29	61
Hepta-PCBs	2.63	1.57	3.44	0.35	3.98	60
Octa-PCBs	1.39	0.83	1.62	0.28	2.31	60
Deca-PCBs	0.94	0.62	0.77	0.39	1.95	66
Non-ortho	2.20	1.30	2.38	0.29	3.67	59
Mono-ortho	3.64	1.27	3.88	1.51	4.65	35
∑Dioxin-like PCBs	5.84	2.29	6.89	1.8	7.28	39
Indicator PCBs	3.46	1.58	3.53	1.58	5.28	46
LC-PCBs	2.50	1.53	2.94	0.45	3.9	61
HC-PCBs	3.91	1.54	3.84	2.43	6	40

Table 2: Comparison of ∑28 PCBs Concentrations in Soils of the Dumpsites Studied with Others Reported for Soil in Literature

Location	No of PCBs Studied	Concentration Range (ng g^{-1})	References
Ika and Aniocha Delta State, Nigeria	28	6.88 - 21.25	This study
Agbobogloshie, Ghana	32	6.5-830	Moeckel *et al*., (2020)
Kingtom, Sierra Leone	32	0.74-43	Moeckel *et al*.(2020)
Kotobe in Addis Ababa	18	0.004862-0.0010275	Dedela *et al*.(2020)
Lagos, Nigeria	12	10.43-43.60	Folarin *et al*.,2018
Plateau State, Nigeria	15	0.0001-0.00584	Ibrahim *et al*.(2018)
Korba, India	28	3.25-25.22	Kumar *et al*.(2014)
Choba, Port Harcourt Nigeria	15	0.014568-0.09304	Adetutu *et al*. (2020)
Yaba,Lagos	17	17.60-82	Fatusin *et al*. (2019)
Niger Delta, Nigeria	14	0.0084-0.51	Aganbia *et al*. (2019)
Mai mahiu Kenya	7	ND-17.80	Sun *et al*. (2015)
Narok Kenya	7	1.99-19.99	Sun *et al*. (2015)
Mount Suswa conservancy Kenya	7	0.04-9.64	Sun *et al*. (2015)
Juja Kenya	7	0.09-46.00	Sun *et al*. (2015)
Limuru town Kenya	7	12.82-55.49	Sun *et al*. (2015)

Ecological Risk Assessment of PCBs in Soils

Hakanson (1980) said $E_r < 40$ = low risk, $40 \leq E_r < 80$ = moderate risk, $80 \leq E_r < 160$ = considerable risk, $160 \leq E_r < 320$ = high risk and $E_r \geq 320$ = very high risk. Dumpsite A shows low risk, dumpsite B and E shows moderate risk, C and D shows considerable risk. The soil sample were below Effect Range Medium (ERM) value (Long et al., 1995), Probable Effect Level (PEL) (Macdonald et al., 1996), and Probable Effect Concentration (PEC) (Gomez-Gutierrez et al., 2007).

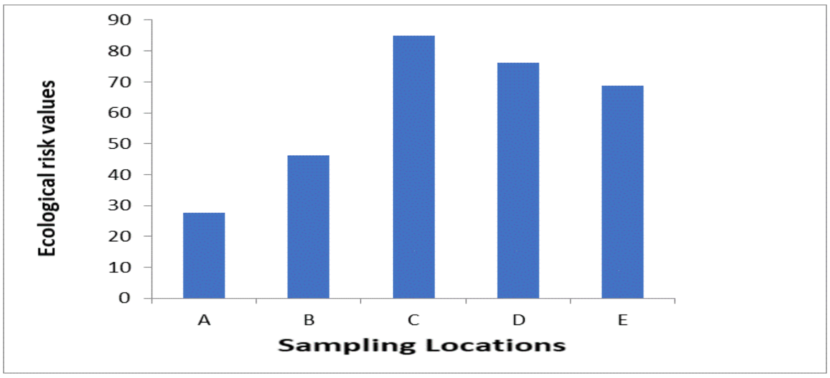

Figure 2: Ecological Risk of PCBs in the Soils

Toxic Equivalency (TEQs) of PCBs in the soils

The toxic equivalency (TEQ) values of PCBs in the soil samples are presented in Table 4.3. The total toxic equivalency (TTEQ) values recorded for Dumpsites A, B, C, D, and E were 0.0226543, 0.011684, 0.007395, 0.103748, and 0.057253 ng TEQ g^{-1}, respectively. Among the studied sites, Dumpsite D exhibited the highest TTEQ value, indicating a relatively greater contribution of dioxin-like PCBs compared with the other dumpsites.

The TEQ values of dioxin-like PCBs (dl-PCBs) detected in these soil samples were below established sediment quality guideline limits, including the Threshold Effect Level (TEL) of 25 pg TEQ g^{-1} (Macdonald et al., 1996), Effect Range Low (ERL) value of 22.7 pg TEQ g^{-1} (Long and Morgan, 1990), Effect Range Medium (ERM) value of 180 pg TEQ g^{-1} (Long et al., 1995), Probable Effect Level (PEL) of 189 pg TEQ g^{-1} (Macdonald et al., 1996), Threshold Effect Concentration (TEC) of 29 pg TEQ g^{-1}, and Probable Effect Concentration (PEC) of 278 pg TEQ g^{-1} (Gomez-Gutierrez et al., 2007). These findings suggest that exposure to PCBs in soils from the investigated dumpsites is unlikely to pose significant ecological or health risks to exposed organisms.

Table 3: TEQs Concentrations (ng/g) of PCBs in Soils from the Dumpsites

	A	**B**	**C**	**D**	**E**
PCB77	0.000003	0.000073	0.000132	0.000026	0.000118
PCB81	0.000006	0.000174	0.000447	0.000282	0.000327
PCB105	0.0000294	8.1E-06	1.8E-06	8.1E-06	8.1E-06
PCB114	0.0000009	3.48E-05	3E-07	1.92E-05	2.22E-05
PCB118	0.0000006	3.27E-05	1.2E-06	2.55E-05	2.73E-05
PCB123	0.0000087	1.5E-06	3.96E-05	2.67E-05	1.02E-05
PCB126	0.022	0.002	0.001	0.097	0.021
PCB156	0.0000003	1.8E-06	1.74E-05	2.34E-05	1.05E-05
PCB157	0.0000015	2.16E-05	2.88E-05	1.29E-05	2.07E-05
PCB167	0.0000006	1.8E-06	1.41E-05	6.9E-06	3.9E-06
PCB169	0.0006	0.0093	0.0057	0.0063	0.0357
PCB189	0.0000033	3.48E-05	1.32E-05	1.68E-05	5.4E-06
TTEQ	0.0226543	0.011684	0.007395	0.103748	0.057253

CONCLUSION

The result of this study has shown that the soil were contaminated with PCBs ranged from 6.88 to 21.25 ng/g and check low to considerable ecological risk associated with PCBs in the soil of the dumpsite, based on Hakanson's ecological risk index, $E_r < 40$ = low risk, $40 \le E_r < 80$ = moderate risk, $80 \le E_r < 160$ = considerable risk,. Its recommended that continuous monitoring of these dumpsite for PCBs concentrations should be carried out to avoid potential ecological and residential exposure risk. Polychlorinated Biphenyls can have serious psychological effects, like anxiety, depression, and cognitive issues when exposed to it. Therefore people should: Get tested and if you have been found exposed, get your levels checked because knowing is half the battle that will request for professional help. People should seek professional help, talk to a therapist or counselor about your experiences and emotions. It is also advised that people should get support groups, and by Joining a group to connect with others who have faced similar challenges. Jenzee generation especially should consider lifestyle changes. They should focus on a healthy diet, exercise, and stress management (meditation, yoga, etc.). Lastly, they should advocate for change through support policies and practices that reduce PCB use and promote environmental health.

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