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POLYCHLORINATED BIPHENYLS IN FISH (*HETEROTIS NILOTICUS)* IN IGBOKODA RIVER, ONDO STATE NIGERIA

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ABSTRACT

Polychlorinated biphenyls are composed of 209 possible chlorinated compounds or congeners with lipophilic properties. They are bioaccumulative, persistent pollutants that have been related to a variety of negative human health effects, including cancer. Humans can be exposed to PCBs by eating contaminated foods such as fish, pig, and dairy products. The purpose of this study was to quantify PCB contents in *heterotis niloticus* using an electron capture detector in gas chromatography (GC-ECD). The presence of PCBs in the fish's head, tail, and centre was determined. The average total PCB concentration was 4.27µg/g in the centre, 6.43µg/g in the tail, and 2.42µg/g in the head. PCBs 8, 18, 28, 44, 156, and 170 were discovered in the fish's head, middle, and tail, except for PCB 8, which was not found in either the head or the tail. The concentration of PCBs in this study found that, except for the middle, which had a mean value of 0.01, there was no PCB8 in the fish's head or tail. The least amount of total PCB was found in the fish head, while the highest concentration was detected in the tail. Except for PCB8, which was not calculated since it only occurred in one location of the fish, the various PCB homologs showed statistical spatial variations. According to the distribution of PCB homologs in fish samples, triPCBs were present in the majority of fish components, whereas tetraPCBs were found in the middle and tail at low levels.

Keywords: Fish**,** Polychlorinated biphenyls, Igbokoda river, Pollution

INTRODUCTION

Polychlorinated biphenyls (PCBs) are a class of synthetic organic chemical compounds that include 209 different possible chlorinated biphenyl molecules. They are persistent organic pollutants (POPs) that have been found as environmental endocrine disruptors (Morgan *et al.*, 2017; Pinson *et al.*, 2017; Wu *et al.*, 2020) and organohalogenic legacy/traditional contaminants (Unyimadu *et al.*, 2018; Dewit *et al.*, 2020; Ediagbonya *et al.*, 2023a, 2023b, 2022ab;). All PCBs are synthetic, hydrophobic organic compounds (HOCs) and other chemicals that are still prevalent in sediment, fish, and other species (Abalos *et al.*, 2020; Ediagbonya and Adesokan, 2019; Edigbonya *et al.*, 2022ab; 2018). Due to their long-term persistence in aquatic ecosystems around the world and inherent risk to natural aquatic resources, these compounds have been studied for temporal environmental hysteresis (Hites *et al.*, 2020; Ediagbonya *et al.*, 2023b). PCBs have been found in both freshwater and marine habitats; however biomagnification is more prevalent in the marine environment (Prince *et al.*, 2020). Human activity produces PCBs, which enter the marine environment through spills, industrial effluents, river runoff, and atmospheric deposition, together with other persistent toxic chemicals (PTCs) (An *et al.*, 2020; Ediagbonya *et al.*, 2015). According to research, the primary way PCBs enter humans is through dietary exposure from aquatic animals, particularly fish (Hulin *et al.*, 2020; Saktrakulglu *et al.*, 2020). Increased PCB levels in humans has been linked to consumption of aquatic foods (Wang *et al.*, 2020). Due to the likelihood of exposure to PCB-saturated dielectric oils, transformer cooling oils, and heat exchange fluids, individuals in the electrical sector have been strongly encouraged to undergo PCB exposure health assessments (Avila; *et al.*, 2020). To swiftly obtain accurate data for environmental risk management, analytical chemists around the world have adopted cutting-edge techniques for measuring PCBs in aquatic species such as finfish and shellfish. For example, (Lee *et al.*, 2020) recently combined gas chromatography, mass spectrometry, and ultrasound-assisted hazy extraction in tandem to achieve this goal. Direct sample introduction GCMS/MS has been used to measure PCBs in mammalian tissue and blood, whereas enzymatic assays have been utilised to assess PCBs in water and food (Artabe *et al.*, 2020; Baume *et al.*, 2020). Hair analysis has also been utilised in China and France to assess human exposure to PCBs (Peng *et al*. 2020). The scientific community has been particularly interested in PCBs because of their propensity to cause teratogenicity, mutation, and cancer (Wangboje and Obotha-Adigbo, 2020). Muir (2020), reported that imported marine fish species can expose human populations in other regions to POPs such as PCBs and have the potential for secondary poisoning. Matsuo *et al.*, (2019) reported that extracted fish oils frequently contain PCBs that cause toxic effects in humans, and that foetuses and infants are especially vulnerable to PCB dangers. PCBs are well-known environmental and dietary concerns (Malish, 2017; Malish & Kotz 2014) and are known to cause endocrine disruption. Environmental issues, such as poor waste management and pollution, afflict developing countries like Nigeria. Organochlorine insecticides have been identified as organic pollutants that may contaminate food and aquatic products (Babayemi, 2016). Polychlorinated biphenyls (PCBs), which have previously been widely employed in the area, are another sort of natural contamination that must be evaluated. Pollutants influence the environment's various components (Babayemi *et al.*, 2016; Abila 2014), monitoring their presence and concentration in the environment is consequently required, particularly in aquatic items to which humans may be exposed. This study aimed to assess the PCB content ranges in fish species (*Heterotis niloticus)* in Igbokoda River. The environment and the technical world have been severely affected as a result of PCB use and poor life cycle management. Sealants, a former open application, continue to pollute the environment and expose people to harmful chemicals (Weber *et al.* 2018).This study is essential due to the hazardous nature of polychlorinated biphenyls (PCBs), which are persistent organic pollutants with significant health and environmental impacts. Assessing the levels of PCBs in fish from the Igbokoda River is crucial as fish serve as a primary exposure pathway to humans. Given the bioaccumulative and toxic properties of PCBs, this research provides neces

MATERIALS AND METHODS

Study Area

The administrative Centre of Ilaje Local Government Area is located in Igbokoda, Ondo State, Nigeria. It is inhabited by the Western Apo tribe's Ijaw (Izon) ethnic subgroup and the Arogbo tribe. According to the 2006 census, it covers 762 km^2 and is home to 154,978 people. Fishing and logging activities have a substantial economic impact on the Igbokoda River. Chemical and biological inputs into the river have significantly contaminated it, potentially leading to a high concentration of PCBs. As an oil producing location, Igbokoda should be extensively contaminated as a result of oil leaks caused by bunkering activities there. The sampling location is shown in Figure 1

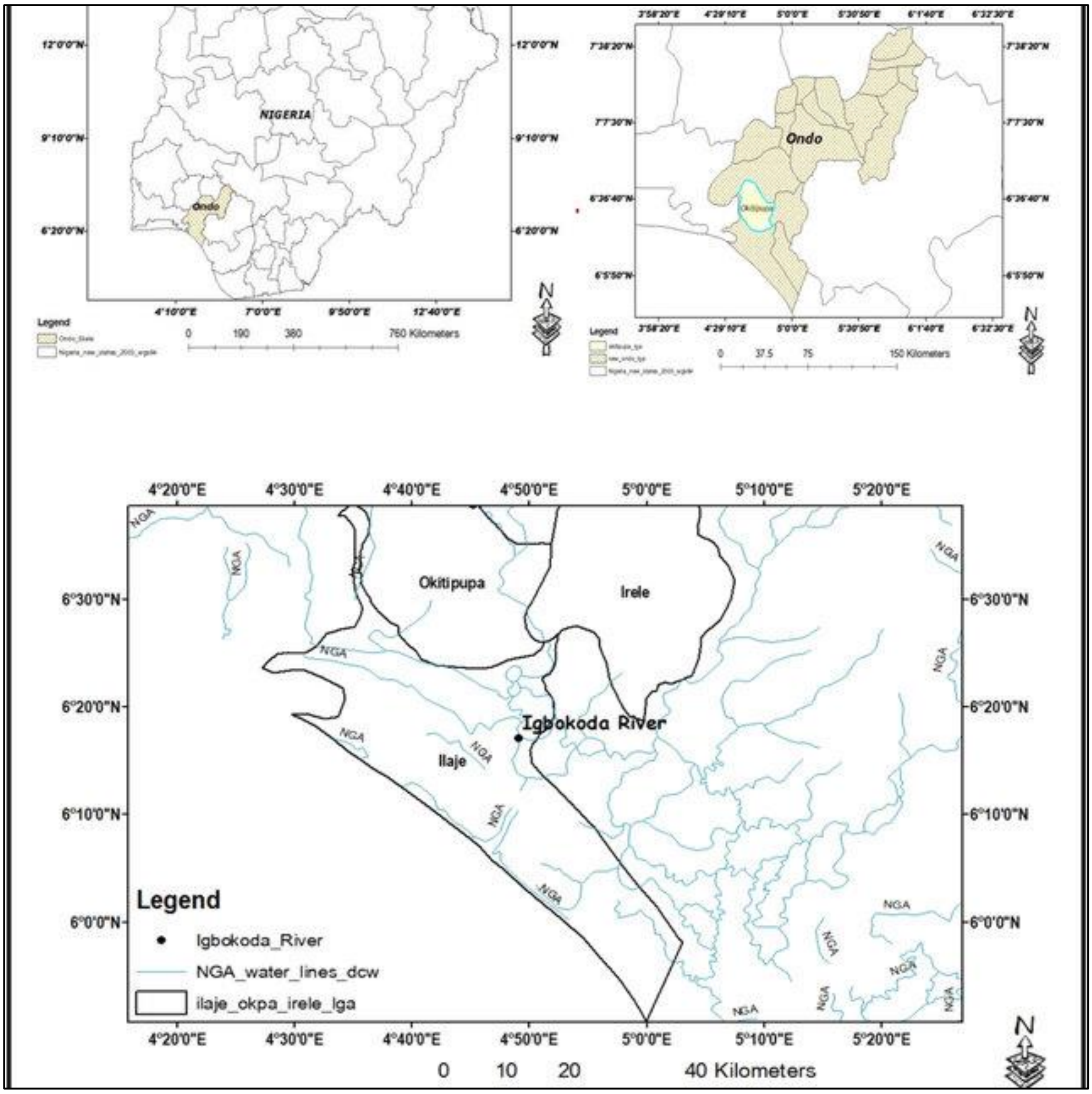

Figure 1: Showing the sampling location

Sample Collection

To determine the PCB amounts in *Heterotis niloticus*, fish samples were purchased from the local fishermen at the riverbank of Igbokoda River Ondo-state. The fish sample (20) were sorted and washed severally with distilled water. The fish material was separated into three sections: head, centre, and tail. Each component, the head, midsection, and tail, was individually wrapped in foil paper, labelled for future testing, placed in food grade coolers and covered with ice blocks. They were then transported quickly as possible to the laboratory and stored in the refrigerator at 4^{0}C prior to laboratory analysis.

Determination of Polychlorinated Biphenyls (PCBs) in Fish

PCBs in *heterotis nicolitus* were analysed using a previously developed method by Igbo *et al.* (2018). 5g of anhydrous sodium sulphate and 50mL/5g of fish sample were ground to generate a homogenate. An ethanolic potassium hydroxide solution was used to saponify the fish samples (Bartalini *et al.*, 2020). An internal standard was applied, and PCBs were extracted from the samples using ultrasonic extraction in 50 mL hexane/acetone (1:1 v/v). The extract was concentrated to roughly 3 mL using a rotary evaporator. To clean up, the sample solution was shaken in a test tube with concentrated H_2SO_4; after centrifugation, the acid layer was removed. This procedure was done numerous times until the hexane layer was dried with anhydrous sodium sulphate and concentrated to about 1 mL for column chromatography clean-up. The concentrations of PCB congeners were tested using an Agilent 7820A GC-ECD. The recovery rate of PCB congeners ranged from 87% to 100%.

RESULTS AND DISCUSSION

Table 1: Mean comparison of PCBs in Heterotis Niloticus fish: the head part, the middle part and the tail part (μg/kg)

	Head part of fish	Tail part of fish	Middle part of fish	P
PCB8	BDL	BDL	0.05±0.00	NC
PCB 44	0.40±0.00	0.54±0.00	0.97±0.00	<0.001
PCB 18	0.16±0.00	3.33±0.15	0.01±0.00	<0.001
PCB28	0.50±0.00	0.03±0.00	1.13±0.01	<0.001
PCB170	0.99±0.00	0.73±0.00	0.98±0.00	<0.001
PCB156	0.37±0.00	1.81±0.00	1.13±0.00	<0.001
Total PCBs	2.42±0.01	6.43±0.16	4.27±0.01	<0.001

Table 1 compares the mean PCB content of the fish *Heterotis Niloticus '* head, middle, and tail. The chart also revealed that, except for the midsection, which had a mean value of 0.050, the fish's head and tail contained no PCB8. PCB44 had the highest measured value in the centre of the fish and the lowest in the head, while PCB18 had the highest recorded value in the tail and the lowest in the middle. The concentration of PCB28 was highest in the fish's belly and lowest in the tail. PCB170 was highest at the head and lowest at the tail of the fish, whereas PCB156 was highest at the tail and lowest at the head. The fish's head contained the least amount of total PCB, while highest concentration was detected in the tail. Except for PCB8, which was not calculated since it only occurred in one location of the fish, the various PCB homologs showed statistical spatial variations. Simpson *et al*., (2018) reported low PCB levels (54.0 – 411.7 μg /kg) in marine fishes. Similarly high levels (0.1 – 1.95 μg/kg) were reported for the Lagos Lagoon Igbo *et al*., (2018). Fish act as indicators of PCB contamination in aquatic habitats because they absorb toxins from their food or the environment around them (Ibeto *et al.*, 2019). PCBs' solubility in lipids, particularly the higher chlorobiphenyls, increases their bioaccumulation and biomagnification, posing a concern to humans and predators when consumed (Bamidele etal., 2020). Fish lipid content varies by species, age, gender, season, and location. According to Simpson *et al*., (2018) ; Ediagbonya *etal* (2024)PCBs enter aquatic species mostly through the lipids in the food they ingest, and the amount of lipid in tissues influences how the chemicals are disseminated.

Table 2: Pearson correlation coefficients for the relationship between the PCB homologs

	DiPCB	TriPCB	tetraPCB	HexaPCB
DiPCB	1	-0.988	-0.866	-0.991
TriPCB	-0.988	1	-0.118	.925**
TetraPCB	-0.866	-0.118	1	0.263
HexaPCB	-0.991	.925**	0.263	1
HexaPCB	-0.991	.925**	0.263	1

** Correlation is significant at the 0.05 level (2-tailed).** Correlation is significant at the 0.01 level (2-tailed).*

The relationship between PCB homologs in fish is seen in Table 2. It shows that triPCBs and hexaPCBs have a strong positive relationship. The PCB homologs of the DiPCB, TriPCB, TetraPCB, and HexaPCB are each represented by one of their respective Pearson correlation coefficients. TriCB and TetraPCB were strongly connected. From previous studies, Igbo *et al*., (2018) reported a strong correlation between triPCB and tetraPCB, while Cui *et.al.*, (2016) reported a strong correlation between DiPCB, tetraPCB and HexaPCB. This variation in correlation showed that the source of PCB in fish differs. Ediagbonya et al (2023ab), Ibeto *et. al.* (2019); reported similar correlation. The atmospheric PCB homologue amounts of these water samples were used to explore the origins and characteristics of PCBs found in fish.

Table 3: Bioaccumulation of PCBs of Heterotis Niloticus fish (the head part, the middle part and the tail part)

	Head part of fish	Tail part of fish	Middle part of fish
PCB8	1.40	1.40	0.03
PCB 18	0.05	1.09	0.03
PCB 28	0.15	0.01	0.35
PCB44	0.07	0.009	0.18
PCB156	0.19	0.95	0.59
PCB176	5.50	4.06	5.44
Total PCBs	7.36	7.519	6.62

The bioaccumulation factors of the analytes were computed using the concentration of PCBs in the sediment in relation to their dissolved content in the fish. According to Bamidele *et al*.,2023; 2022a;;Simpson *et al*.,2023c), bioaccumulation was calculated by dividing the concentration of each chemical component in the tissue by the concentration of PCBs in sediment. PCBs can affect fish in a variety of ways, including metabolism, genotoxicity, and reproduction. These pollutants may bioaccumulate in fish by one of two basic mechanisms: ingestion through food or absorption of the compounds dissolved in the water through the skin and gills (Masset *et al.*, 2019). As a result, determining PCB concentrations in Igbokoda River fish and sediment is critical for determining the principal route of bioaccumulation in aquatic animals. Table 3 showed that PCB 176 has the highest bioaccumulation levels in fish's heads, middles, and tails, indicating that the Igbokoda River is more polluted with PCBs and that eating river fish can pose larger health hazards.

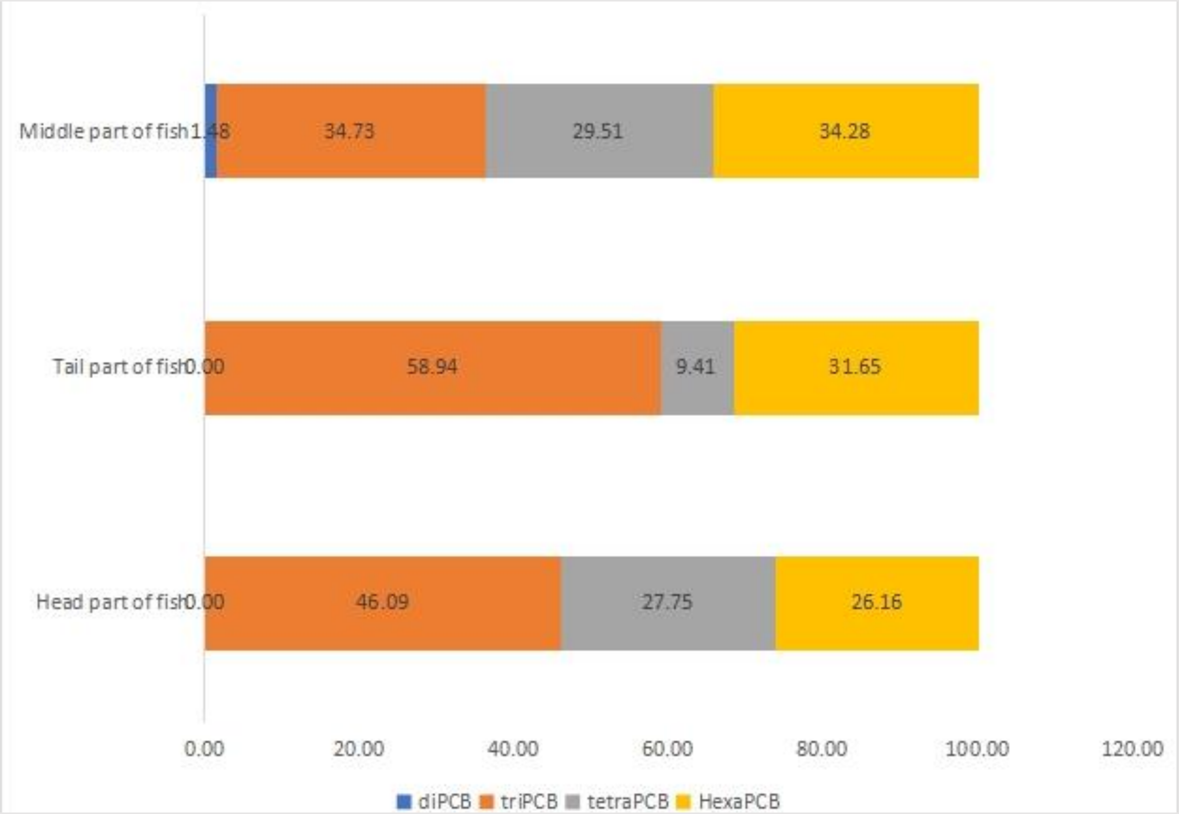

Figure 2**:** Distribution of the PCB homologs in Fish samples

Figure 2 shows that triPCBs contributed the most to all areas of the fish, while tetraPCBs contributed the least to the middle and tail. The DiPCB's core area has 1.48 PCBs, whereas the tail and head sections are PCB-free. The TriPCB had the highest PCB homologs of any region of the *Heterotis Niloticus* fish samples, with 34.73 in the centre, 58.94 in the tail, and 46.09 in the skull. TetraPCB had one of the lowest PCB amounts in the homologous fish sample, measuring 29.51 in the middle, 9.41 in the tail, and 27.73 in the head. The HexaPCB contains one of the highest concentrations of PCB homologs in the fish samples, with 34.28 in the middle, 31.65 in the tail, and 26.16 in the head.

CONCLUSION

The study identified significant PCB contamination in fish from the Igbokoda River, with concentrations varying across different fish parts. The findings underscore the river's pollution levels and its implications for human health through dietary exposure. Mitigation strategies and regular monitoring are recommended to protect the aquatic ecosystem and reduce human health risks associated with PCB exposure.

REFERENCES

Ábalos,M .,Parera,E., Abad, E Rivera, J(2008)PCDD/Fs and DL-PCBs in feeding fats

Abila, N. (2014). Managing municipal wastes for energy generation in Nigeria. Renew Sustain Energy Rev; 37: 182-190.

An, Y., Hong, S., Yoon, S. J., Cha, S. Shin, J. K. and Khim, J.S. (2020). “Current contamination status of traditional and emerging persistent toxic substances in the sediments of Ulsa Bay, South Korea,” Marine Pollution Bulletin. 23-25.

Artabe, A.E., Cunha-Silva, H. and Barranco, A. (2020). “Enzymatic assays for assessment of toxic effects of halogenated organic contaminants in water and food. A review,” Food and Chemical Toxicology, 2(1): 700 -705. c

Avila, B.S.; Ramirez, C.; Tellez-Avila, E. and Combariza, D. (2020), “Occupational exposure to polychlorinated biphenyls (PCBs) in workers at companies in the Colombian electricity sector,” International Journal of Environmental Health Research, 2020.

Babayemi, J. O; Ogundiran, M. B; Osibanjo, O. (2016). Overview of environmental hazards and health effects of pollution in developing countries: a case of Nigeria. *Environ Qual Manag*, *26*(1):51-71.

Babayemi, J.O. (2016). Overview of levels of organochlorine pesticides in surface water and food items in Nigeria. *J Environ Earth Sci*. 6(8):77-86.

Bamidele, A., Kuton, M.P., Iniobong, A.D.(2020) Bioaccumulation of Polychlorinated Biphenyls (PCBs) in Fish Host-Parasite Bentho-Pelagic Food Chain in Epe Lagoon, Lagos, Nigeria. *Bull Environ Contam Toxicol* 105, 770–776

Bartalini,A., Muñoz-Arnanz,J., Baini, M., Panti,C., Galli, M., Giani, D., Fossi,M.C., Jiménez,B (2020)Relevance of current PCB concentrations in edible fish species from the Mediterranean Sea,Science of The Total Environment, 737,139520

Baumer, A., Escher, B.I., Landmann, J. and Ulrich, N. (2020). "Direct sample introduction GC-MS/MS for quantification of organic chemicals in mammalian tissues and blood extracted with polymers without cleanup," *Analytical and Bioanalytical Chemistry,* 2(1):256-263.

Berninger ,J.P., Tillitt, D.E(2019) Polychlorinated biphenyl tissue-concentration thresholds for survival, growth, and reproduction in fish. Environ Toxicol Chem. 38(4):712-736.

Cui,S., Fu,Q., Guo,L., Li,Y., Li,T., Ma,W., Wang,M., Li, W(2016)Spatial–temporal variation, possible source and ecological risk of PCBs in sediments from Songhua River, China: Effects of PCB elimination policy and reverse management framework, Marine Pollution Bulletin, 106, Issues 1–2,s 109-118,

DeWit C.A.; Bossi R., Dietz, R.; Dreyer A., Faxneld, S.; Garbus, S.E.; Hellstrom P.,Koschorreck, J.; Lohmann, N.; Roos, A.; Sellstrom U.; Sonne, C.; Treu G., Vorkamp K., Yuan, B and Eulaers I. (2020). "Organohalogen compounds of emerging concern in Baltic Sea biota Levels, biomagnification potential and comparisons with legacy contaminants," *Environment International,* Vol. 144, 2020. https://doi.org/10.1016/j.envint.2020.106037

Ediagbonya, T. F and Adesokan R (2019) Elements present in three different fish species captured from Oluwa River, Okitipupa, Ondo State, Nigeria. *Pertanika Journal of Science and Technology* 27 (4) :2201-2220

Ediagbonya, T. F., Oyinlusi O. C Okungbowa E.G, and Uche I. J (2022b) Environmental and Human Health risk assessments of polycyclic aromatic hydrocarbons in particulate matter in okitipupa, Ondo State, Nigeria. *Environmental Monitoring and Assessment* 194, (9):556

Ediagbonya, T. F., Ikuesan, F.A., Oyeyemi, A.M., Ogunjobi, A. J and Omoyugbo E.O (2023c). The quantum of polycyclic aromatic hydrocarbon in amphibian (frog) and sediment *in* Igbekebo River, Ondo State, Nigeria. *Ceylon Journal of Science* 54(5): 40-57.

Ediagbonya, T. F., Okungbowa E.G and Titilayo O (2020). Background study of natural radioactive in soil. *Journal of Chemical Society of Nigeria* 45 (2) :290-298

Ediagbonya, T. F., Tobin, A. E., Ehidiamen, G., Asogun, D. A.and Uwidia, I. E (2015). Heterotrophic bacteria and some selected heavy metals in rainwater harvesting system in Usugbenu, Edo State. *Biological and Environmental Sciences Journal for The Tropics* 12(2): 795-801

Ediagbonya, T. F., Uche I. J., Esi, O.E and Afolabi, O.J(2023a). Determination of Polychlorinated Biphenyls PCBs) in Surface water in Ondo State. *Coast J. Sch. Sci* 5(1):580- 863.

Ediagbonya, T. F., Uche I. J., Esi, O.E and Akinrefon, D.O. (2023b) Evaluation of Polychlorinated Biphenyls (PCBs) in sediment from surface water of Igodan,Okunmo ,Lebbi, Idepe and Oaustech in Okitipupa in Ondo State. *J. Appl. Sci. Environ. Manage. 27*(9):2041- 2050

Ediagbonya, T.F and Gbolahan O. I (2018). Determination of radioactive isotopes and some physio-chemical parameters in five different rivers in South-South Ondo State, Nigeria. *International Journal of Low Radiation* 11(1): 45- 65

Ediagbonya,T.F., Ogunjobi, A. J.Odinaka V.C.,, Adenikinju, A. C.(2022a) Bioaccumulation of Elemental Concentrations in Sediment and Frog (*Pyxicephalus edulis)* in Igbokeobo River, Ondo State, Nigeria. *Journal of Africa Chemistry*. 5 (3):790-803

Hites, R.A.; Lehman, D.C.; Salamova, A. and Venier, M. (2020). "Temporal environmental hysteresis: A definition and implication for polybrominated diphenyl ethers," *Science of the Total Environment,* 1 – 10.

Hulin M., Sirot V., Vasseur P., Mahe A., Leblanc J.C., Jean J., Marchand P., Venisseau A., Le Bizec B. and Rivière G. (2020). Health risk assessment to dioxins, furans and PCBs in young children: The first French evaluation. *Food and chemical toxicology*, *139*:111-292.

Ibeto,C.N., W.C. Nkechi,W.C., N.R. Ekere,N.R (2019) Health risks of polychlorinated biphenyls (PCBs) levels in fish and sediment from River Niger (Onitsha Axis), Journal of Aquatic Food Product Technology 28 1–12

Igbo, J.K., Chukwu, L.O.,Oyewo, E.O (2018)Assessment of Polychlorinated Biphenyls (PCBs) in Water, Sediments and Biota from E1waste Dumpsites in Lagos and Osun States, South-West, Nigeria.J. Appl. Sci. Environ. Manage. 22 (4) 459 – 464

James, M.O., Kleinow, K.M. Seasonal influences on PCB retention and biotransformation in fish. *Environ Sci Pollut Res* **21**, 6324–6333 (2014)

Lee J.; Lee S.Y.; Park K.; Lim H. and Shin H. (2020). "Simultaneous determination of PCBs, OCPs and PAHs in mussel by ultrasound assisted cloudy extraction and gas chromatography-tandem mass spectrometry," *Food Additives and Contaminants Part A.* 20(2): 100 - 120.

Li A., Rockne K.J., Sturchio N., Song W., Ford J.C. & Wei H. (2009). PCBs in sediments of the Great Lakes – distribution and trends, homolog and chlorine patterns, and *in situ* degradation. *Environ. Pollut,* 157:141-147.

Malisch R (2017) Incidents with dioxins and PCBs in food and feeding investigative work, risk management and economic consequences. *J Environ Prot* 8:744–785.

Malisch R, Kotz A (2014). Dioxins and PCBs in feed and food—review from European perspective. *Sci Total Environ* 491–492:2–10.

Masset T., Frossard V., Perga M., Cottin N., Piot C., Cachera S., Naffrechoux E. (2019). Trophic position and individual feeding habits as drivers of differential PCB bioaccumulation in fish populations. *Sci. Total Environ.* 674:472–481.

Matsuo, Y.; Nakai, K., Sakuma, I.; Akutsu, K., Tatsuta, N., Ishiyama, M., Higuchi, T., Ryuda, N. and Ueno, D. (2019). “Estimation of PCB intake through fish oil derived dietary supplements and prescription drugs in the Japanese population,” *Journal of Food Quality and Hazards Control*, 6: 146-152.

Morgan M, Deoraj A, Felty Q, & Roy D. (2017). Environmental estrogen-like endocrine disrupting chemicals and breast cancer. *Moll Cell Endocrinol.* 20 – 30.

Muir D.C.G. (2020). “Toxic chemical exposure from global fish trade,” *Nature Food*, 1: 259. obtained as co-products or by-products derived from the food chain, *Chemosphere*, 71 (6):1115-1126,

Peng F., Hardy E. M., Beranger R., Mezzache S., Bourokba N., Bastien P., Li. J., Zaros C. Chevrier C., Palazzi P., Soeur J. and Appenzeller B.M.R. (2020). “Human exposure to PCBs, PBDEs and biphenols revealed by hair analysis: A comparison between two adult populations in China and France,” *Environmental Pollution.*, 52:332-336.

Pinson A, Franssen D, Gerard A, Parent AS, Bourguignon JP (2017). Neuroendocrine disruption without direct endocrine mode of action: polychloro-biphenyls (PCBs) and bisphenol A (BPA) as case studies. *ComptesRendusBiologies.* 340(9-10):432-8.

Prince, D.K.; Taylor, S.D. and Angelini, C. (2020). “A global cross-system meta-analysis of polychlorinated biphenyl biomagnification,” *Environmental Science and Technology*, 1(2):200 – 205.

Saktrakulkla P., Lan T., Hua J., Marek R.F., Thorne P.S., Hornbuckle K.C. (2020) Polychlorinated Biphenyls in Food. *Environ. Sci. Technol.;* 54:11443–11452. Doi: 10.1021/acs.est.0c03632.

Simpson, A.M., Nutile, S.A., Hodgson, O.C., Russell, A.E., Keyes, J.D., Wood, C.C., Buckanovich, R.J(2023) Evaluating the trophic transfer of PCBs from fish to humans: Insights from a synergism of environmental monitoring and physiologically-based pharmacokinetic modeling. Environ Pollut. 1;336:122419.

Unyimadu J.P, Osibanjo O, Babayemi J.O. (2018). Polychlorinated biphenyls (PCBs) in River Niger, Nigeria: occurrence, distribution and composition profiles. *Toxicol Ind Health*. 1:54-67.

Wang Q; Chu L.; Peng F; Li J; Chen H. and Jin L. (2020). “Contribution of aquatic products consumption to total human exposure to PAHs in Eastern China: The source matters,” *Environmental Pollution.* 28 – 45.

Wangboje O.M. and Obotha-Adigo, O. (2020). “Residual levels of polychlorinated biphenyls (PCBs) in the Atlantic Mackerel (*Scomberscombrus, Linnaeus*, 1758) marketed within a Niger Delta Community,” *European Journal of Agriculture and Food Sciences*, 30 - 40.

Weber R, Herold C, Hollert H, Kamphues J, Ungemach L, Blepp M, Ballschmiter K (2018) Life cycle of PCBs and contamination of the environment and of food products from animal origin. *Environ Sci Pollut Res*. 5(2): 125 -136.

Wu W.L., Deng S.J., Zhou H., Liang H., Yang X.F. and Wen J. (2020). “Levels, Congener profile and dietary intake assessment of polychlorinated dibenzofurans and dioxin-like polychlorinated biphenyls in beef, freshwater fish and pork marketed in Guangdong Province, China,” *Science of the Total Environment*, 615: 412-421.