Distribution and Risk Assessment of Polychlorinated Biphenyls in Soil and Plants in Koko Town, Delta State, Nigeria

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Abstract

The distribution of Polychlorinated Biphenyls (PCBs) in Soils and Plants in Koko Town, Delta State, Nigeria, was studied using five soil samples and five edible plants collected from five industrial locations in the study area. Using Soxhlet apparatus and gas chromatography for the extraction of contaminants, and analysis, mean PCB concentrations were found to be significantly higher in plants (20.75mg/kg) than in soils (10.32mg/kg), exceeding the WHO safety thresholds. The sampled plants significantly accumulated PCBs in the following order; *Pueraria phaseoloides* > *Ceiba pentandra* > *Chromolaena odorata* > *Vermonia amygdalina* > *Musa sapientum*. Estimated daily intake of 0.000007mg/kg for adults and children and a hazard ratio of 1.0 as stipulated by USEPA, indicated substantial human health risks, especially among children. These findings underscore the ecological and toxicological urgency of controlling industrial PCB emissions in oil-producing regions.

1. INTRODUCTION

Polychlorinated biphenyls (PCBs) are dioxin-like chemicals of similar structure and chemistry to PCDD/Fs and, are of global concern due to their potential for long-range transport, persistence in the environment, ability to bio-magnify and bio-accumulate in biota as well as their toxicity [3]. There are no known natural sources of PCBs in the environment except anthropogenic activities such as petrochemical production, industrial and municipal wastes [21]. PCBs availability in soil and other related environmental media is determined by the chemical properties of the compound, the physical and chemical properties of the soil, and the environmental conditions at the time of exposure [26]. They are readily ingested by animals from contaminated soil and plants, and this increases the effects of this pollutant across the food web [12]. Their toxicological effects on humans have continued to evolve with a significant range of health impacts including chronic lymphocytic leukemia, soft-tissue sarcoma, hodgkin's disease, non-hodgkin's lymphoma, and limited evidence of association to lung cancer, prostate cancer, bronchus, laryngeal cancer, multiple myeloma, hypertension, spina bifida in offspring, early-onset transient peripheral neuropathy, and amyloidosis [7].

Studies have reported the cause-effect of consuming PCBs to significant concentrations of the lower chlorinated congeners (2-Cl to 5-Cl) above the higher chlorinated congeners (6-Cl to 10-Cl) in the environment [2,15]. In plants' potential to store contaminants, leafy vegetables have been investigated to have elevated bioaccumulating factors (BAF) for lower congeners than higher congeners [19]. Conversely, mean concentrations have been recorded low in leafy vegetables than in other crop yield [2]. The concentrations of PCB congeners vary at soil depth, in vegetables, and in other related transport systems in the environment [3]. This relative is attributed to factors such as differential adsorption rate in soils, soil abstraction, translocation, variation in aerial uptake, soil stability and composition, climatic conditions, resistance to degradation, and plant uptake [6]. These characteristics are typically exhibited in tropical soils as found in Koko Town [4].

Several research has shown that the concentrations of PCBs in vegetables fall below the World Health Organization (WHO) standards of ≥ 400 g/day and the Food and Drug Administration (FDA) [11] recommended tolerances of 200-3000ng/g [2,9,19,26]. Regardless of these discoveries, the sum of PCB concentrations can develop a high toxicity equivalent to the most toxic dioxin congeners [2].

The release of PCBs from industrial activities, the ability of lower congeners of PCBs to bioaccumulate significantly in soils, and the potential of leafy vegetables to absorb lower concentrations of PCBs from the environment has necessitated this study to be carried out in the oil-producing area of Koko. In Koko, historic and ongoing waste dumping has intensified concerns over plant and soil contamination. While previous studies have addressed individual congeners, comprehensive risk assessment for commonly consumed edible plants in this region remains limited. Hence, the present study focuses on the potential of vegetables to accumulate PCBs in general and not on specific congeners. The purpose was to investigate the distribution of polychlorinated biphenyls (PCBs) in soils and plants in Koko town, Delta State, Nigeria. The objectives were to determine: (1) PCB concentrations in soils and plants; (2) bioaccumulation concentrations in soils and plants; and (3) risk assessment to humans.

2. MATERIALS AND METHODS

2.1 Study Location

The study area was Koko, which is the headquarters of Warri North Local Government Area, Delta State, Nigeria, with geographical coordinates of 5°44′0″, 6°08′0″N and 5°4′0″, 5°36′0″E (Fig. 1). The climatic condition of the area is of typical tropical rainforest with an annual rainfall of 2000mm to 3000mm yearly. It experiences the wet and dry seasons annually but more of the wet season. The area has a mean temperature of 21–35°C and a relative humidity of 90%-60% seasonally. It consists of adjoining rivers used for fishing and movement of commercial goods, flowing in and out of the town and empties in the Gulf of Guinea, of the Atlantic Ocean. The town is a hub of oil activities and other commercial farming products of palm oil, cassava, fruits, etc. Nevertheless, it became known globally following the dumping of hazardous wastes in the 1980s, which prompted international and national concerns about the effects it posed on human health, agriculture, and other commercial activities that were beneficial to the town.

2.2 Sample collection

Plants and soil samples (PSS) were collected from the vicinity of the five industrial sites of potential sources of contamination, using a stratified random technique with the aid of a global positioning system (GPS 73-Garmin). The sample locations were categorized as follows: Koko Seaport (site 1), plant and lubricant production company (site 2), industrial waste treatment company (site 3), conglomerate of oil shipping companies (site 4), and bitumen production company (site 5). For soil representatives, the study area was divided into 10 by 10m area, and composite samples of topsoil (0–15cm) and subsoil (15–30cm) were collected in quintuplets using soil augers. In each sampling location, the soil samples were and wrapped in aluminum foil, labelled with markers, and placed in an ice chest to preserve their soil moisture while, leguminous plants such as silk-cotton (*Ceiba pentandra.)*, kudzu *(Pueraria phaseoloides)*- an invasive vine used for medicinal purposes, bitter leaf *(Vermonia amygdalina)*, banana (*Musa sapientum)* and awolowo leaf (*Chromolaena odorata)* were sampled and 20–30 leaves per plant were collected, placed in zip-locks to keep plant texture and moisture and labelled properly. Plants were selected following Plank's [20] method for the determination of plant growth and maturity. Identification was carried out by Amaka Michael and Akinnibosun H. Adewale. Voucher specimen of the plant species (UBH-C531 *Ceiba pentandra*, UBH-P565 *Pueraria phaseoloides*, UBH-V342 *Vermonia amygdalina*, UBH-M416 *Musa sapientum.* and UBH-C496 *Chromolaena odorata)* were deposited at the University of Benin Herbarium. Both soil and plants samples were transported to the EISL Laboratory in Port Harcourt for analysis.

2.3 Sample Preparation Reagents

A measured 10g soil sample was extracted using Method 3540 (Soxhlet) to extract the nonvolatile and semi-volatile organic PCB compounds from the soil. The extracts for PCB analysis were subjected to a sequential hexane cleanup (Method 8082) according to USEPA [22]. After cleanup, the extract was analyzed by injecting a measured aliquot into a gas chromatograph (Agilent 7890A) equipped with a wide-bore fused silica capillary column, an electron capture detector (GC/ECD) and a GC-MS confirmation. Plant samples were air-dried for seven days in a fume hood at 60°C temperature to a constant weight of 10g and ground to powder. 2g of the plant material was placed in a cellulose thimble and extracted by heating the flask until the hexane solvent vaporizes, condenses, and drips on the plant material to extract the PCBs. This continued for 6 hours using a Soxhlet extractor until the solvent was colourless and odourless. Impurities were removed using column chromatography, and the extract was analyzed for PCBs using a GC-MS.

2.4 Quality Control and Quality Assurance

All equipment used for analysis was calibrated to standards. The detected concentrations of targeted compounds were compared with certified reference materials following the Acq Method 3540 and multi-level calibration standards. For quantification, calibration curves were constructed for PCBs compounds using a series level of quantification values (Q- values) for both low and high chlorinated congeners. The quantitation ion (QIon) was a constant of 57 for higher congeners and precisely 149 for the PCB-167 in plant samples at sites 1,2 and 5 with varying responses.

2.5 Data Analysis

Data of PSS were analysed using SPSS version 25.0. This supported the computation and presentation of the analysed results into mean and standard deviation. Comparative analysis using ANOVA was carried out at a probability level of 0.05 (95% confidence level).

2.6 Bioaccumulation factor

The bioaccumulation factor was calculated by dividing the concentration of PCBs in plants as against the concentration in soil.

$BAF = Concentration_{Plant} / Concentration_{Soil}$ (1)

2.7 Human Health Risk Assessment

To evaluate the human health risk associated with the consumption of edible plants contaminated with PCBs, the risk assessment was calculated using the estimated daily intake (EDI) and hazard ratio (HR). The EDI was calculated by using Eq. (2).

$EDI = C \times CR/BW$ (2)

where EDI = the estimated daily intake for edible plants (mg kg^{-1} day^{-1}), C = PCB concentration in plant in mg kg^{-1}, CR = plant ingestion rate using FAO Food Balance Sheets for Nigeria [10] and BW = average body weight for Nigerians, which is 60.7kg for adults [24] and 30kg for children [13].

The hazard ratio was calculated following Eq. (3).

$HR = EDI/RfD$ (3)

where, RfD = reference dose factors according to the United States Environmental Protection Agency values [23].

3. RESULTS AND DISCUSSION

3.1 Mean Concentration of PCBs

The result revealed the concentrations of 28 PCB compounds in soils and five species of plants in Table 1. Amongst the analyzed compounds are 12 dioxin-like PCBs (DL-PCBs) (77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189), which have similar toxicity as 2,3,7,8-TCDD and non-dioxin-like PCBs (NDL-PCBs). The concentrations of 27 compounds were higher than the permissible limits for soil except for PCB-167, with no recorded concentration, and all the analyzed compounds for plants [8]. PCB-66 exhibited the highest concentrations across both soil and plant samples in Table 1, suggesting high mobility and uptake potential and, aligns with its known volatility and widespread industrial use. The higher chlorinated compounds were concentrated moderately in the PSS. The compounds were PCBs 114,118 in soils, while in plants, were PCBs 126, 153, 169, 170, 180, 187, 195, 206, and 209. The translocation of this persistent pollutant in biota has been elaborated previously by Cheng et al. [6] as against concentrations recorded in Arshad et al. [2].

Table 1
Summary concentration (mean + standard deviation) of PCB in soil and plants in Koko, Delta State

	Soil	**Plant**	**P-Value**
PCB-8	8.52 ± 12.91	26.68 ± 12.29	P > 0.05
PCB-18	6.27 ± 8.74	9.01 ± 2.86	P > 0.05
PCB-28	1.27 ± 1.82	1.76 ± 0.71	P > 0.05
PCB-44	9.37 ± 11.99	11.9 ± 3.27	P > 0.05
PCB-52	9.4 ± 12.2	32.25 ± 51.67	P > 0.05
PCB-66	37.82 ± 46.27	116.72 ± 84.4	P > 0.05
PCB-77	3.55 ± 4.32	20.75 ± 28.37	P > 0.05
PCB-81	6.93 ± 8.09	16.06 ± 6.21	P > 0.05
PCB-101	6.27 ± 0.25	4.1 ± 1.16	P > 0.05
PCB-105	10.32 ± 15.25	11.36 ± 5.15	P > 0.05
PCB-114	12.49 ± 20.95	28.84 ± 16	P > 0.05
PCB-118	16.79 ± 16.96	13.04 ± 3.68	P > 0.05
PCB-123	5.68 ± 8.97	7.07 ± 6.92	P > 0.05
PCB-126	9.85 ± 14.23	12.49 ± 3.62	P > 0.05
PCB-128	1.85 ± 2.23	1.3 ± 0.81	P > 0.05
PCB-138	2.05 ± 2.08	2.71 ± 2.23	P > 0.05
PCB-153	4.32 ± 4.03	13.17 ± 15.03	P > 0.05
PCB-156	0.98 ± 1.3	0.95 ± 0.42	P > 0.05
PCB-157	1.57 ± 1.91	2.42 ± 8.17	P > 0.05
PCB-167	0 ± 0	4.57 ± 6.55	P > 0.05
PCB-169	4.47 ± 5.03	33.72 ± 65.45	P > 0.05
PCB-170	2.91 ± 2.57	12.32 ± 10.04	P > 0.05
PCB-180	2.96 ± 4.02	38.34 ± 37.37	P > 0.05
PCB-187	3.63 ± 5.1	13.78 ± 17.43	P > 0.05
PCB-189	11.85 ± 16.42	1.76 ± 2.32	P > 0.05
PCB-195	6.86 ± 7.95	22.02 ± 22.73	P > 0.05

	Soil	Plant	P-Value
PCB-206	10.91 ± 19.23	19.41 ± 20.32	P > 0.05
PCB-209	3.48 ± 1.83	46.68 ± 83.46	P > 0.05

3.2 Bioaccumulation factor (BAF)

The bioaccumulation factor reflects the accumulation of contaminants in a biota compared to the concentration in the surroundings. This makes it important to determine the concentrations of PCBs in plants in contrast to those in soils. In this study, the calculated BAF values were > 1 except in Site 4 which recorded BAF value below 1 (Table 2). The significantly elevated BAF in *P. phaseoloides* may be due to its extensive root system and medicinal use, which raises further concerns over human exposure through traditional plant consumption. The BAF values for the sampled sites were in the decreasing order of Site 2 > Site 1 > Site 5 > Site 3 > Site 4. This is corroborated by studies of significant concentrations of PCBs in hyper-accumulating plant-based foods from the surroundings [16–18].

Table 2
Bioaccumulation factor for dioxins congeners in soil and plant collected from Koko, Delta State.

Sites	Plants	Soil	BAF
Site 1	22.87	0.71	32.21
Site 2	18.53	0.42	44.12
Site 3	14.09	7.74	1.82
Site 4	8.96	14.91	0.6
Site 5	30.28	11.97	2.53

3.3 Health Risk Assessment to Humans

The most notable pathway of exposure to PCBs is through ingestion (food or dietary) nevertheless, there have been inconsistent research on vegetables and other leguminous products which have been specified to the low concentrations of PCBs in plants. Table 3 shows the calculated estimated daily intake and hazard ratio to estimate the risk levels associated with PCB concentrations in the studied plants for adults and children. The EDI reveals the average daily intake of PCBs through edible plants consumption for both adults and children compared to the reference dose. An HR value less than 1.0 indicates a low threat, while a value above 1.0 means a high threat. The permissible daily intake for PCBs by FAO [10] is 0.000007mg/kg and hazard ratio equal 1.0 by USEPA [23] however, the calculated EDI and HR was higher than the FAO [10] and USEPA [23] standards which clearly depicts health danger.

From Table 3 below, the daily intake of PCB concentrates was highest in *V. amygdalina* except for *C. pentandra* whose values fell below the stipulated permissible limit. Hazard ratios exceeded 1.0 for all species except *C. pentandra*, indicating a considerable health risk. The highest HR values in *C. odorata* and *P. phaseoloides* highlight their role as hyperaccumulators. Given the widespread use of these plants in traditional medicine and diet, the implications for chronic exposure are significant. These results from both the estimated daily intake and the hazard ratio satisfy studies by Bantum et al. [4], Irerhievwie et al. [15], and Aziza et al. [3] whose work covers the soil contamination from PCBs along the borders of Warri North as well as the impacts associated from industrial activities, the seasonal variation of temperature, rainfall and other abiotic factors that aid the translocation of PCB pollutants in plants in the area from the environment. Furthermore, the rate of absorption of the contaminants in these plants and their translocation potentials from soil is confirmed to be true [6,25]. The results in Table 3 strongly contradicts the estimated daily intake from studies by Arshad *et al.*, Esposito *et al.*, Olatunji and Zhang *et al.*, [2,9,19,26], whose values fell below the WHO/FAO permissible limits.

Table 3
Human Health Risk Assessment from Edible plants in Koko, Delta State.

Risk Indicator	**Categories**	***Ceiba pentandra***	***Pueraria phaseoloides***	***Vermonia amygdalina***	***Musa sapientum***	***Chromolaena odorata***
EDI	Adult	0.000003	0.001562	0.000812	0.000152	0.002553
	Children	0.000005	0.003161	0.001643	0.000307	0.005166
HR	Adult	0.38	223.19	116.01	21.64	364.77
	Children	0.76	451.60	234.73	43.82	738.05

The chief contributors to these values in the edible plants include shipment of oil and gas consignments, production of paints and lubricants, management of petroleum wastes as well as dumpsite of hazardous wastes and bitumen production. The edible hyper-accumulating plants such as *C. odorata* popularly known as Awolowo leaf in Africa and *V. amygdalina* also known as bitter leaf, have been discovered beneficial to human health because of their antibacterial and antioxidant properties [5,14]. Yet, the capacity of the studied plants to accumulate contaminants of concern, makes them good genetically-modified materials for phytoremediation while harmful to the ecosystem [26]. Environmental contamination of the persistent organic pollutant (PCBs) is comprehensive and serves as an interesting tool in the study of toxicity effects on humans [1,12].

CONCLUSION

The study reveals critical levels of PCB contamination in soils and edible plants in Koko, Delta State. The substantial bioaccumulation, especially in *P. phaseoloides* and *C. odorata*, poses a serious threat to public health. These findings advocate for urgent regulatory action, phytoremediation strategies, and routine environmental monitoring to mitigate long-term exposure in oil-impacted communities. This is a red flag on fruit/vegetable consumption in this region which transcends globally in industrial areas, as this study provides baseline concentrations of PCBs on edible plants in Koko, Delta State, Nigeria. Lower congeners of PCBs are highly adsorbed in soils along the Niger Delta coasts which raises concern over industrial operations in Koko and its environs. Soil biodiversity and public health are at maximal danger and it is needful that anthropogenic sources be minimized to the barest levels to reduce PCB concentrations in the environment.

Declarations

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

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Author Contributions

Amaka Michael, prepared the manuscript, interpreted the results and wrote the paper, Abraham O. Ekperusi revised the work, Ndu P. Okeke initiated the study, and Anthonia E. Gbuvboro wrote the summary. All authors read and approve the final manuscript.

Ethical Approval

No ethical approval is required for this study.

Approval for Animal Experiments

This is not applicable.

Approval for Human Experiments

This is not applicable.

Research involving plants

The study was conducted in accordance with relevant institutional guidelines and regulations.

Consent to Participate/Consent to Publish

This is not applicable.

Dual Publication

This is not applicable as the data represented in this study is original.

Permission to use third-party material

This is not applicable.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Data availability statement

All data generated and analyzed during this study are included in this published article (and its supplementary files).

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Figures

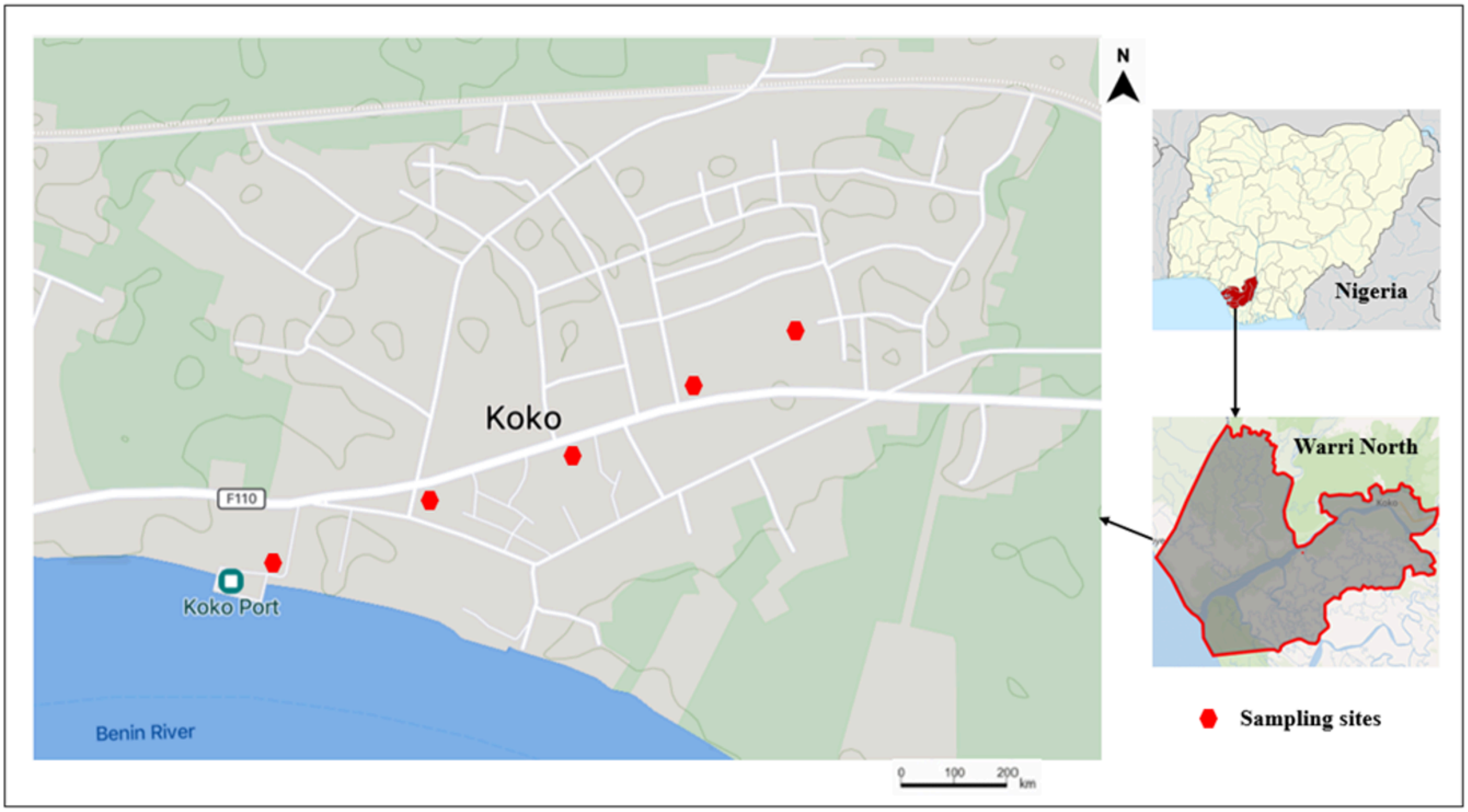

Figure 1

Map of Study Area

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