International Journal of Maritime and Interdisciplinary Research
©2025 IJMIR/Volume 8(1) July-December | ISSN: 2734-3286.
Journal homepage: www.ijmir.edu.ng

SEDIMENT LOADS OF POLYCHLORINATED BIPHENYL (PCBS) IN BAKANA CREEK, IN THE NIGER DELTA REGION OF NIGERIA.

***[1]Patricia D. Effiong and [2]Edoghotu A. Jonah**

[1]Department of Biology, Faculty of Science, Nigeria Maritime University, Okerenkoko, PMB 1005, Delta State, Nigeria.

[2]Department of Biology, Ignatius Ajuru University of Education, Port-Harcourt, Nigeria.

ABSTRACT

PCBs are produced as blends of 60 to 90 distinct congeners, they are environmentally toxic, thus, classified as persistent organic pollutants (POPs) and have strong affinity with sediments. This purpose of this study is to assess the levels of PCB accumulation and identify the types of PCBs present in the sediments of Bakana Creek, Rivers State, Nigeria. Sediment samples were collected randomly from the study area. Gas chromatograph (Agilent 7890A, Palo Alto, CA, USA) with electron capture detection (ECD) were used to determine the PCB levels and types. The total mean concerntration and types of PCB in the 5 stations obtained from sediment are in decreasing mean order of; PCB 1248 (94.93±14.19) >> PCB 1232 (66.79±18.17) >> PCB 1221 (62.10±3.25) >> PCB 1242 (43.49±10.98) >> PCB 1260 (35.72±6.34) >> PCB 1016 (20.36±2.19) >> PCB 1254 (17.88±10.32). The concentration of PCBs from the Bakana Creek were significantly higher at ($p<0.05$) as shown by (ANOVA). Tukey HSD Post-hoc comparison reveals that PCB 1221, 1232 and 1248 bio-accumulated more strongly than the other congeners. PCB exceeded the Canadian Sediment Quality standard threshold effect level (CSQ TEL) of (0.03 µg/kg) and the United State Environmental Protection Agency (USEPA) permissible limit of 0.0005 ppm for Sediment. This implied that there are potential health risk to those who are in contact with sediment and those who consume organisms that inhabit the sediment of Bakana and it's surrounding on a daily basis. Indicating that the Bakana creek is under pollution threat and calls for immediate attention.

Keywords: polychlorinated biphenyl (PCB), Sediment, bioaccumulation, Pollution, Persistent organic pollutants, Congeners.

[1] Corresponding Author's E-mail: ponuoha26@yahoo.com

1 INTRODUCTION

As a naturally occurring material, sediments which are made up of rocks, minerals, remains of plants and animals are known to be rich in biodiversity and generally better for farming as they frequently enrich the soil with nutrients. Notably, the productive agricultural regions are frequently the deltas and riverbanks with substantial sediment deposits which serves as shelter, protection, food, reproductory habitat for sedentary organisms like the molluscs and fiddler crab. Pollution through spills, leaks from toxic landfill, outdated electrical equipment's; such as television sets, fluorescent lights and x-ray machines, release from hazardous waste sites, illegal dumps, runoffs from old power transformers (Polychlorinated Biphenyls, 2021), precipitation, industrial effluents, waste and remains of organisms allow lot's of Persistent Organic Pollutants (POPs) like the polychlorinated biphenyl (PCBs) which are hydrophobic to bind to suspended organic particles and organic carbons of sediments in aquatic environments particularly in (marine/coastal environments) and biota (inactive filter-feeding bivalves and bottom-dwelling organisms) (Kampire et al., 2016), through bio-magnification and bioaccumulation and are readily retained within sedentary organisms, including the human body (World Health Organisation (WHO), 1993; Olenycz et al., 2015; Norström et al., 2010; Christian et al., 2017; Inês et al., 2019) via channels like; food, breathing contaminated air and by skin contact, making the sediment, the marine lives inhabiting the sediment, it's surrounding and humans more prone to contamination. The findings of Alexander and Larrisa, (2008) and Gerald, (2018) reveals that PCBs are toxicants to humans and are global environmental contaminant of food, their toxicity depends not only on the number of chlorine present, but also on the positioning of the chlorine on the biphenyl structures, which made their production restricted and prohibited for many years by the United States federal law in 1978 and the Stockholm Convention on Persistent Organic Pollutants in 2001 and also classified them as persistent organic pollutants (POPs) (Porta and Zumeta, 2002). Within the body, some PCBs can transform to different chemicals after exposure, these chemicals or unaltered PCBs can be excreted in faeces or may remain in a person's body for years, with half-lives estimated at 10–15 years (Crinnion, 2011). Environmental levels of PCBs have been linked to immune responses in certain human population studies (United States Environmental Protection Agency, 2016, 2021).

Many rivers, buildings, sediments, soils and other sites have been contaminated with PCBs. Research done by Yang et al., (2019) and Schmid et al., (2005) indicates that sediments are significant PCBs reservoirs and remain static for an extended period of time. Although, the

United Nations Environment Programme (UNEP) established the Stockholm Convention in 2001 with the goal of eradicating PCB-containing products by 2028, however, these products are still present in the environment and can be found everywhere in the atmosphere (Rudel et al., 2008), the biosphere and primarily the hydrosphere (main reservoir), even in places where they have never been used (Dang et al., 2010; Li et al., 2010; Rodenburg et al., 2010). However, As stated by Mitchell and Robert., (2011), the non-biodegradable property of PCBs when exposed to heat or chemical treatment makes them attractive to industries and their resistance to biodegradation pose some of the greatest environmental and health risks thereby, causing significant health challenges in later years like; alteration in the immune system, skin conditions similar to acne (chloracne), jaundice, respiratory tract infections, changes in blood and urine that could indicate liver damage (Aoki., 2001), high birth defects, developmental delays, behavioural alterations and mortality through their continued presence in sediment and products manufactured prior to 1979 (Chappell, 2020). PCBs are also known to cause cancer in animals and humans (Sisay et al., 2021; USEPA, 2016, 2021). Nonetheless, PCB has been effectively destroyed and physically by incineration at 1000 °C. (Rossberg et al, 2006; De Windt et al, 2005; Chun et al, 2003; and Cvančarová et al, 2012).

Taxa that consume these PCBs through filtering and suspension feeding, such as demersal fish, annelids, bivalves and sediments have long been employed as markers of contamination (Kimberly et al., 2021), Previous studies have reported different levels of PCBs in Sediment by (Van der oost et al, 1996; Divagar et al, 2010; Igbo et al, 2018; Obanya et al, 2019; Akinsaya et al., 2020; Adeogun et al. 2013) all in Nigeria. Other studies have demonstrated that the degree of sediment contamination can impact the bioaccumulation of PCBs in an organism (Corsolini and Sarà, 2017). To our knowledge, no data is available on sediment Loads of PCBs from the Bakana Creek, Therefore, it is necessary to investigate PCB levels in sediment and take necessary measures to prevent/control sediment contamination in a bid to control PCB bioaccumulation in organisms, which is an essential key to enhance the ability to understand and predict subsequent bio-magnification across food webs (Kimberly et al. 2021).

Due to hunger and massive consumption of certain marine organisms for food by organisms and humans, primarily those from the Niger Delta and Africa, the scout and harvesting of some edible marine forms by humans enhance direct skin contact of sediment with humans. When PCBs enter the body through the skin or are inhaled overtime, they can lead to serious health problems. As a result of these potential health risk, there has been widespread concern about PCBs and their possible negative effects on a variety of organisms, including humans.

Therefore, the purpose of this study is to assess the levels of PCB accumulation and identify the types of PCBs present in the sediments of Bakana Creek in Rivers State. This work contributes to the dissemination of information about PCBs and raises awareness among residents of Bakana, Nigerians and the world at large on the detrimental effects of PCBs in living forms, including humans who continuously come in contact with sediments or sedentary organisms that have accumulated PCBs.

2 MATERIALS AND METHODS

The Study Area

The study site is the creeks of Bakana, located at the South-East of the Niger Delta, in Degema Local Government Area of Rivers State, Nigeria (Fiq. 1). It is between longitudes 7^0 05' E and $7^0$20' E and latitude 4^0 10' N and $4^0$40' N. The Bakana river connects to large number of associated creeks and creeks-lets. It is tidal with exposed mudflats at low tide. The river aids several communities, such as Oguruama (Old Bakana), Elem Kalabari (the old shipping of the Kalabari), Buguma Town etc, with lots of fishing ports like; Asemebo ama, Oru Kiri, Osokoroso, where fishing is a major livelihood for residents of these communities. Activities such as washing clothes, bathing, swimming also take place there.

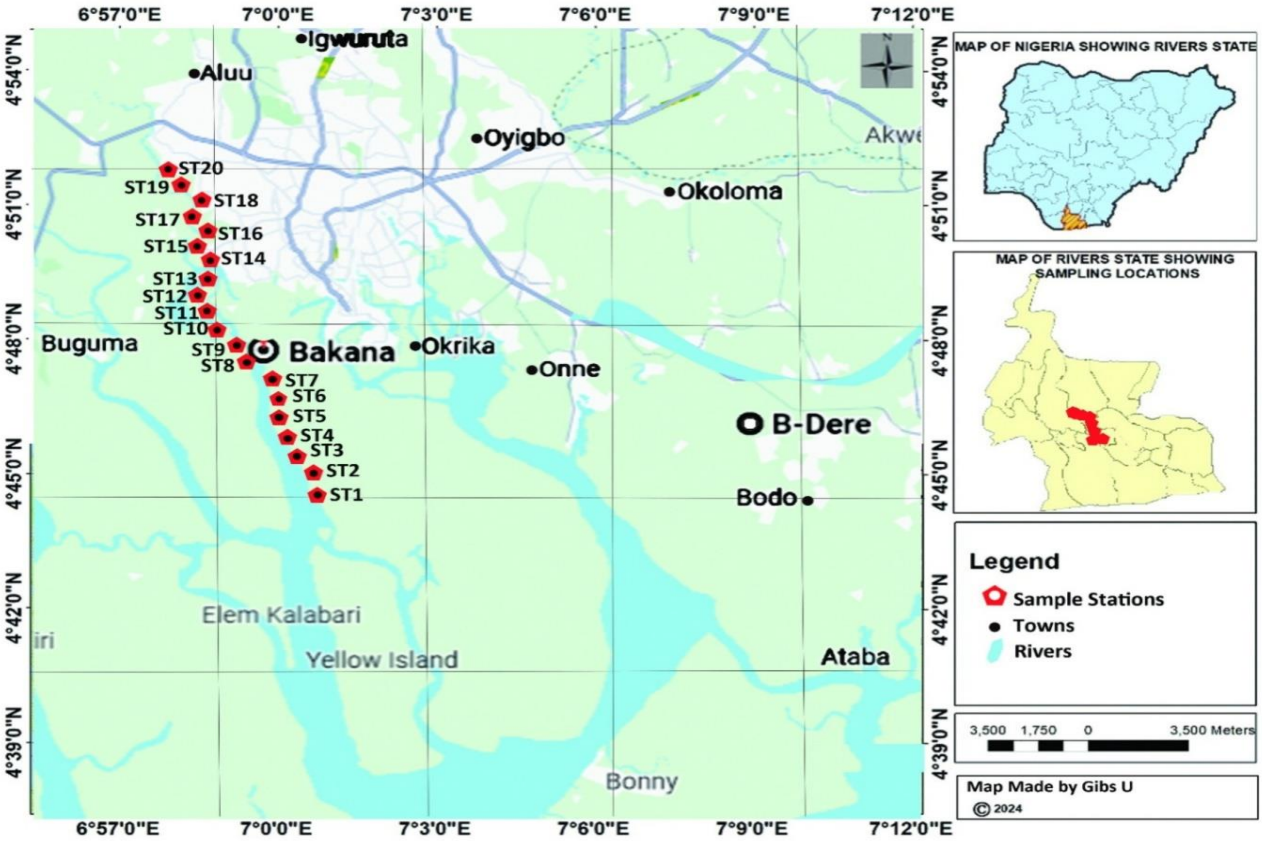


Fig. 1: Map of Rivers State showing the Bakana community and the sample locations

Sampling and Sample Preparation

Sediments samples were collected via the stratified random sampling method every two weeks of each month (September and October) in 2022 from 5 locations.

Sediment; At each sampling site, sediment samples were collected in triplicates, stored in pre-cleaned aluminium bags, sealed and transported to the laboratory, the triplicate samples were thereafter composited (combined) and thoroughly homogenized by a mixer to obtain a representative sample for onward determination of polychlorinated biphenyl (PCB) congener. Rationale behind the locations chosen were; proximity to point source, areas of high depositions, reduced water tide and fine-sediment areas because PCBs preferentially associate with silt/sediment with high organic carbon content.

Analytical procedures

Extraction of sediment samples

Sediment: An aliquot of sediment sample of 5 g was weighed from each station (station 1-5) into different beaker, 50 and 5 ml of ethanol and potassium hydroxide were added to each sample respectively. The samples properly mixed for 30 – 1 hr using a magnetic heating mixer, upon cooling, the solution was filtered with a funnel and filter paper from sample 1- 5. The filtered samples was poured into different separating funnels, 50 ml of ethanol, 100 ml of distilled and 50 ml of n-hexane was added into each separating funnel and shaken vigorously for 5 minutes and allowed to separate, it was thereafter decanted, leaving little portion of n-hexane and the distilled water, then 100 ml of distilled water and 50 ml of n- hexane was added again and shaken vigorously for 5 minutes again to remove the remaining potassium hydrooxide, this process was repeated twice, the mixture was allowed to settle and the distilled water decanted, leaving only the n-hexane which was then released from the separating funnel via 1 g of sodium sulphate into a beaker bit by bit until it is properly filtered. The beakers were then covered with foil paper and put in an oven to dry at 60°C, thereafter, 10 ml of methanol was added to each beaker and placed in a shaker, filtered and put in a sterile bottle for analysis, this was done in accordance with the methods described by Adeogun et al., (2016) (Slightly modified: Regarding to the ratio of sample gram to chemical reagents used). Analysis were performed using a gas chromatograph (Agilent 7890A, Agilent Technologies, Palo Alto, CA, USA) with electron capture detection (ECD).

Statistical analyses

The data were analysed with STATISTICA 11.0 soft-ware. Significant differences of the means and variances were determined using one-way analysis of variance (ANOVA) at ($P<0.05$). A Tukey Post Hoc test was conducted to tell where the difference lies.

3 RESULTS

PCBs in Sediment: The result of the different PCBs found in sediment in the five locations for the duration of four weeks is shown in table 4.1a.

Table 4.1: 4 Weeks sample collection of PCBs from 5 locations of Sediments (µg/kg).

Sampling Location	PCBs Types	Sediments 1st week	2nd Week	3rd Week	4th Week	Weekly Mean	Weekly SE
1	1016	22.94	23.90	27.16	34.82	27.20	2.69
	1221	54.94	70.44	80.04	42.80	62.05	8.24
	1232	46.00	102.23	104.31	71.94	81.12	13.85
	1242	11.44	20.43	17.17	29.60	19.66	3.80
	1248	119.62	135.93	144.61	155.49	138.91	7.58
	1254	0.16	0.47	0.62	0.81	0.51	0.14
	1260	44.50	51.15	46.92	80.90	55.86	8.46
2	1016	18.34	19.11	21.71	27.84	21.75	2.16
	1221	65.00	83.33	94.69	50.64	73.41	9.75
	1232	33.33	74.06	75.57	52.12	58.77	10.03
	1242	26.12	46.63	39.19	67.57	44.88	8.67
	1248	87.84	99.82	106.19	114.19	102.01	5.57
	1254	3.63	10.68	14.05	18.24	11.65	3.09
	1260	33.06	38.00	34.86	60.10	41.50	6.29
3	1016	11.61	12.09	13.74	17.61	13.76	1.36
	1221	50.94	65.31	74.22	39.69	57.54	7.64
	1232	13.05	29.00	29.59	20.41	23.01	3.93
	1242	33.55	59.90	50.34	86.79	57.64	11.14
	1248	46.22	52.52	55.87	60.08	53.67	2.93
	1254	18.05	53.09	69.86	90.72	57.93	15.36
	1260	21.28	24.46	22.44	38.68	26.71	4.05
4	1016	15.67	16.33	18.55	23.78	18.58	1.84
	1221	48.05	61.60	70.00	37.43	54.27	7.21
	1232	72.94	162.09	165.40	114.07	128.62	21.96
	1242	11.23	20.04	16.85	29.04	19.29	3.73
	1248	67.16	76.32	81.19	87.30	77.99	4.25
	1254	1.46	4.30	5.65	7.34	4.69	1.24
	1260	28.39	32.63	29.94	51.62	35.64	5.40
5	1016	17.29	18.01	20.46	26.23	20.50	2.03
	1221	56.00	71.79	81.58	43.63	63.25	8.40
	1232	24.05	53.45	54.54	37.61	42.41	7.24
	1242	44.23	78.97	66.37	114.43	76.00	14.69
	1248	87.89	99.87	106.25	114.24	102.06	5.57
	1254	4.55	13.38	17.61	22.87	14.60	3.87
	1260	15.05	17.30	15.87	27.37	18.90	2.86

PCBs values in sediments from the 5 stations showed remarkable variation. PCB; 1016, 1221, 1232, 1242, 1248, 1254 and 1260 where found in the sample during this study (table 4.1).

PCB "1016" values ranges between 22.94-34.82µg/kg, with a weekly mean of 27.20±2.69µg/kg, 18.34 - 27.84µg/kg (21.75±2.16µg/kg), 11.61 - 17.61µg/kg (13.76±1.36µg/kg), 15.67 - 23.78µg/kg (18.58±1.84µg/kg) & 17.29 - 26.23µg/kg (20.50±2.03µg/kg). For location 1-5 respectively.

PCB "1221" value ranges between 42.89 - 80.04µg/kg (62.05±8.24µg/kg), 50.64 - 94.64µg/kg (73.41±9.75µg/kg), 39.69- 74.22µg/kg (57.54±7.64µg/kg), 37.43 - 70.00µg/kg (54.27±7.21µg/kg) & 43.63 - 81.58µg/kg (63.25±8.40µg/kg). For location 1- 5 respectively.

PCB "1232" value ranges between 46.00 - 104.31µg/kg (81.12±13.85µg/kg), 33.33 - 75.57µg/kg (58.77±10.03µg/kg), 13.05 - 29.59µg/kg (23.01±3.93µg/kg), 72.94 - 165.40µg/kg (128.62±21.96µg/kg), 24.05 - 54.54µg/kg (42.41±7.24µg/kg). For location 1- 5 respectively.

PCB "1242" value ranges between 11.44 - 29.60µg/kg (19.66±3.80µg/kg), 26.12 - 67.57µg/kg (44.88±8.67µg/kg), 33.55 - 86.79µg/kg (57.64±11.14µg/kg), 11.23 - 29.04µg/kg (19.29±3.73µg/kg), 44.23 - 114.43µg/kg (76.00±14.69µg/kg). For location 1- 5 respectively.

PCB"1248" value ranges between 119.62 - 155.49µg/kg (138.91±7.58µg/kg), 87.84 - 114.19µg/kg (102.01±5.57µg/kg), 46.22 - 60.08µg/kg (53.67±2.93µg/kg), 67.16 - 87.30µg/kg (77.99±4.25µg/kg), 87.89 - 114.24µg/kg (102.06±5.57µg/kg). For location 1- 5 respectively.

PCB "1254" value ranges between 0.16 - 0.81µg/kg (0.51±0.14µg/kg), 3.63 - 18.24µg/kg (11.65±3.09µg/kg), 18.05 - 90.72µg/kg (57.93±15.36µg/kg), 1.46 - 7.34µg/kg (4.69±1.24µg/kg), 4.55 - 22.87µg/kg (14.60±3.87µg/kg). For location 1- 5 respectively.

PCB "1260" value ranges between 44.50 - 80.90µg/kg (55.86±8.46µg/kg), 33.06 - 60.10µg/kg (41.50±6.29µg/kg), 21.28-38.68µg/kg (26.71±4.05µg/kg), 28.39-51.62µg/kg (35.64±5.40µg/kg), 15.05 - 27.37µg/kg (18.90±2.86µg/kg). For location 1- 5 respectively.

Levels of polychlorinated biphenyls in Sediment

Table 4.2: Levels of polychlorinated biphenyls in Sediment (µg/kg)

PCBs Types	PCBs Mean	SE	N
PCB 1016	20.36	2.19	5
PCB 1221	62.10	3.25	5
PCB 1232	66.79	18.17	5
PCB 1242	43.49	10.98	5
PCB 1248	94.93	14.19	5
PCB 1254	17.88	10.32	5
PCB 1260	35.72	6.34	5
Total	48.75	9.35	35

Table 4.2, shows the Levels of polychlorinated biphenyls in Sediment.

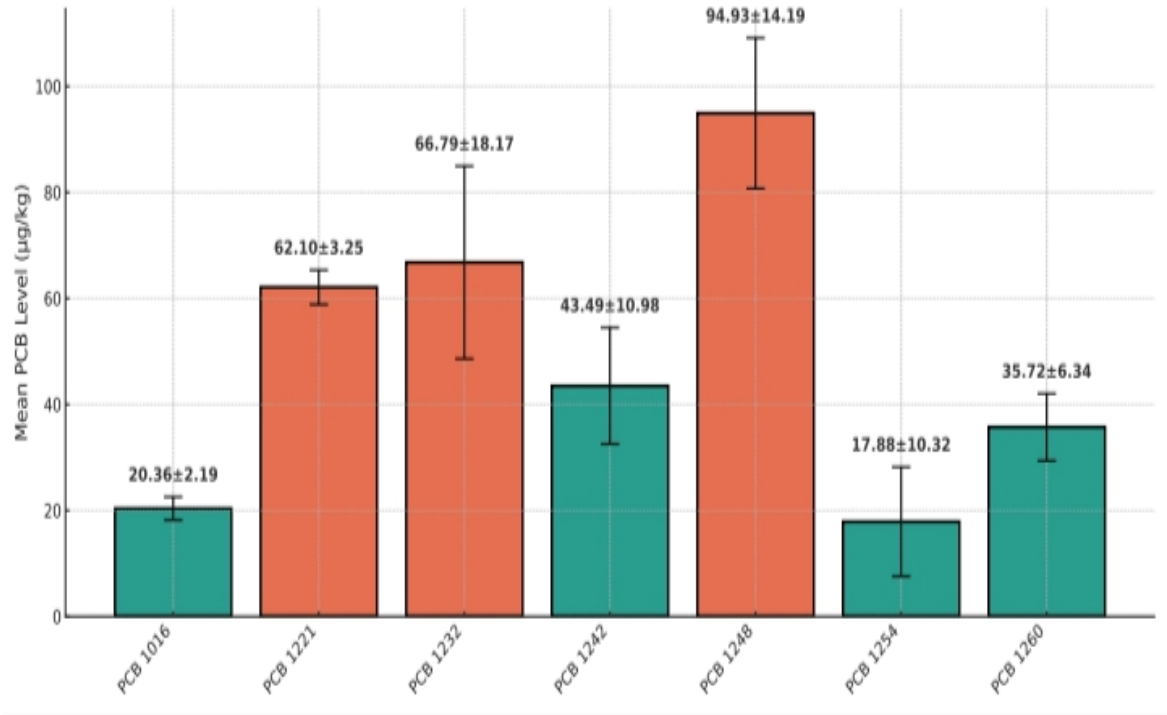


Fig 2: A bar chart of Tukey's Honestly Significant Difference (HSD) Post-Hoc test at ($p < 0.05$), showing the total mean levels and SE of each PCB types in sediment (Bakana Creek) and where the difference lies.

Types of PCBs in sediments(µg/kg)

The types of PCBs identified in sediments are: PCB 1016, PCB 1221, PCB 1232, PCB 1242, PCB 1248, PCB 1254 and PCB 1260 among others.

4 DISCUSSION

The analysis of Sediment Loads of Polychlorinated Biphenyl (PCBs) in Bakana Creek, in the Niger Delta Region of Nigeria revealed a total of 7 PCBs and all stations had all 7 PCBs types found in them (Table 4.1). The mean standard error of PCB (1016, 1221, 1232, 1242, 1248, 1254, 1260) found in the sediment is 48.753±9.35µg/kg and the (F-value is 4.08). This suggests that the PCBs in the sediment differ significantly at ($p<0.05$) significant level, as indicated by (ANOVA). The PCBs found is in decreasing mean order of; PCB 1248 (94.93±14.19) >> PCB 1232 (66.79±18.17) >> PCB 1221 (62.10±3.25) >> PCB 1242 (43.49±10.98) >> PCB 1260 (35.72±6.34) >> PCB 1016 (20.36±2.19) >> PCB 1254 (17.88±10.32).

Tukey Post-Hoc Test, showed that the highest mean concentrations of PCB was found with PCB 1248, 1232, and 1221, while the lower means were found with congeners like; PCB 1242,1260, 1016 and 1254 respectively (Fiqure 2), with no significant difference amongst the lower congeners, indicating a non-uniform variation among the PCB types. This implies that higher-chlorinated congeners (e.g., PCB 1248, 1232) tend to accumulate more in sediment, likely due to their greater hydrophobicity, environmental persistence, lower rates of volatilization and degradation, while lower-chlorinated congeners such as PCB 1016 and PCB 1254 appear at lower concentrations, possibly reflecting higher mobility, rapid degradation or they are introduced in smaller quantities.

This is in conformity with the findings of the World Health Organisation., (1993), that PCBs with a high degree of chlorination have greater tendency to adsorb on sediments than the less chlorinated and remain static for long periods. This is similar to the report of Adeogun et al. (2013) from Eleyele Reservoir in South-West Nigeria, stating that the concentrations of heavier PCB congeners are higher than the lighter congeners in sediment. Like many other POPs, PCBs are hydrophobic and bind strongly to the organic part of sediments where they can be absorbed by plants and ingested by aquatic organisms like crabs and periwinkles (ATSDR, 2000; Tomza et al., 2006).

The elevated concentrations from the Creek could be as a result of the presence of PCBs in the environment which has been contributed from industrial, urban activities and surface runoff (Obanya et al., 2019) into the creek. This aligns with the work done by Ramu et al., (2007) in Korea, Indonesia, the Philippines, and India and by Divagar and Larry (2010) in the Houston Ship Channel (HSC) where the observed highest concentrations of PCBs occurred within the industrialized segments. Also, seasonal variations could cause a rise in PCB during the rainy season as a result of runoffs into the water body (Fu and Wu., 2006). These heavier congeners are commonly associated with transformer oils discharge, hydraulic fluids, and other industrial mixtures used in electrical and petroleum installations and atmospheric fallout, with potential implications for benthic organisms and sediment-dwelling fauna through bioaccumulation and trophic transfer.

Continued industrial discharge and poor waste management could further elevate PCB loads, posing ecological and public health risks in the region. Obanya et al., (2018) "asserted that chronic exposure to low concentrations of toxicants (PCBs) plays a greater role in toxicology than acute exposure" (p.1807), with 100% of the samples having PCB concentrations above the (0.0005ppm and 0.03 µg/kg) permissible limit set by the United State Environmental Protection Agency (USEPA) and the Canadian Sediment Quality standard threshold effect level (CSQ TEL) for sediment respectively. The concentration of PCBs reported in this Study is similar to the values reported for Sediment from Belford Harbor, Massachussets, USA (Subedi et al., 2014), (Odabasi et al., 2017), Du Toit sampling site in South Africa (Adeyinka et al., 2018). In Nigeria, similar values were reported from the Afiesere, Edor, and Okpare River (Iwegbue et al., 2022) in Niger Delta respectively. In contrast, lower values were reported for Sediment from the Udu river (Paschal and Enyohwo., 2022) and Choba River (Archibong et al., 2017) in the Niger Delta of Nigeria.

5 CONCLUSION

Polychlorinated biphenyl (PCBs) which are known "Persistent Organic Pollutants (POPs)" binds to suspended organic particles, biota and organic carbons of sediments in coastal environments, in that, their elevated concentration could pose significant ecological challenges, even in food chain and therefore requires regular assessment of their levels in the sediment of Bakana creek. This study assess the levels of PCB accumulation and identify the types of PCBs present in the sediments of Bakana Creek in Rivers State. The data from this study suggest that

higher-chlorinated PCB congeners are accumulated more in sediment, while lower-chlorinated congeners is less accumulated in sediment. In general, the concentration of PCBs in sediment obtained from the creek is significantly high and it's a potential health risk to those who are in contact with it and those who consume organisms that inhabit sediments contaminated by PCBs and it's surrounding on a daily basis. This calls for immediate attention as the PCB levels are higher than the USEPA and CSQ's safe limit for sediment. This indicates that the Bakana creek is under pollution threat and calls for immediate remediation.

6 RECOMMENDATIONS

(1) It is therefore recommended that routine monitoring and environmental assessment should be implemented to track temporal changes in PCB levels.

(2) Regulatory agencies should enforce strict control of industrial effluents and oil-related discharges, particularly from power and petroleum facilities operating near the creek.

(3) Proper education should be given on contact with sediments and how to harvest sedentary organisms without much contact with the sediment from the Bakana Creek.

(4) The consumption of sedentary organisms from that creek should be reduced due to their potential adverse effects on humans, especially the residence of Bakana, and the world at large.

(5) Sediment remediation programs, such as selective dredging or bioremediation using microbial consortia, may be considered to reduce PCB burden in critical zones.

(6) Additionally, public awareness and community engagement should be promoted to discourage improper waste disposal into waterways that sinks into the sediments, as this will help mitigate the long-term ecological and potential health risks associated with PCB contamination in the Niger Delta environment.

References

Abani, O., Godswill, O. T., Mary, S. D., and Haruna, D. A. (2022). Occurrence and risks of polychlorinated biphenyls in water, sediment, and fish of Wupa River, Nigeria. *Journal Environment Exposure Assessment, 1*(4),19. https://doi.org/10.20517/jeea.2022.13.

Adeogun, A. O., Adedara, I. A., and Farombi, E. O. (2013). Evidence of elevated levels of polychlorinated biphenyl congeners in commonly consumed fish from Eleyele Reservoir, South-Western Nigeria, *Toxicology and Industrial Health, 32*(1), 22-29. https://doi.org/10.1177%2F0748233713495585.

Adeogun, A. O., Chukwuka, A. V., Okoli, C. P., and Arukwe, A. (2016). Concentration of polychlorinated biphenyl (PCB) congeners in the muscle of *Clarias gariepinus* and sediment from inland rivers of southwestern Nigeria and estimated potential human health consequences. *Journal of Toxicology and Environmental Health, Part A, 79*(21), 969-983. https://doi.org/10.1080/15287394.2016.1209141.

Adeyinka, G. C., Moodley, B., Birungi, G., and Ndungu, P. (2018). Quantitative analyses of selected polychlorinated biphenyl (PCB) congeners in water, soil, and sediment during winter and spring seasons from Msunduzi River, South Africa. *Environmental Monitoring Assessment, 190*(10), 621. https://doi.org/10.1007/s10661-018-6993-8G.

Akinsanya, B., Minasu, P. K., and Ukwa, U. D. (2020). Bioaccumulation of Polychlorinated Biphenyls (PCBs) in Fish Host-Parasite Bentho-Pelagic Food Chain in Epe Lagoon, Lagos, Nigeria, *Bulletin of Environmental Contamination and Toxicology, 105*(5), 770–776. https://doi.org/10.1007/s00128-020-02893-y.

Alexander, S., and Larissa, T. (2008). Facing the Challenge of Data Transfer from Animal Models to Humans: the Case of Persistent Organohalogens, *Environmental Health, 7*(1), 58. https://doi.org/10.1186/1476-069X-7-58.

Aoki, Y. (2001). "Polychlorinated Biphenyls, Polychloronated Dibenzo-p-dioxins, and Polychlorinated Dibenzofurans as Endocrine Disrupters-What We Have Learned from Yusho Disease". *Environmental Research, 86*(1), 2-11. https://doi.org/10.1006/enrs.2001.4244.

Archibong, I. E., Okonkwo, C. J., Wegwu, M. O., and Okonkwo, C. J. (2017). Distribution and health risk assessment of selected endocrine disrupting chemicals in two fish species obtained from Choba River in Rivers State, Nigeria. *Bioengineering and Bioscience, 5*(4), 65-73. https://doi.org/10.13189/bb.2017.050402.

ATSDR (2000). Toxicological Profile for Polychlorinated Biphenyls. Atlanta, GA. Agency for Toxic Substances and Disease Registry. http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=142&tid=26.

Barakat, A. O., Khairy, M., and Aukaily, I. (2013). Persistent organochlorine pesticide and PCB residues in surface sediments of Lake Qarun, a protected area of Egypt. *Chemosphere*, *90*(9), 2467-2476. https://doi.org/10.1016/j.chemosphere.2012.11.012.

Berry, W., Rubenstein, N., Melzion, B., and Hill, B. (2003). The biological effects of suspended and bedded sediment (SABS) in aquatic systems: A review. Internal Report of the U.S. Environmental Protection Agency, Office of Research and Development, Narragansett RI. https://downloads.regulations.gov/EPA-HQ-OW-2012-0195-0005/content.pdf&sa=U&ved=2ahhUKEwiHw8S-2-TyAhVCsKQKHS09CwIQFnoECAEQAg&usg=AOvVaw1qwEIzh-3Dr4nkdqjmDY9I.

Chappell, B. (2020, June 24). *bayer to pay more than $10 billion to resolve cancer lawsuits over weedkiller roundup.* NPR. https://www.npr.org/2020/06/24/882949098/bayer-to-pay-more-than-10-billion-to-resolve-roundup-cancer-lawsuits.

Christian, S., Tobias, K., and Stephan, W. (2017). Export of plastic debris by rivers into the sea (PDF). *Environmental Science & Technology, 51*(21), 12246–12253. https://*doi*.org/*10.1021/acs.est.7b02368*.

Chun, C. L., Payne, R. B., Sowers, K. R., and May, H. D. (2003). Electrical stimulation of microbial PCB degradation in sediment. *Water Research, 47*(1), 141–152. https://*doi*.org/*10.1016/j.watres.2012.09.038*.

Corsolini, S., and Sarà, G. (2017). The trophic transfer of persistent pollutants (HCB, DDTs, PCBs) within polar marine food webs, *Chemosphere, 177*, 189–199. http://doi.org/10.1016/j.chemosphere.2017.02.116.

Crinnion, W. (2011). Polychlorinated Biphenyls: Persistent Pollutants with Immunological, Neurological, and Endocrinological Consequences (PDF). *Environmental Medicine, 16*(1), 5–13.

Cvančarová, M., Křesinová, Z., Filipová, A., Covino, S., and Cajthaml, T. (2012). Biodegradation of PCBs by ligninolytic fungi and characterization of the degradation products. *Chemosphere, 88*(11), 1317-1323. https://*doi*.org/*10.1016/j.chemosphere.2012.03.107.*

Dang, V.D., Walters, D. M., and Lee, C.M. (2010). Transformation of chiral polychlorinated (PCBs) in a stream food web. *Environmental Science Technology, 44*(8), 2836–2841. https://doi.org/10.1021/es902227a.

De Windt, W., Aelterman, P., and Verstraete, W. (2005). Bioreductive deposition of palladium (0) nanoparticles on *Shewanella oneidensis* with catalytic activity towards reductive dechlorination of polychlorinated biphenyls. *Environmental Microbiology, 7*(3), 314–25. https://*doi*.org/*10.1111/j.1462-2920.2005.00696.x*.

Divagar, L., Nathan, L.H., Hanadi, S. R., and Larry, E. (2010). Spatial and temporal variation of polychlorinated biphenyls in the Houston Ship Channel. *Chemosphere*, *80*(2), 100-112. https://doi.org/10.1016/j.chemosphere.2010.04.014.

Eqani, S. A., Malik, R. N., Zhang, G., Mohammad, A., and Chakraborty, P. (2012). Polychlorinated biphenyls (PCBs) in the sediments of the River Chenab, Pakistan. *Journal of Chemical Ecology*, *28*(4), 327-39. http://dx.doi.org/10.1080/02757540.2012.667085.

Fu, C. T., and Wu, S. C. (2006). Seasonal variation of the distribution of PCBs in sediments and biota in a PCB-contaminated estuary. *Chemosphere*, *62*(11), 1786-1794. https://doi.org/10.1016/j.chemosphere.2005.07.034.

Gerald, M. (2018). From Industrial Toxins to Worldwide Pollutants: A Brief History of Polychlorinated Biphenyls. *Public Health Reports, 133*(6), 721–725. https://*doi*.org/10.1177/0033354918801578.

Godish, T. (2001). *Indoor environmental quality* (1st ed.). Lewis Publishers. pp. *110*–30.

He, M. C., Sun, Y., Li, X. R., and Yang, Z. F. (2006). Distribution patterns of nitrobenzenes and polychlorinated biphenyls in water, suspended particulate matter and sediment from mid- and down-stream of the Yellow River (China). *Chemosphere, 65*(3), 365–374. https://doi.org/10.1016/j.chemosphere.2006.02.033.

Igbo, J. K., Chukwu, L. O., and Oyewo, E. O. (2018). Assessment of Polychlorinated Biphenyls (PCBs) in water, sediments and biota from e-waste dumpsites in Lagos and Osun States, South-West, Nigeria, *Journal of Applied Sciences and Environmental Management*, *22*(4), 459–464 https://doi.org/10.4314/jasem.v22i4.3.

Ilechukwu, I., Mgbemena, N. M., Inagbor, P. O., and Ndukwe, G. I. (2018). Assessment of the levels of polychlorinated biphenyls in sediments of new Calabar River, Niger Delta Region, Nigeria. *Ovidius University Annals of Chemistry, 29*(1), 36-40. https://doi.org/10.2478/auoc-2018-0005.

Inês, F., Cátia, V., Isabel, L., and Miguel, O. (2019). Nanoplastics and Marine Organisms: What Has Been Studied?. *Environmental Toxicology and Pharmacology, 67*, 1–7. https://*doi*.org/*10.1016/j.etap.2019.01.006*.

Iwegbue, C. M. A, Bebenimibo, E., Tesi, G. O., Egobueze, F. E., and Martincigh, B. S. (2020). Spatial characteristics and risk assessment of polychlorinated biphenyls in surficial sediments around crude oil production facilities in the Escravos River Basin, Niger Delta, Nigeria. Marine *Pollution Bulletin, 159,* 111462. https://doi.org/10.1016/j.marpolbul.2020.111462.

Iwegbue, C. M. A., Oshenyen, V. E., Tesi, G. O., Olisah, C., Nwajei, G. E., and Martincigh, B. S. (2022). Occurrence and spatial characteristics of polychlorinated biphenyls (PCBs) in sediments from rivers in the western Niger delta of Nigeria impacted by

urban and industrial activities. *Chemosphere, 291*(3), 132671. https://doi.org/10.1016/j.chemosphere.2021.13267.

Kampire, E., Rubidge, G., Adams, J. B., and Human, L. (2016). Congener profiles of polychlorinated biphenyls and the effect on marine mussels at an outfall site, Port Elizabeth, South Africa, *Water SA, 42*(3), 496-504. http://doi.org/10.4314/wsa.v42i3.16.

Kampire, E., Rubidge, G., and Adams, J. B. (2017). Characterization of polychlorinated biphenyls in surface sediments of the North End Lake, Port Elizabeth, South Africa. *Water SA, 43*(4), 646-654. https://doi.org/10.4314/wsa.v43i4.12.

Kimberly, D. P., Sinead, M., Crotty, A. C., Joseph, J. D., Todd, M. P., Nancy, D. D., and Christine, A. (2021). Mussels drive polychlorinated biphenyl (PCB) bio-magnification in a coastal food web. *Scientific Reports, 11*(1), 9180. https://doi.org/10.1038/s41598-021-88684-9.

Li, Y.F., Harner, T., Liu, L., Zhang, Z., Ren, N.Q., Jia, H., Ma, J., and Sverko, E. (2010). Polychlorinated biphenyls in global air and surface soil: distributions, air–soil exchange, and fractionation effect. *Environmental Science Technology, 44*(8), 2784–2790. https://doi.org/10.1021/es901871e.

Liu, H. X., Zhang, Q. H., Wang, Y. W., Cai, Z. W., & Jiang, G. B. (2007). Occurrence of polychlorinated dibenzo-p-dioxins, dibenzofurans and biphenyls pollution in sediments from the Haihe River and Dagu Drainage River in Tianjin City, China. *Chemosphere*, *68*(9), 1772–1778. https://doi.org/10.1016/j.chemosphere.2007.03.061.

Mai, B., Fu, H., Sheng, G., Kang, Y., Lin, Z., Zhang, G., Yu-Shuan Min, Y., and Zeng, E. Y. (2002). Chlorinated and polycyclic aromatic hydrocarbons in riverine and estuarine sediments from Pearl River Delta, China. *Environmental Pollution, 117*(3), 457–474. https://doi.org/10.1016/s0269-7491(01)00193-2.

Martinez, A., Norström, K., Wang, K., and Hornbuckle, K. C. (2010) Polychlorinated biphenyls in the surficial sediment of Indiana Harbor and Ship Canal, Lake Michigan. *Environmental International, 36*(8), 849-54. https://doi.org/10.1016/j.envint.2009.01.015.

Mitchell, D. E., and Robert, G. K. (2011). Applications of polychlorinated biphenyls. *Environmental Science and Pollution Research, 18*(2), 135-51. https://:doi.org/10.1007/s11356-010-0392-1.

Norström, K., Czub, G., McLachlan, M., Hu, D., Thorne, P. S., and Hornbuckle, K. C. (2010). External exposure and bioaccumulation of PCBs in humans living in a contaminated urban environment. *Environment International, 36*(8), 855–861. https://doi.org/*10.1016/j.envint.2009.03.005*.

Obanya, H. E., Amaeze, N. H., Togunde, O., and Otitoloju, A. A. (2018). Air pollution monitoring around residential and transportation sector locations in Lagos Mainland.

Journal of Health and Pollution, 8(19), 1-10. https://doi.org/10.5696/2156-9614-8.19.180903.

Obanya, H. E., Ntor, C., Okoroafor, C. U., and Nwanzwe, R. (2019). Occurrence of a Polychlorinated Biphenyl (PCB) Congener in Surface Water, Sediments and Blackchin Tilapia (*Sarotherodon melanotheron*) from Ologe Lagoon, Nigeria, *Journal of Applied Sciences & Environmental Management, 23*(10), 1805-1811. https://doi.org/10.4314/jasem.v23i10.6.

Odabasi, M., Dumanoglu, Y., Kara, M., Altiok, H., Elbir, T., and Bayram, A. (2017). Spatial variation of PAHs and PCBs in coastal air, seawater, and sediments in a heavily industrialized region. *Environmental Science and Pollution Research, 24*(15), 13749-13759. https://doi.org/10.1007/s11356-017-8991-8.

Olenycz, M., Sokolowski, A., Niewinska, A., Wolowicz, M., Namiesnik, J., Hummel, H., and Jansen, J. (2015). Comparison of PCBs and PAHs levels in European coastal waters using mussels from the *Mytilus edulis* complex as biomonitors, *Oceanologia, 57*(2), 196–211**.** https://doi.org/10.1016/j.oceano.2014.12.001.

Paschal, O. I., and Enyohwo, D. K. (2022). Polychlorinated biphenyls (PCBs) in water and sediments from the Udu River, Niger Delta, Nigeria: concentration, distribution and risk assessment. *Journal of Environmental Exposure Assessment,1*(3), 20. https://doi.org/10.20517/jeea.2022.19.

Perga, M. E., Nellier, Y-M., Cottin, N., Fanget, P., and Naffrechoux, E. (2017). Bioconcentration may be favoured over biomagnification for fish PCB contamination in high altitude lakes. *Inland Waters,7*(1), 14–26. https://doi.org/10.1080/20442041.2017.1294320.

Pivnenko, K., Olsson, M. E., Götze, R., Eriksson, E., and Astrup, T. F. (2016). Quantification of chemical contaminants in the paper and board fractions of municipal solid waste *(PDF)*. *Waste Management, 51*, 43–54. https:// doi.org/1*0.1016/j.wasman.2016.03.008*.

Polychlorinated Biphenyls. (2021, July 6). Wikipedia.https://en.m.wikipedia.org/wiki/Polychlorinated_biphenyl.

Porta, M., and Zumeta, E. (2002). "Implementing the Stockholm Treaty on Persistent Organic Pollutants". *Occupational and Environmental Medicine, 59* (10), 651-2. https://doi.org/1*0.1136/oem.59.10.651*.

Ramu, K., Kajiwara, N., Sudaryanto, A., Isobe, T., Takahashi, S., Subramanian, A., Ueno, D., Zheng, G. J., Lam, P. K. S., Takada, H., Zakaria, M. P., Viet, P. H., Prudente, M., Tana, T. S., and Tanabe, S. (2007). Asian mussel watch program: contamination status of polybrominated diphenyl ethers and organochlorines in coastal waters of Asian countries. *Environmental Science and Technology, 41*(13), 4580–4586. https://doi.org/10.1021/es070380p.

Rodenburg, L. A., Guo, J., Du, S. & Cavallo, G. J. (2010). Evidence for unique and ubiquitous environmental sources of 3, 3-dichlorobiphenyl (PCB11). *Environmental Science Technology, 44*(8)*,* 2816–2821. http://dx.doi.org/10.1021/es901155h.

Rossberg, M., Lendle, W., Pfleiderer, G., Tögel, A., Dreher, E., Langer, E., Rassaerts, H., Kleinschmidt, P., Strack, H., Cook, J. R., Beck, U., Lipper, K., Torkelson, R. T., Löser, E., Beutel, K. K., and Mann, T. (2006). "Chlorinated Hydrocarbons". *Ullmann's Encyclopedia of Industrial Chemistry*. Weinheim: Wiley-VCH. https:// doi.org/*10.1002/14356007.a06_233.pub2.*

Rudel, R. A., Seryak, L. M., and Brody, J. G. (2008). PCB-containing wood floor finish is a likely source of elevated PCBs in residents' blood, household air and dust: A case study of exposure*. Environmental Health. 7*(1), 2. https:// doi.org/0.1186/1476-069X-7-2.

Schmid, P., Gujer, E., Zennegg, M., Bucheli, T. D., and Desaules, A. (2005). Correlation of PCDD/F and PCB concentrations in soil samples from the Swisss oil monitoring network (NABO) to specific parameters of the observation sites. *Chemosphere, 58*(3), 227–234. https://doi.org/ 10.1016/j.chemosphere.2004.08.045.

Sisay, A.D., Ishmail, S., Endashaw, A. D., Musa, T. S., Alemu T., and Michaela, S. T. (2021). Assessment of Perceptions and Cancer Risks of Workers at a Polychlorinated Biphenyl-Contaminated Hotspot in Ethiopia. *Journal of Health Pollution, 11*(30), 210-609. https://doi.org/10.5696/2156-9614-11.30.210609.

Subedi, B., Yun, S., Jayaraman, S., Bergen, B. J., and Kannan, K. (2014). Retrospective monitoring of persistent organic pollutants, including PCBs, PBDEs, and polycyclic musks in blue mussels (*Mytilus edulis*) and sediments from New Bedford Harbor, Massachussets, USA: 1991-2005. *Environmental Monitoring and Assessment, 186*(8), 5273-84. https://doi.org/10.1007/s10661-014-3776-8.

Tomza, A., Witczak, A., and Ciereszko, W. (2006). Uptake of Polychlorinated Biphenyl Congeners in Freshwater Mussels (*Anodonta complanata)* from the Lower Odra River. *Polish Journal of Environmental Studies, 15*(4), 603-608.

UNEP Chemicals (2021). Guidelines for the identification of PCBs and materials containing PCBs (PDF). United Nations Environment Programme. p. 40. https://web.archive.org/web/20080414094255/http://www.chem.unep.ch/pops/pdf/PCBident/pcbid1.pdf.

United States Environmental Protection Agency (2016, September 15). *Polychlorinated Biphenyls (PCBs)*. https://19january2017snapshot.epa.gov/pcbs/learn-about-polychlorinated-biphenyls-pcbs_.html#healtheffects.

United States Environmental Protection Agency. (2021, February 10). *Sediments*. https://www.epa.gov/caddis-vol2/caddis-volume-2-sources-stressors-responses-sediments.

United States Environmental Protection Agency. (2021, May 13). *Polychlorinated Biphenyls (PCBs)*. https://www.epa.gov/pcbs/learn-about-polychlorinated-biphenyls-pcbs#healtheffects.

van der Oost, R., Opperhuizen, A., Satumalay, K., Heida, H., and Vermeulen, N. P. E. (1996). Biomonitoring aquatic pollution with feral eel (*Anguilla anguilla)* I. Bioaccumulation: biota-sediment ratios of PCBs, OCPs, PCDDs and PCDFs. *Aquatic toxicology, 35*(1), 21-46, https://doi.org/10.1016/0166-445X(96)00002-1.

Verhaert, V., Covaci, A., Bouillon, S., Abrantes, K., Musibono, D., Bervoets, L., Verheyen, E., and Blust, R. (2013). Baseline levels and trophic transfer of persistent organic pollutants in sediments and biota from the Congo River Basin (DR Congo). *Environment International,59*, 290-302. https://doi.org/10.1016/j.envint.2013.05.015.

World Health Organisation. (1993). *Polychlorinated Biphenyls and Terphenyls Environmental Health Criteria.* Geneva. p. 140.

Yang, X., Wang, L., Zhang, A., Liu, X., Bidegain, G., Zong, H., Guan, C., Song, M., Qu, L., Huang, W., and Yuan, X. (2019). Levels, sources and potential risks of polychlorinated biphenyls and organochlorine pesticides in sediments of Qingduizi Bay, China: does developing mariculture matter? *Frontiers in Marine Science ,6,* 602. https://doi.org/10.3389/fmars.2019.00602.

Zahed, M. A., Nabi, B. G., Pardakhti, A., Esmaili-Sari, A.., and Mohajeri, S. (2009). Determination of polychlorinated biphenyl congeners in water and sediment in North West Persian Gulf, Iran. *Bulletin of Environmental Contamination and Toxicology, 83*(6)*,* 899-902. https://doi.org/10.1007/s00128-009-9874-6.