Research article

Human health risk assessment of TPHs in brackish water prawn (*Nematopalaemon hastatus*, AURIVILLUS, 1898)

Joshua Oluwatobi Akinola a,*, Olamide Olaronke Olawusi-Peters a, Victoria Omolara Enobong Apkambang b

a Department of Fisheries and Aquaculture Technology, Federal University of Technology, Akure Ondo State, Nigeria
b Department of Industrial Chemistry, Federal University of Technology, Akure Ondo State, Nigeria

**ARTICLE INFO**

**Keywords:**
- Environmental science
- Nematopalaemon hastatus
- Carcinogenic
- Petroleum aliphatic hydrocarbon
- Health risk

**ABSTRACT**

Edible aquatic brackish water shellfish (*Nematopalaemon hastatus*) obtained from the coastal waters of Ondo state, Nigeria was analyzed between 2017 and 2018 for the concentration of Total Petroleum Hydrocarbons (TPHs). TPHs level in the sampled species was measured using gas chromatography-flame ionization detector (GC/FID). Possible human health risks associated with the ingestion of the sampled species were determined by estimated dietary intake (EDI) and health risk index (HRI). The TPH level observed in the biota species (*Nematopalaemon hastatus*) varied across the period of study. The highest concentration was recorded in February (3401.55 mg/kg) while the lowest was recorded in April (1995.99 mg/kg). The TPH values of the analyzed fish species exceeded the threshold value of 50 mg/kg for fish. Petroleum aliphatic hydrocarbons attained higher concentration in n-Hentriacontane, n-Tridecane, n-Nonane, n-Tetradecane, n-Triacontane, n-Tetracosane and n-Octacosane with mean concentration values of (2242.02, 189.60, 40.90, 40.72, 25.79, 15.40 and 8.73 mg/kg) respectively. The EDI and HRI had their peak dose and index value (1.19 and 2.37) in February and lowest dose and index value (0.70 and 1.39) in April respectively. In addition, the HRI exceeded the safety limit of one. The findings from this study reveal a significant carcinogenic health risk connected with the consumption of the sea species. Thus, the species is therefore considered unfit and unsafe for consumption.

**1. Introduction**

Total petroleum hydrocarbons (TPH) are persistent and priority pollutants that evolve from the increased exploration and exploitation of crude oil and gas resources in the coastal zones. These chemical substances rank high among the global environmental disasters and are sourced from increased industrial, agricultural and anthropogenic activities in the environment (Copat et al., 2013; Awajiukwu, 2015).

Due to aliphatics lipophilicity and high toxicity, petroleum hydrocarbons biologically amplify to high concentrations in food webs and accumulate in fishes (fin and shellfish), binding to the muscle tissues (Akinola et al., 2019). The susceptibility, exposure level and duration of aliphatic hydrocarbons in organisms and exposed individuals often result in numerous health implications. The associated implications include; disruption in the activities of various body organs, severe damage to the pancreas, kidney, liver, blood circulatory system, etc, disorders, diseases and ultimately death (Abha and Singh, 2012; Oyinbo et al., 2018).

Fish is a staple source of proteins with numerous health benefits. It is rich in minerals (calcium, phosphorus, iron, magnesium, etc), vitamins (Riboflavin, D, B12, etc), omega-3 fatty acids (Wim et al., 2007; Castro-Gonzalez and Mendez-Arment, 2008). Despite these numerous benefits to human health, huge potential risks arising from the exposure of toxic chemicals to fish species makes them unfit and unhealthy for consumption.

According to USEPA (2012), Human health risk assessment can be defined as the classification of present and future adverse human health effects to hazards exposed in the environment. This method uses scientific and statistical tools/models to classify and quantify various hazards, authenticates possible routes and channels of exposure, and compute a numerical value to represent the impending risk (Lushenko, 2010).

TPH levels in Nigeria Niger Delta areas have received considerable attention in recent times due to its high carcinogenic and mutagenic potential. Akinola et al. (2019) evaluated the ecological hazards of TPH infected *Nematopalaemon hastatus* and obtained high values attributing it...
to the pollution status of the environment. The authors called for a study on the potential health risks of eating TPH contaminated aquatic species as food. Since shellfish is highly nutritive and essential in the human diet composition of the Coastal areas of Nigeria (Olawusi-Peters et al., 2017), to sustain a healthy and diverse coastal environment and secure the health benefits of fish consumers thus becomes imperative.

Therefore, this research was done to evaluate the level of contamination and assess the possible hazards of TPH to human health from consumption. This will provide baseline information on the human health status of the species inhabiting the aquatic ecosystem.

2. Materials and methods

2.1. Study area

The location of study falls within latitudes 6°11’58.88”North and longitudes 4°40’21.259”East of the Greenwich Meridian (Figure 1). Ayetoro was purposefully selected based on previous information for extensive shrimping, accessibility and the high concentration of effluents it receives from various industrial activities (Olawusi-Peters et al., 2017).

2.2. Research methods

2.2.1. Collection of samples

A widely distributed, commercially important and extensively exploited species for food in Ondo State coastal areas, Nigeria (Nematopalaemon hastatus) was chosen as a bioindicator of TPH. The samples were collected monthly in triplicate between 10:00 h to 12:00 h at the landing site of shrimpers and were wrapped in aluminium foil. The samples were immediately preserved in ice-packed cooler and transferred to the laboratory where they were frozen at -4°C to preserve their quality. Identification of the shrimps to species level was done using the FAO Species Identification Guide (FAO, 1987).

2.2.2. Determination of total petroleum hydrocarbon (TPH)

TPHs was determined according to the method prescribed by EPA (2000) and the analysis was carried out at the Sustainable Development Laboratory, Lekki Phase II, Lagos Nigeria.

2.2.2.1. Extraction of petroleum hydrocarbons from fish samples. Fifteen grams (15 g) of fish tissue was weighed using analytical balance into a clean mortar and then grounded with pestle alongside 10 g of anhydrous sodium sulfate until it was completely dried and homogenized. The sample extraction was carried out using 50 ml 1:1 Hexane: Dichloromethane (DCM) as an extracting solvent. Ten grams of the homogenized fish sample was placed in 50 ml extraction bottle with the fish TPH contents extracted by shaking as described by Schwab et al. (1999) and Okpashi et al. (2017). The bottle with the content was placed in an ultrasonic bath for 60 min, agitated and allowed to settle. The samples extract was carefully decanted and dried with anhydrous sodium sulfate. The samples’ extract was then concentrated to 2 ml using rotary evaporator maintained at 20°C.

2.2.2.2. Silica gel clean-up and separation. Fish extracts were prepared in a chromatographic column (10 mm i. d. × 30 cm) filled with prepared slurry from 10 g activated silica gel and 2 cm anhydrous sodium sulphate
(Na₂SO₄). The sample was eluted using 20 ml of n-pentane. It was then concentrated with the solvent exchanged to n-hexane. A blank sample was processed the same way for quality assurance (Olaniran et al., 2019).

### 2.2.2.3. GC-FID determination of saturated (aliphatic) hydrocarbons (TPH)

Aliphatic standard, 1000 ppm (Catalog Number: DRH-008S-R2) containing 35 aliphatic hydrocarbon components (C₈ – C₄₀, Pristane, and Phytane) was purchased from AccuStandard. Five (5) point serial dilution calibration standards (2.00, 6.00, 10.00, 50.00, 100.00 ppm) was prepared from the stock and used to calibrate the GC-FID prior analysis. Saturated hydrocarbon (n-alkanes) was analyzed using Agilent 7890B Gas chromatograph equipped with a flame ionization detector (FID), fitted with an HP-5 capillary column and coated with 5% Phenyl Methyl Siloxane (30 m length × 0.32mm diameter × 0.25μm film thickness) (Agilent Technologies). One microlitre of the sample was injected in splitless mode at an injection temperature of 220°C, pressure of 14.861 psi and a total flow of 21.364 ml/min. Purge flow to split vent was set at 15 ml/min at 0.75 minute. The oven was initially programmed at 60°C (1 min), then ramped at 7.5°C/min to 300°C (9 min). FID temperature was 300°C with Hydrogen: Air flow at 30 ml/min: 300 ml/min. Nitrogen was used as makeup gas at a flow of 18 ml/min. After calibration, the samples were analyzed and corresponding concentrations were calculated. The SHC labelled chromatograms were also extracted and reported.

### 2.2.3. Risk assessment of total petroleum hydrocarbons (Carcinogens)

A risk assessment is used to evaluate common, potential environmental contaminants released into the environment and determine the need for additional and remedial actions. The risks assessed were the estimated dietary intake (EDI) and health risk index (HRI). Calculations were done using standard methods. A risk assessment index greater than 1 indicates a threat to human health (USEPA, 1986).

#### 2.2.3.1. Potential dietary intake estimation (EDI)

The estimated dietary intake of the aliphatic hydrocarbons in *Nematopalaemon hastatus* was determined by the following equation:

\[
\text{EDI} = \frac{C_m \times DFI \times BW}{\text{SF}}
\]

Where: EDI is Estimated Dietary Intake.

- **Cm**: Concentration of chemical substances.
- **DFI**: Daily fish intake is 0.048 mg/kg (FAO, 2007).
- **BW**: Average body weight is 70 kg (FAO, 2014).

#### 2.2.3.2. Health risk index (HRI)

Health risk index of the aliphatic hydrocarbons through consumption of the contaminated seafood was calculated using the equation below (US EPA, 2000). Values greater than 1 is an indicator of potential cancer risk.

\[
\text{HRI} = \frac{\text{EDI}}{\text{SF}}
\]

| Components | November 2017 | December 2017 | January 2018 | February 2018 | March 2018 | April 2018 |
|------------|---------------|---------------|--------------|--------------|------------|------------|
| C₈ - (n-Octane) | ND            | 1.82          | ND           | ND           | ND         | ND         |
| C₉ - (n-Nonane) | 6.89          | ND           | 58.71        | 78.69        | 39.39      | 61.71      |
| C₁₀ - (n-Decane) | 2.91          | 0.70          | 2.95         | 5.53         | 6.57       | 3.95       |
| C₁₁ - (n-Undecane) | 24.011       | 0.20          | 0.03         | 0.08         | 0.05       | 0.04       |
| C₁₂ - (n-Dodecane) | 1.55          | 1.77          | ND           | ND           | ND         | ND         |
| C₁₃ - (n-Tridecane) | 108.26        | 207.40        | 156.77       | 378.67       | 220.65     | 65.88      |
| C₁₄ - (n-Tetradecane) | 4.74          | 69.94         | 45.88        | 57.65        | 32.32      | 33.77      |
| C₁₅ - (n-Pentadecane) | ND           | ND            | ND           | ND           | ND         | ND         |
| C₁₆ - (n-Hexadecane) | 4.65          | 3.01          | 2.87         | 4.46         | 4.57       | 2.87       |
| C₁₇ - (n-Heptadecane) | ND           | ND            | 1.14         | 2.35         | 0.15       | 1.14       |
| Pristane | ND            | 0.09          | ND           | ND           | ND         | ND         |
| Phytane | 0.34          | 0.16          | 0.44         | 0.65         | 0.32       | 0.44       |
| C₁₈ - (n-Octadecane) | 0.19          | 0.09          | 0.20         | 0.17         | 0.10       | 0.20       |
| C₁₉ - (n-Nonadecane) | 1.03          | 0.75          | ND           | 0            | ND         | ND         |
| C₂₀ - (n-Icosane) | 0.23          | 0.09          | ND           | 0.13         | ND         | ND         |
| C₂₁ - (n-Heneicosane) | 0.26          | 0.67          | ND           | ND           | ND         | ND         |
| C₂₂ - (n-Tricosane) | 0.50          | 0.72          | 0.44         | 0.02         | 0.01       | 0.06       |
| C₂₃ - (n-Tetracosane) | 18.84         | 14.40         | 11.55        | 17.35        | 16.57      | 13.58      |
| C₂₄ - (n-Pentacosane) | 1.13          | 1.70          | 0.49         | 1.57         | 1.23       | 0.49       |
| C₂₅ - (n-Hexacosane) | 1.07          | 0.55          | 1.46         | 1.57         | 1.00       | 1.46       |
| C₂₆ - (n-Heptacosane) | 5.20          | 9.77          | 1.75         | 6.54         | 2.06       | 1.75       |
| C₂₇ - (n-Octacosane) | 27.15         | 6.39          | 1.52         | 14.35        | 1.46       | 1.52       |
| C₂₈ - (n-Nonacosane) | 0.67          | 0.82          | 3.94         | 3.45         | 2.39       | 3.94       |
| C₂₉ - (n-Hentriacontane) | 20.61         | 22.13         | 25.19        | 35.46        | 26.15      | 25.19      |
| C₃₀ - (n-Dotriacontane) | 1990.92       | 2496.57       | 1998.66      | 2765.67      | 2434.77    | 1765.57    |
| C₃₁ - (n-Tritriacontane) | 7.64          | 7.00          | 5.55         | 7.77         | 4.01       | 3.00       |
| C₃₂ - (n-Tetratriacontane) | 5.17          | 3.14          | 2.34         | 5.35         | 3.37       | 1.05       |
| C₃₃ - (n-Pentatriacontane) | 1.02          | 2.12          | 1.32         | 3.46         | 3.57       | 2.85       |
| C₃₄ - (n-Hexatriacontane) | 5.88          | 1.12          | 2.01         | 4.54         | 5.44       | 4.79       |
| C₃₅ - (n-Heptatriacontane) | 2.92          | 1.82          | 1.66         | 4.77         | 4.36       | ND         |
| **Total Aliphatic (mg/kg)** | **2244.29** | **2856.99** | **2203.18** | **3401.55** | **2811.73** | **1995.99** |

ND = Not detected.
Where: HRI is Health Risk Index.
EDI: Estimated Dietary Intake.
SF: Slope Factor, which is 2.0 (mg/kg/day).

2.2.4. Statistical analysis

All data obtained were subjected to descriptive statistics to evaluate statistical variation across the period of study using the Statistical Package for Social Scientists, SPSS (Software version 20.0- Full version).

3. Results

3.1. Total petroleum hydrocarbon concentration in N. hastatus

The mean concentration of TPH in N. hastatus from the coastal waters of Ondo State are presented in Table 1. The mean concentration of the total petroleum hydrocarbons across the study period were above the (50 mg/kg) threshold limit of DPR (2011). The trend of concentration across the period of study followed the order: February > December > March > November > January > April. The highest and lowest concentration (3401.55 mg/kg and 1995.99 mg/kg) was recorded in February and April respectively. The month of December, March, November, and January recorded mean concentrations of 2856.99, 2811.73, 2244.29 and 2203.19 mg/kg respectively. n-Hentriacontane (C31) was greatly bioaccumulated by the aquatic species across the study period followed by n-Tridecane, n-Nonane, n-Tetradecane, n-Triacontane, n-Tetracosane and n-Octacosane. The highest mean concentration of the analyzed aliphatics was recorded in February and the lowest concentration in April.

3.2. Estimated dietary intake

The EDI of the aliphatic hydrocarbons through the consumption of N. hastatus is presented in Figure 2. The Figure revealed that the total aliphatics examined had significant dietary intake (0.903 mg/kg) which was above the daily fish intake 0.048 mg/kg (FAO, 2007). The Figure also shows the EDI across the period of study. The highest intake (1.19 mg/kg) was recorded in February and the lowest intake (0.70 mg/kg) in April.

3.3. Health risk index (HRI)

The HRI of the total aliphatic hydrocarbon in N. hastatus (Figure 3) reveals that there was high health hazard (1.80) associated with the consumption of the species as the value was above the safety limit of one (1). The Figure also reveals the HRI across the period of study exceeded the safety limit of one (1). The highest value (2.37) and the lowest value (1.39) was recorded in February and April respectively.

4. Discussion

The relatively high concentrations of individual aliphatics observed in the aquatic biota are clearly related to the rapid deterioration of the coastal species and ecosystem. The predominance of both lighter and higher members of the aliphatic hydrocarbons, odd and even chain hydrocarbons in the aquatic species could be adduced to the extensive anthropogenic and industrial activities in the area. It is evident that aliphatic hydrocarbons are mostly sourced from crude oils which are produced, processed and channelled across the coastal zones. The prevalence of crude oil cracking in the study area could be the reason for the high concentration and accumulation across the period of study. Effluents from various petrochemical fractions, continuous crude oils discharge during oil drilling pose a great health hazard to the aquatic species. This menace jeopardizes marine biodiversity and takes the aquatic ecosystem beyond sustainability (Gertler et al., 2009).

The high values of the individual aliphatic hydrocarbons observed in February when compared with the other months could be linked to climatic variability on the aquatic ecosystem. The sudden heavy rainfall that occurred in the month would strongly have influenced the discharge of industrial effluents, pollutants, sewage, associated runoffs and high level of dissolved ions into the coastal area thereby causing bad effect on the coastal species. This, therefore, makes the water body inimical to the aquatic fauna, inhibiting growth, reproduction and survival fish species.

The result of this study was higher than the results of Oparaji et al. (2017) and Oyibo et al. (2018) who worked on the estimation of total petroleum hydrocarbon, polycyclic aromatic hydrocarbon and risk assessment of some selected aquatic fauna in Forcado terminals, rivers in Delta and Rivers state, Nigeria and obtained TPH values ranging between (0.09–3.63 mg/kg) and (0.002–0.29 mg/kg) respectively attributing it to the low level and influence of industrial activities in the terminals.

In addition, the predominance of aliphatics with carbon numbers >10–35 in the aquatic fauna could be linked to the constant influx of pollutants from the coastal shipping services by the people and high effluents from treatment plants in the coastal zone. Oil discharges from heavy-duty boats, cleaning of tanks and disposal of oily engine room waste into the coastal zone could also account for this. These activities threaten the vulnerable coastal ecosystem/resources, food security, socio-economic benefits, and sustainability.

In the analyzed aquatic fauna (N. hastatus), it was observed that thirty-one (31) aliphatic hydrocarbons were bioaccumulated by the coastal species. This finding can be adduced to the high composition, distribution and diversity of the aquatic biota in the study area as observed by Olawusi-Peters and Ajibare (2014) in the study area.

Total Petroleum Hydrocarbons (TPHs) harms marine organisms via acute toxicity, sublethal health effects, reducing fitness with greater risk for fish eggs and juveniles. Also, disruption of marine communities and total collapse of the benthic communities are some of the damaging disasters of total petroleum hydrocarbon (NRC, 2003).

Control samples of the analysed species inhabiting cleaner waters (comparatively less polluted with TPH) could not be assessed around the region sampled as the coastal waters of Ondo State are in the Niger Delta region (Figure 1) which is well documented as a polluted zone (Adesina and Ogunseiju, 2017; Olawusi-Peters et al., 2017; Ajibare et al., 2019; Akinola et al., 2019).

The result of the EDI and HRI showed that N. hastatus (a demersal species and an important source of proteins) which is widely used in the preparation of local delicacies by inhabitants of the coastal region induces adverse health hazards to man the final consumer. Since some of these chemical compounds such as the decane and eicosane groups are capable of causing cancer and genetic mutation, they often result in various consequences such as body organ and system failures, different
behavioural, physiological and cognitive changes, and ultimately death in man (Isibor and Imoobe, 2017; Oparaji et al., 2017).

The principal acute health effects of these aliphatic hydrocarbons on consumption include headaches, eye itching and redness, skin irritation, sore throat through dermal absorption and inhalation (Bingham et al., 2001; Aguilera et al., 2010). Other acute symptoms include nerve irritation, pain, and disorder, migraine, skin inflammation, eye irritation, respiratory problems and nausea (Schwoerer et al., 2000). Studies have also revealed that aliphatic hydrocarbons have some toxicological effect on the blood, immune system, spleen, kidneys, lungs, reproductive system and even developing fetus (USEPA, 2000).

Furthermore, the HRI values across the period of study were above the safety limit of one (1) raising concerns on the great threat and health danger the consumption of N. hastatus and other fish species in the coastal waters of Ondo state, Nigeria, poses to the consumers. Considering the undeniable nutritional and socio-economic benefits seafood production and consumption provides to the coastal populace and country, this emerging environmental threat to food security, sustainability, and healthy living must, therefore, be monitored, measured, mitigated and managed.

5. Conclusion

This study used various ratios and indices to assess the health risk of total petroleum hydrocarbons (TPHs) from the consumption of the seafood (Nematopalaemon hastatus) in the coastal waters of Ondo state. It deduced the profound ecological impact of anthropogenic activities, substantial exposure of the aliphatic hydrocarbons to the aquatic biota and carcinogenic/mutagenic human health hazard associated with the consumption of the coastal species. This indeed is an alarm to regulating authorities and agencies, stakeholders and policymakers on the saddening (deteriorating) state of the coastal species and ecosystem. Proactive and effective measures, strategies and policies must thus be employed to secure the coastal food (fish species), safeguard lives and the entire ecosystem where human needs are closely tied to the environment.

Declarations

Author contribution statement

Joshua Oluwatobi Akinola: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Olamide Olorunke Olawusi-Peters: Contributed reagents, materials, analysis tools or data.
Victoria Omolara Enobong Akpambang: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

We appreciate the Department of Marine Science Technology, The Federal University of, Akure and Mr Ojogbon Sunday for their innovative ideas, support and contributions towards the research work.

References

Abba, S., Singh, C.S., 2012. Hydrocarbon pollution: effects on living organisms’ remediation of contaminated environments, and effects of heavy metals co-contamination on bioremediation. J. Environ. Sci. 24, 227–230.

Aguilera, F., Mendez, J., Pasaro, E., Laffon, B., et al., 2010. Review on the effects of exposure to spilled oils on human health. J. Appl. Toxicol. 30, 291–310.

Ajibare, A.O., Olawusi-Peters, O.O., Bella-Oluwoji, O.A., et al., 2019. Plankton dynamics as pollution indicator in the coastal waters of Ondo state, Nigeria. Int. J. Fish. Aquicult. Res. 5 (1), 22–31.

Akinola, J.O., Oluwarotimi, O.O., Olawusi-Peters, O.O., Akpambang, V.O.E., 2019. Ecological hazards of Total petroleum hydrocarbon in brackish water white shrimp Nematopalaemon hastatus (AURIVILLUS 1898). Egypt. J. Aquat. Res. 45 (3), 205–210.

Awuj dies, F.J., 2015. Aquatic pollution in the Niger Delta: an ethical appraisal. J. Niger. Environ. Soc. 9 (1), 63–72.

Bingham, E., Colesens, R., Powell, C.H., 2001. Patty’s Toxicology Volumes 1–9 fifth ed., 6th John Wiley & Sons, New York, N.Y., p. 440

Castro-Gonzalez, M., Mendez-Arment, M., 2008. Heavy metals: implications associated with fish consumption. Environ. Toxicol. Pharmacol. 26, 263–271.

Cotop, C., Conti, G.O., Signorelli, C., Marmirou, S., Sicciar, S., Vincieri, F., M., Ferrante, M., et al., 2013. Risk assessment for metals and PAHs by Mediterranean seafood. Food Nutr. Sci. 4, 10–13.

Department of Petroleum Resources (DPR), 2011, Revised edition. Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN). Universal Press, Lagos, Nigeria, pp. 276–297.

Environmental Protection Agency (EPA), 2000. Bioaccumulation Testing and Interpretation for the purpose of Surface Quality Assessment: Status and Needs. Bioaccumulation analysis workshop, Washington D.C.

FAO/WHO, 2007. Evaluation of certain Food Additives and Contaminants: Sixty-Seventh Report of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization (WHO Technical Report Series, No. 940), Geneva.

Food Agricultural Organization (FAO), 2014. Fishery and Aquaculture Statistics 2014. In: Statistics and Information Services of the Fisheries and Aquaculture Department/Service. FAO Rome, Roma.

Food and Agriculture Organization (FAO), 1987. Species identification sheets. Food and Agricultural Organization of the United Nations, (Volume VI). Department of Fisheries and Oceans, Canada, pp. 7–35.

Gertler, C., Gerdts, G., Timmis, K., Yakimov, M., Golyshin, P., et al., 2009. Populations of heavy fuel oil-degrading marine microbial community in presence of sorbent. Aquacult. Res. 5 (1), 22–35.

Izbeor, P.O., Imoobe, T.O.T., 2017. Comparative analysis of contaminability between Clarias gariepinus and Tilapia mariae. Ann. Res. Rev. Biol. 16 (5), 1–14.

Kizuka, M.A., 2010. A Risk Assessment for Ingestion of Toxic Chemicals in Fish from Imperial Beach. San Diego State University, California.

NRC (National Research Council), 2003. Oil in the Sea III: Inputs, Fates, and Effects. National Academic Press, Washington, DC.

Ogugua, V.N., Ubani, S.C., Ujah, I.I., Ozioko, J.N., et al., 2017. Estimation of some Decapod Crustaceans in coastal waters of Ondo State, South West, Nigeria. Int. J. Fauna Biol. Stud. 1 (5), 44–51.
Olawusi-Peters, O.O., Akinola, J.O., Jelili, A.O., et al., 2017. Assessment of heavy metal pollution in water, shrimps, and sediments of some selected water bodies in Ondo state. J. Res. Agric. Sci. 5 (2), 55–66.

Oparaji, E.H., Nweze, E.J., Agbo, K.U., Arinzechukwu, E.O., Anosike, J.C., et al., 2017. Estimations of polycyclic aliphatic hydrocarbon and total petroleum hydrocarbon in aquatic faunas found in forcados terminal river in Port harcourt, Rivers state. J. Environ. Anal. Toxicol. 7 (6), 519–523.

Oyibo, J.N., Wegwu, M.O., Uwakwe, A.A., Osuoh, J.O., et al., 2018. Analysis of total petroleum hydrocarbons, polycyclic aromatic hydrocarbons and risk assessment of heavy metals in some selected finfishes at Forcados Terminal, Delta State, Nigeria. Environ. Nanotechnol. Monit. Manag. 9, 128–135.

Schvoerer, C., Gourier-Frery, C., Ledrans, M., Gérmonneau, P., Derrien, J., Prat, M., Mansotte, F., Guillaumot, P., Tual, F., Vieuxbled, J., Marzin, M., 2000. Epidemiologic study on short-term health alterations in people participating in the clean-up of places contaminated by Erika oil (in French). Available from: http://www.invs.sante.fr/publications/erika3/rapmaree_dist.pdf.

Schwab, A.P., Su, J., Wetzel, S., Pekare, S., Banks, M.K., et al., 1999. Extraction of petroleum hydrocarbon from the soil by mechanical shaking. Environ. Sci. Technol. 33, 1940–1941.

US Environmental Protection Agency (USEPA), 1986. Analysis of Polynuclear Aromatic hydrocarbons. Method of 8100. US Environmental Protection Agency, US Environmental Protection Agency (USEPA), 2000. Guidance for Assessing Chemical Contaminant, Data for Use in Fish Advisories In: Fish Sampling and Analysis, third ed., 1. EPA Office of Water, Washington, DC.

US EPA (U.S. Environmental Protection Agency), 2000. Supplemental Guidance for Conducting for Health Risk Assessment of Chemical Mixtures. EPA/630/R-00/002. May.

US EPA (U.S. Environmental Protection Agency), 2012. Framework for Human Health Risk Assessment to Inform Decision Making. EPA External Review Draft. Office of the Science Advisor. Risk Assessment Forum, Washington, DC, 601-D12-001.

Wim, V., Issabel, S., Stefan, D., John, V., et al., 2007. Consumer prescription versus scientific evidence of farmed and wild fish: exploratory insights for Belgium. Aquacult. Int. 15, 121–136.