Bioaccumulation and Human Health Risk of Polycyclic Aromatic Hydrocarbons (Pahs) Concentration in Fiddler Crab (*Afruca Tangeri*) From Bomu Creek, Niger Delta, Nigeria.

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Abstract
Fiddler crabs are sediment-dwelling intertidal crustaceans that are continuously exposed to hydrocarbons deposited in mangrove creeks and may pass them on through the food web. This study determined the concentrations of the sixteen USEPA priority polycyclic aromatic hydrocarbons (PAHs) in the West African fiddler crab (Afruca tangeri) from Bomu Creek, Gokana, Rivers State, Nigeria, and estimated the human health risk associated with consumption of the crab tissue. Crab tissue was collected monthly from three stations (in duplicate) between February and May 2026 and analysed by gas chromatography-mass spectrometry (GC-MS). Dietary daily intake (DDI), carcinogenic potency (B(A)Peq), toxic equivalents (TEQ), PAH4, excess cancer risk (ECR) and margin of exposure (MOE) were computed using regulatory limits of the European Union and the European Food Safety Authority (MOE, 10,000) for guidance. All sixteen PAHs were detected, with mean concentrations ranging from 0.152 µg/kg (naphthalene) to 8.432 µg/kg (dibenzo[a,h]anthracene); high molecular weight congeners accounted for 87% of the total PAH Concentration in Afruca tangeri. Concentrations did not differ significantly among stations (P>0.05) but varied between months for fluorene, fluoranthene, pyrene, benzo[a]anthracene and chrysene (P<0.05). Benzo[a]pyrene (0.885 µg/kg) and PAH4 (8.000 µg/kg) were below the European Union maximum limits of 5.0 and 30.0 µg/kg, respectively. The DDI of individual congeners ranged from 0.0084 to 0.4621 µg/day. The TEQ was 48.25 µg/kg BaP equivalents, 87% of which came from dibenzo[a,h]anthracene. The summed ECR (8.58 × 10-4) exceeded the USEPA benchmark of 10^{-6}. whereas the MOE of every congener and of PAH4 exceeded the critical value of 10,000, although that of dibenzo[a,h]anthracene (10,605) was close to it. Diagnostic ratios indicated PAH sources of pyrogenic origin. The study concluded that Afruca tangeri in Bomu Creek has a measurable PAH concentration of potential carcinogenic concern, and recommends regular monitoring, investigation of combustion-related sources, and use of the species as a sentinel for PAH pollution.

Keywords: *Bioaccumulation; Afruca tangeri; Polycyclic aromatic hydrocarbons; Health risk; Niger Delta*

Introduction

In the Niger Delta, the problem of water and sediment pollution has been of concern to all stakeholders, following the rate and extent of degradation of the environment and water bodies by human activities, particularly from industrial and domestic sources (Daka *et al.*, 2007; Daka and Moslen, 2013; Moslen and Daka, 2014; Moslen and Daka 2016). Polycyclic aromatic hydrocarbons (PAHs) are semi-volatile organic compounds made up of two or more fused aromatic rings. They occur widely in the environment from both natural processes and anthropogenic activities, the major sources being petroleum spills, industrial and domestic effluents, and the incomplete combustion of coal, oil, gas, wood, plastics and other organic materials (Abdel-Shafy and Mansour, 2016; Lee *et al.,* 2021; Ambade *et al.,* 2022). Sixteen PAHs are designated priority pollutants by the United States Environmental Protection Agency (USEPA), and several of them are classified as probable or possible human carcinogens (US EPA, 2013; IARC, 2023). Seafood is an important route through which humans are exposed, so the occurrence of PAHs in edible aquatic organisms is of public health concern (Moslen *et al.,* 2019). The Niger Delta of Nigeria is a region where decades of oil exploration, pipeline vandalism and artisanal refining have released hydrocarbons into creeks and mangrove swamps, with attendant damage to ecosystems and local livelihoods (Okechukwu *et al.,* 2021; Udofia *et al.,* 2021). PAHs have been reported in sediments and edible aquatic species of the region, with variable cancer risk estimates for consumers (Ofori *et al.,* 2021; Saunders *et al*., 2022). Hydrophobic PAHs bind to particles and settle into bottom sediments, which then act as a long-term source of exposure to benthic organisms.

The West African fiddler crab, *Afruca tangeri* (Eydoux, 1835), is a burrowing intertidal crab of the family Ocypodidae that feeds on organic matter in the surface mud of mangrove and estuarine flats (Moruf and Ojetayo, 2017). Its constant contact with, and ingestion of, sediment exposes it to sediment-bound contaminants, and crustaceans have a more limited capacity than fish to metabolise and eliminate parent PAHs (Honda and Suzuki, 2020). The crab has therefore been proposed as a biomonitor of hydrocarbons and metals in Niger Delta mangroves, and it is a prey item that can pass contaminants to larger crabs, birds and fish eaten by local people (Numbere, 2020). Despite this, data on PAH concentrations in *Afruca tangeri* and on the health risk associated with its tissue are scarce, particularly for Bomu Creek in Gokana, Rivers State.

This study was therefore undertaken to determine the concentrations of the sixteen USEPA priority PAHs in the tissue of *Afruca tangeri* from Bomu Creek, to examine their spatial and temporal variation, to infer likely sources, and to assess the human health risk associated with consumption using regulatory limits for guidance.

Materials and Methods

Study area: The study was carried out in Bomu Creek, Gokana Local Government Area of Rivers State, in the Niger Delta (Fig. 1). The creek is tidally influenced and fringed by mangrove forest with muddy, organic-rich sediments that provide habitat for benthic invertebrates including *Afruca tangeri*. The creek supports fishing and other livelihood activities, and is exposed to oil and gas infrastructure and illegal refining (Numbere, 2020).

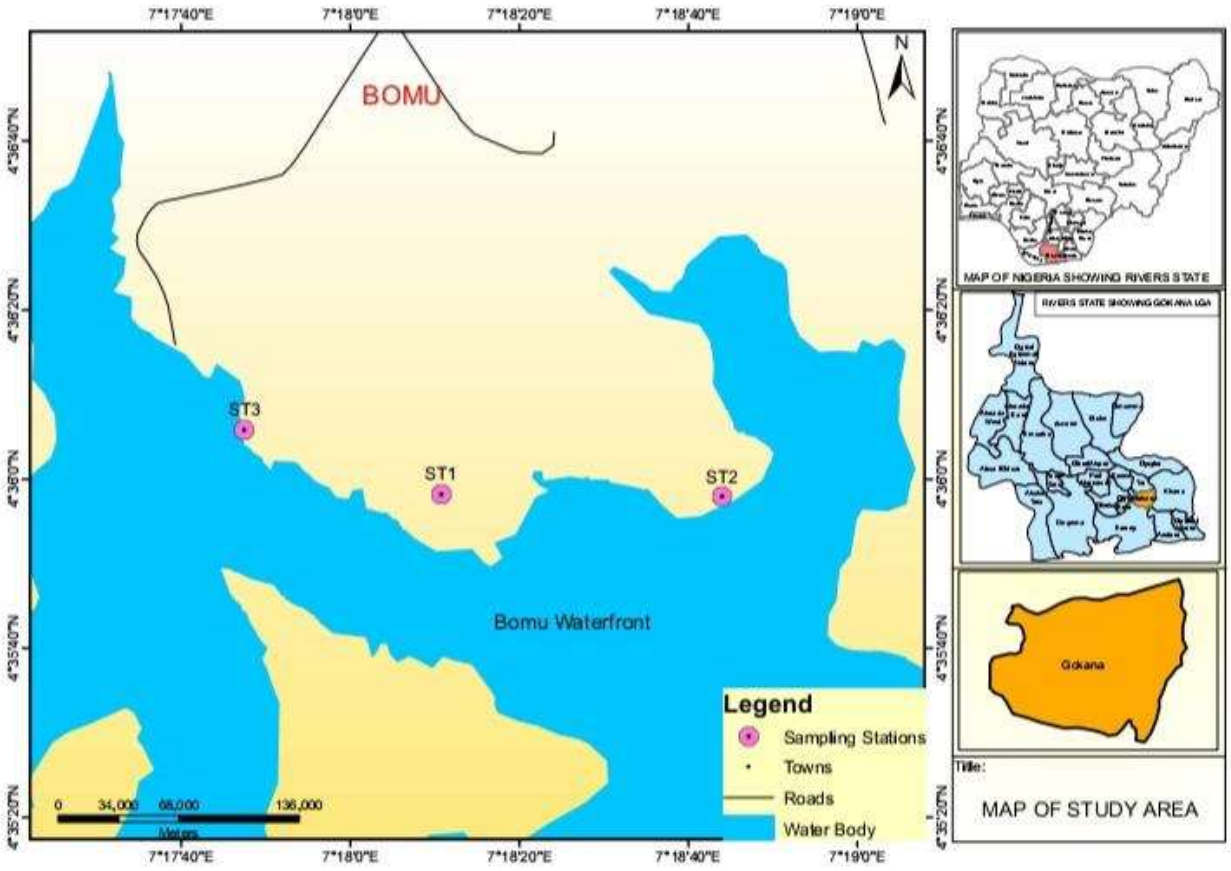


Fig. 1: Map of the study area showing the three sampling stations (ST1–ST3) in Bomu Creek, Gokana LGA, Rivers State

Collection of Samples: Crabs (*Afruca tangeri*) were handpicked at low tide at the different stations (Fig 1) on the intertidal zones. Samples were collected at the three stations irrespective of size and sex and the coordinates of each station were recorded with a global positioning system. Sampling was carried out monthly for four consecutive months (February to May 2026). Duplicate samples were collected at each station to account for microspatial variation (APHA, 2017), giving 24 samples (3 stations × 2 replicates × 4 months)). The sampling points are indicated on the map (Fig 1).

The samples were put in a labelled container, stored in an ice chest, and transported to the laboratory immediately.

Extraction, Analysis and Gas chromatography: To get rid of pollutants and adherent sediments, the crab samples were thoroughly cleaned with distilled water. Clean dissection instruments were then used to gently extract the edible tissues.

To guarantee consistency, the tissues were homogenized. A sonicating tube that had been previously rinsed with dichloromethane was filled with approximately 5 g of homogenized tissue. 20ml dichloromethane was added, to remove PAHs from the tissue matrix, the mixture was sonicated for an hour. To get rid of lipids, moisture, and contaminants, the extract was run through

a column filled with silica gel and anhydrous sodium sulphate. A Petri dish was used to collect filtrate.
20ml of the extracts were concentrated. Solvent exchange was carried out by adding 4ml cyclohexane. The extract was re-concentrated to 2 mL and transferred into a GC vial.

GC-MS analysis: The extracts were analysed on an Agilent 7890 gas chromatograph coupled to a 5975 mass selective detector (Agilent Technologies, Santa Clara, CA, USA). The sixteen USEPA priority PAHs determined were naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Ace), fluorene (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Fla), pyrene (Pyr), benzo[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), indeno[1,2,3-cd]pyrene (InP), dibenzo[a,h]anthracene (DbA) and benzo[g,h,i]perylene (BghiP). Values below the detection limit were treated as zero in computing means.

Exposure Assessment: Evaluation of the Dietary Daily Intake (DDI) by consuming PAHs contaminated seafood (*Afruca tangeri*) was done for the adult population using a seafood ingestion rate (IFR) of 0.0548 kg/day as applied by Moslen *et al.* (2021) and an average adult body weight (BW) of 70 kg (Tongo et al., 2017).
DDI = Ci × IFR(1)
where Ci is the mean concentration of congener i (µg/kg) and DDI is expressed in µg/day.
Health risk assessment: Carcinogenic potency of each congener, expressed as benzo[a]pyrene equivalents, was calculated as B(A)Peq = Ci × TEFi (Equation 2), where TEFi is the toxic equivalency factor of Nisbet and LaGoy (1992). The toxic equivalent quotient (TEQ) is the sum of B(A)Peq over all sixteen congeners (Equation 3), and the PAH4 index is the sum of BaA, Chr, BbF and BaP (Equation 4).
B(A)Peq = Ci × TEFi(2)
TEQ = Σ B(A)Peq(3)
PAH4 = BaA + Chr + BbF + BaP(4)
Excess cancer risk (ECR) was estimated with Equation 5 (Xia et al., 2010), where Q is the carcinogenic slope factor of BaP (7.3 (mg/kg/day)-1), ED is the exposure duration (30 years), BW is adult body weight (70 kg) and ATn is the averaging time (8,760 days). An ECR above 10^{-6} was taken to exceed the USEPA guideline, and 10^{-4} or more was regarded as serious (Jing et al., 2013).
ECR = (Q × B(A)Peq × IFR × ED) / (BW × ATn)(5)
The margin of exposure (MOE) was calculated with Equation 6, where BMDL10 is 70 µg/kg bw/day for individual congeners (BaP) and 340 µg/kg bw/day for PAH4 (EFSA, 2008). An MOE below 10,000 indicates a potential concern for public health (EFSA, 2005).
MOE = (BMDL10 × BW) / DDI(6)

Statistical analysis: Differences in congener concentrations among stations and among months were tested by two-way analysis of variance (ANOVA) using adjusted sums of squares, and differences were considered significant at $P<0.05$.

Results and Discussion
Concentrations of PAHs in *Afruca tangeri*: All sixteen USEPA priority PAHs were detected in the tissue of *Afruca tangeri* (Table 1). Mean concentrations ranged from 0.152 µg/kg for naphthalene to 8.432 µg/kg for dibenzo[a,h]anthracene, which was followed by

benzo[b]fluoranthene (4.879 µg/kg), while naphthalene, anthracene, fluorene and acenaphthene were the lowest. The sum of the sixteen congeners was 23.33 µg/kg, of which the HMW congeners made up 87% (20.39 µg/kg) and the LMW congeners 13% (2.94 µg/kg). The total PAH values of this study were inconsistent with those earlier reported by Moslen *et al* (2021) in another biota (Thais coronata) with total PAH concentrations (µg/kg) varying between 65.68 -- 173.52 within the same study region.

Table 1: Mean concentrations (µg/kg) of PAHs in *Afruca tangeri* tissue from Bomu Creek (n = 24) and associated dietary daily intake (DDI, µg/day), carcinogenic potency (B(A)Peq, µg/kg), excess cancer risk (ECR) and margin of exposure (MOE)

PAH	MEAN (ug/kg)	TEF	DDI	B(A)Pteq	ECR	MOE
Naphthalene	0.152	0.001	0.0084	0.0002	$2.98x10^{-9}$	587,036
Acenaphthylene	1.180	0.001	0.0647	0.0012	$2.31x10^{-8}$	75,772
Acenaphthene	0.260	0.001	0.0143	0.0003	$5.09x10^{-9}$	343,874
Fluorene	0.243	0.001	0.0133	0.0002	$4.75x10^{-9}$	368,074
Phenanthrene	0.923	0.001	0.0506	0.0009	$1.81x10^{-8}$	96,914
Anthracene	0.178	0.01	0.0098	0.0018	$3.48x10^{-8}$	502,402
Fluoranthene	0.509	0.001	0.0279	0.0005	$9.96x10^{-9}$	175,628
Pyrene	0.580	0.001	0.0318	0.0006	$1.14x10^{-8}$	154,149
Benzo(a)anthracene	1.010	0.1	0.0554	0.1010	$1.98x10^{-6}$	88,500
Chrysene	1.226	0.01	0.0672	0.0123	$2.40x10^{-7}$	72,916
Benzo(b)fluoranthene	4.879	1.0	0.2674	4.879	$9.55x10^{-6}$	18,326
Benzo(k)fluoranthene	1.170	0.1	0.0641	0.1170	$2.29x10^{-6}$	76,422
Benzo(a)pyrene	0.885	0.1	0.0485	0.8850	$1.73x10^{-5}$	101,082
Indeno(1,2,3-cd)pyrene	0.796	0.1	0.0436	0.0796	$1.56x10^{-6}$	112,332
Dibenzo(a,h)anthracene	8.432	5.0	0.4621	42.159	$8.25x10^{-4}$	10,605
Benzo(g,h,i)perylene	0.904	0.01	0.0495	0.0090	$1.77x10^{-7}$	98,931

PAH4 = 8.000 ug/kg; DDI(PAH4) = 0.4384; TEQ(PAH4) = 1.486; ECR(PAH4) = $9.94e^{-5}$; MOE(PAH4) = 54,285.
TEQ (all 16 congeners) = 43.86 µg/kg. Sum of individual ECR values = 8.58 x 10-4

Spatial and temporal variation: Concentrations of all sixteen congeners were statistically similar among the three stations (P>0.05; Table 3), which suggests comparable exposure along the creek, probably because of comparable intertidal habitats and tidal mixing. Significant differences between months were found for fluorene (P = 0.022) and for fluoranthene, pyrene, benzo[a]anthracene and chrysene (P = 0.001), and anthracene was marginal (P = 0.053) (Table 2). For most congeners the highest concentrations were recorded in February, the dry-season month, with lower values in later months. Such a February peak is consistent with episodic inputs of combustion-related hydrocarbons in the dry season, when artisanal refining activity along creek banks is easier, followed by dilution, tidal flushing and degradation as the detectable in crab tissue at St 3 in April and May at about 1.3 µg/kg although most other congeners had declined, illustrating the persistence of HMW PAHs in tissue after the ambient pulse has passed, and supporting the use of A. tangeri as a sentinel that integrates earlier exposure (Numbere, 2020). Moslen and Aigberua

(2018) in their studies also reported PAH in surface water of the Niger Delta Region with mean values ranging from 0.001 ± 0.0003 – 0.384 ± 0.104 mg/l with
significant difference ($p<0.001$) between locations. In another study of biota (Anadara senilis) in the Niger Delta region, Moslen et al (2019) reported mean PAH concentration (ngkg−1) ranging from 12.0 + 5.0–5500.0 +1000 ngkg-1 while total PAH values ranged from 3000.0-16,000.0. ngkg-1.

Table 2: Summary of two-way ANOVA (F- and P-values) for PAH congeners in *Afruca tangeri* tissued among months

Parameter	F-value	P-value
Naphthalene	2.91	0.123
Acenaphthylene	1.84	0.240
Acenaphthene	3.22	0.104
Fluorene	7.03	. 0.022
Phenanthrene	1.11	0.417
Anthracene	4.63	0.053
Fluoranthene	95.27	0.001
Pyrene	250.73	0.001
Benzo(a)anthracene	109.81	0.001
Chrysene	75.75	0.001
Benzo(b)fluoranthene	1.33	0.351
Benzo(k)fluoranthene	3.97	0.071
Benzo(a)pyrene	3.82	0.076
Dibenzo(a,h)anthracene	1.00	0.455
Indeno(1,2.3-cd)pyrene	1.00	0.455
Benzo(g,h,i)perylene	1.00	0.455

Table 3: Summary of two-way ANOVA (F- and P-values) for PAH congeners in *Afruca tangeri* tissue among stations.

Parameter	F-value	P-value
Naphthalene	0.90	0.454
Acenaphthylene	1.01	0.419
Acenaphthene	0.97	0.430
Fluorene	0.95	0.438
Phenanthrene	0.79	0.498
Anthracene	1.00	0.422
Fluoranthene	0.75	0.511
Pyrene	1.00	0.422
Benzo(a)anthracene	0.53	0.615
Chrysene	1.00	0.422
Benzo(b)fluoranthene	1.00	0.422
Benzo(k)fluoranthene	1.00	0.422
Benzo(a)pyrene	1.00	0.422
Dibenzo(a,h)anthracene	1.00	0.422

Indeno(1,2.3-cd)pyrene	1.00	0.422
Benzo(g,h,i)perylene	1.00	0.422

Dietary intake and carcinogenic potency: The DDI of individual congeners ranged from 0.0084 to 0.4621 µg/day (Table 1), and was 0.4384 µg/day for PAH4. Expressed per kilogram body weight, the highest intake (0.0066 µg/kg bw/day for DbA) falls within the range of 0 -- 0.0005 mg/kg/day reported for shellfish in the Niger Delta (Tongo et al., 2018). The carcinogenic potencies (B(A)Peq) ranged from 0.0002 µg/kg for naphthalene to 42.159 µg/kg for dibenzo[a,h]anthracene. The TEQ of all sixteen congeners was 48.25 µg/kg BaP equivalents, of which DbA contributed 87%, BbF 10% and BaP 2%; the TEQ of PAH4 was 5.88 µg/kg. The dominance of DbA arises from the combination of the highest mean concentration and the highest toxic equivalency factor (5), so that a modest tissue concentration translates into a large toxic equivalent.

Excess cancer risk: ECR values of individual congeners ranged from 2.98×10^{-9} (naphthalene) to 8.25×10^{-4}(DbA), and the sum over all congeners was 8.58×10^{-4} (Fig. 3). Dibenzo[a,h]anthracene alone contributed 96% of this sum, followed by BaP (2.0%) and BbF (1.1%). The summed ECR exceeds the USEPA guideline of 10^{-6} (one additional cancer case in a million over a lifetime) and the value of 10^{-4} conventionally regarded as serious (Jing et al., 2013). It is considerably higher than the values of 10^{-8} - 10^{-5} reported for T. coronata (Moslen et al., 2021) and the 1.3×10^{-6} 4.1×10^{-6} reported for edible species from Bodo, Rivers State (Saunders *et al.,* 2022). Because the estimate uses mean concentrations over the four months, the high value reflects mainly the large contribution of DbA and BbF to the February samples. Excluding DbA, the summed ECR of the remaining congeners is of the order of 3×10^{-6} which is still above 10^{-6}.

Margin of exposure: The MOE of all individual congeners ranged from 10,605 (DbA) to 587,036 (naphthalene), and that of PAH4 was 54,285. All are above the critical value of 10,000 (EFSA, 2005), which indicates low concern for public health from the margin-of-exposure approach. The MOE of DbA, however, was only marginally above the threshold, and that of BbF (18,326) was also low, so the safety margin for these two congeners is small.

Conclusion

This study determined PAH concentrations in the fiddler crab *Afruca tangeri* from Bomu Creek and evaluated the health risk of consuming its tissue. All sixteen priority PAHs were detected, with HMW congeners, especially dibenzo[a,h]anthracene and benzo[b]fluoranthene, dominating the burden. Concentrations did not vary among stations but varied between months for several congeners, with highest values generally in February. BaP and PAH4 were below the European Union limits, and the MOE of all congeners and of PAH4 exceeded 10,000, although that of DbA was close to the threshold. The summed ECR of 8.58×10^{-4} exceeded the USEPA guideline of 10^{-6}, with DbA the main contributor, and diagnostic ratios indicated pyrogenic sources. The study therefore concludes that *Afruca tangeri* in Bomu Creek carries a PAH burden of potential carcinogenic concern, and recommends (i) higher-frequency monitoring of PAHs in the creek and its biota, with attention to DbA and BbF, (ii) investigation of combustion-related sources, including artisanal refining, by the relevant regulatory agencies, and (iii) use of *Afruca tangeri* as a sentinel species for PAH pollution in Niger Delta mangroves.

References

Abdel-Shafy, H. I., & Mansour, M. S. M. (2016). A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. Egyptian Journal of Petroleum, 25(1), 107–123.

Ambade, B., Sethi, S. S., Kurwadkar, S., Mishra, T., & Tripathee, L. (2022). Accumulation of polycyclic aromatic hydrocarbons (PAHs) in surface sediments and soil of Mahanadi River Estuary: Abundance, source, risk. Marine Pollution Bulletin, 183, Article 114073.

American Public Health Association, American Water Works Association, & Water Environment Federation. (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association.

Brandli, R. C., Bucheli, T. D., Kupper, T., Mayer, J., Stadelmann, F. X., & Tarradellas, T. (2007). Fate of PCBs, PAHs and their source characteristic ratios during composting and digestion of source-separated organic waste in full-scale plants. Environmental Pollution, 148, 520–528.

Daka, E. R., & Moslen, M. (2013). Spatial and temporal variation of physicochemical parameters of sediment from Azuabie Creek of the upper Bonny Estuary, Niger Delta. Research Journal of Environmental and Earth Sciences, 5(4), 219–228.

Daka, E. R., Moslen, M., Ekeh, C. A., & Ekweozor, I. K. E. (2007). Sediment quality status of two creeks in the upper Bonny Estuary, Niger Delta, in relation to urban/industrial activities. Bulletin of Environmental Contamination and Toxicology, 78, 515–521.

European Commission. (2011). Commission Regulation (EU) No 835/2011 of 19 August 2011 amending Regulation (EC) No 1881/2006 as regards maximum levels for polycyclic aromatic hydrocarbons in foodstuffs. Official Journal of the European Union, L215, 4–8.

European Food Safety Authority. (2005). Opinion of the Scientific Committee on a request from EFSA related to a harmonised approach for risk assessment of substances which are both genotoxic and carcinogenic. EFSA Journal, 3(10), Article 282.

European Food Safety Authority. (2008). Scientific opinion of the Panel on Contaminants in the Food Chain on a request from the European Commission on polycyclic aromatic hydrocarbons in food. EFSA Journal, 724, 1–114.

Honda, M., & Suzuki, N. (2020). Toxicities of polycyclic aromatic hydrocarbons for aquatic animals. International Journal of Environmental Research and Public Health, 17(4), Article 1363.

International Agency for Research on Cancer. (2023). IARC monographs on the identification of carcinogenic hazards to humans. World Health Organization.

Jing, N., Shi, J., Duan, X., Wang, B., Huang, N., & Zhao, X. (2013). Health risk assessment of dietary exposure to polycyclic aromatic hydrocarbons in Taiyuan, China. Journal of Environmental Sciences, 26, 432–439.

Lee, C. C., Chen, C. S., Wang, Z. X., & Tien, C. J. (2021). Polycyclic aromatic hydrocarbons in 30 river ecosystems, Taiwan: Sources, and ecological and human health risks. Science of the Total Environment, 795, Article 148867.

Moruf, R. O., & Ojetayo, T. A. (2017). Biology of the West African fiddler crab, Uca tangeri (Eydoux, 1835) (Decapoda: Ocypodidae) from a mangrove wetland in Lagos, Nigeria. International Journal of Aquatic Biology, 5(4), 263–267.

Moslen, M., & Aigberua, A. (2018). Heavy metals and hydrocarbon contamination of surface water in Azuabie Creek within Bonny Estuary, Nigeria. Journal of Applied Sciences and Environmental Management, 22(7), 1083–1088.

Moslen, M., Aniekan, I., Onwuteaka, J., & Miebaka, C. A. (2021). Bioaccumulation and consumption safety of a sea food, gastropod mollusc (Thais coronata): Polycyclic aromatic hydrocarbon (PAH) perspective. Journal of Applied Sciences and Environmental Management, 25(7), 1209–1217.

Moslen, M., & Daka, E. R. (2014). Attributes of the subtidal macrobenthos of Azuabie Creek in the upper Bonny Estuary, Niger Delta, Nigeria. Research Journal of Environmental and Earth Sciences, 6, 143–155.

Moslen, M., & Daka, E. R. (2016). Spatio-temporal differences of physico-chemical variables in relation to industrial effluent discharges into Ekerekana and Okochiri creeks, Bonny Estuary of the Niger Delta, Nigeria. Journal of the Nigerian Environmental Society, 10(2), 152–167.

Moslen, M., Miebaka, C. A., & Boisa, N. (2019). Bioaccumulation of polycyclic aromatic hydrocarbon (PAH) in a bivalve (Arca senilis, blood cockles) and health risk assessment. Toxicology Reports, 6, 990–997.

Nasher, E., Heng, L. Y., Zakaria, Z., & Surif, S. (2013). Assessing the ecological risk of polycyclic aromatic hydrocarbons in sediments at Langkawi Island, Malaysia. The Scientific World Journal, 1–3.

Nisbet, I., & LaGoy, P. (1992). Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs). Regulatory Toxicology and Pharmacology, 16, 290–300.

Numbere, A. O. (2020). Mangrove forest management and utilisation under climate change along the Niger Delta coastline. In Mangrove ecosystem ecology and function.

Nyarko, E., Botwe, B. O., & Klubi, E. (2011). Polycyclic aromatic hydrocarbons (PAHs) levels in two commercially important fish species from the coastal waters of Ghana and their carcinogenic health risks. West African Journal of Applied Ecology, 19, 53–66.

Ofori, S. A., Cobbina, S. J., Imoro, A. Z., Doke, D. A., & Gaiser, T. (2021). Polycyclic aromatic hydrocarbon (PAH) pollution and its associated human health risks in the Niger Delta region of Nigeria: A systematic review. Environmental Processes, 8(2), 455–482.

Okechukwu, H. O., Onyena, A. P., Sam, K., Zabbey, N., & Osuji, L. C. (2021). Review of polycyclic aromatic hydrocarbons (PAHs) contamination issues in the Niger Delta environment, Nigeria. Research Journal of Environmental Sciences, 15(1), 1–19.

Pham, L. T., Hoang, T. T. T., Tu, L. C. T., Tran, Y. H. T., Le, B. D., Nguyen, D. V., Do, H. X., & Thai, N. V. (2019). Bioaccumulation and health risk assessment of polycyclic aromatic hydrocarbons in oyster (Crassostrea sp.) and gastropod (Cymatium sp.) species from the Can Gio Coastal Wetland in Vietnam. Marine and Freshwater Research. https://doi.org/10.1071/MF19055

Saunders, D., Carrillo, J. C., Gundlach, E. R., Iroakasi, O., Visigah, K., Zabbey, N., & Bonte, M. (2022). Analysis of polycyclic aromatic hydrocarbons (PAHs) in surface sediments and edible aquatic species in an oil-contaminated mangrove ecosystem in Bodo, Niger Delta, Nigeria. Science of the Total Environment, 832, Article 154802.

Tongo, I., Etor, I. E. E., & Ezemonye, L. I. N. (2018). Human health risk assessment of PAHs in fish and shellfish from Amariaria community, Bonny River, Nigeria. Journal of Applied Sciences and Environmental Management, 22(5), 731–736.

Tongo, I., Ogbeide, O., & Ezemonye, L. (2017). Human health risk assessment of polycyclic aromatic hydrocarbons (PAHs) in smoked fish species from markets in southern Nigeria. Toxicology Reports, 4, 55–61.

Udofia, U. S., Ameh, C., Miller, E., & Ekpenyong, M. S. (2021). Investigating the origin and tissue concentration of polycyclic aromatic hydrocarbon in seafood and health risk in Niger Delta, Nigeria. Environmental Science: Processes & Impacts, 23, 1803–1814.

U.S. Environmental Protection Agency. (2013). Polycyclic aromatic hydrocarbons (PAHs) fact sheet. Office of Solid Waste and Emergency Response.

Xia, Z., Duan, X., Qiu, W., Liu, D., Wang, B., Tao, S., Jiang, Q., Lu, B., Song, Y., & Hu, X. (2010). Health risk assessment on dietary exposure to polycyclic aromatic hydrocarbons (PAHs) in Taiyuan, China. Science of the Total Environment, 408(22), 5331–5337. https://doi.org/10.1016/j.scitotenv.2010.08.008