Polycyclic Aromatic Hydrocarbons in Ologe Lagoon and Effects of Benzo[b]fluoranthene in African Catfish

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Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic pollutants that contain ≥2 fused aromatic rings composed of hydrogen and carbon. They are solids that have high melting and boiling points, and low vapor pressure and aqueous solubility. There are pyrogenic, petrogenic and biological sources of PAHs. Pyrogenic sources of PAHs are formed by the incomplete combustion of organic substances such as coal, wood, and petroleum, whereas petrogenic sources of PAHs are petroleum products such as kerosene, diesel fuel, gasoline, lubricating oil, and asphalt. Biologically, PAHs can be formed by the degradation of vegetative matter. Forest fires, volcanoes, algal synthesis, and petroleum seeps are natural sources of PAHs. Anthropogenic sources of PAHs include automotive emissions, petroleum product spills, incineration, cigarette smoke, and sewage sludge. An important route of PAH transport is through the atmosphere. Some PAHs released into the atmosphere settle on surface waters by wet and dry deposition and are thereafter integrated with sediments through water currents. Surface waters and sediments also receive PAHs from effluents and road runoffs. Due to the persistence of PAHs in aquatic environments, they can bioaccumulate in aquatic organisms. The occurrence of PAHs in aquatic foods is an important route of human exposure, particularly as some PAHs are known carcinogens. The International Agency for Research on Cancer (IARC) has classified PAHs into Groups 1 (known carcinogens), 2A (possibly carcinogenic to humans) and 2B (probably carcinogenic to humans). The highly investigated benzo[a]pyrene is in Group 1 whereas naphthalene, chrysene, benz[a]anthracene, benzo[k]fluoranthene and benzo[b]fluoranthene are Group 2B.

Background. Ologe Lagoon is an important water body that receives effluents from neighboring industries. These effluents may increase the levels of anthropogenic contaminants in the lagoon, thereby creating stressors for aquatic organisms.

Objectives. To assess the occurrence of polycyclic aromatic hydrocarbons (PAHs) in Ologe Lagoon, along with the histopathological, biochemical and genotoxic effects of the most prevalent PAH compound.

Methods. An initial field study was performed to determine the concentrations of PAHs in Ologe Lagoon, followed by a chronic toxicity test to assess the effects of the most prevalent PAH compound in a fish model (Clarias gariepinus).

Results. High molecular weight PAHs were more predominant than low molecular weight PAHs in the lagoon, with B[b]F being the most predominant. The formation of micronuclei and binuclei was induced by a 10-fold increase over the present environmental concentration of B[b]F in Ologe Lagoon. Histopathological studies showed that epithelial necrosis, fused lamellae, shortened lamellae, and desquamation were the major histological anomalies induced by ERGs of B[b]F. Results from the biochemical assay indicated that ERGs of B[b]F increased aspartate aminotransferase and alanine transaminase levels in fish. Glutathione-S-transferase, superoxide dismutase and catalase were inhibited in the exposed fish, whereas malondialdehyde was significantly increased.

Conclusions. Concentrations of fluoranthene, pyrene, benzo[a]anthracene, and benzo[a]pyrene in the surface water of Ologe Lagoon were above the Canadian Council of Ministers of the Environment’s (CCME) safe limits, suggesting that the water may not be safe for domestic uses, and the present concentration of B[b]F in Ologe Lagoon may be chronically toxic to aquatic organisms, in terms of oxidative stress and hepatotoxicity.

Competing Interests. The authors declare no competing financial interests.

Keywords. polycyclic aromatic hydrocarbons, benzo[b]fluoranthene, hepatotoxicity, environmental relevance, biomarkers, genotoxicity, oxidative stress

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economically important aquatic ecosystems in Lagos State, as it is located near Agbara Industrial Estate, a major manufacturing hub, which discharges effluents into the lagoon via the central sewage treatment plant. There is limited information on the occurrence of organic compounds in the lagoon. Moreover, there is no published literature on the occurrence of PAHs in the lagoon. Therefore, the present study aimed to quantify the occurrence of PAHs in the lagoon and determine the ecotoxicological effects of the predominant PAH compound in the lagoon.

Methods

The field study was carried out in May 2017 at Ologe Lagoon, a water body notable for the receipt of effluents from Agbara Industrial Estate. The lagoon is located between latitudes 6° 26’ N and 6° 30’ N, and longitudes 3° 03’ E and 3° 07’ E. Surface water samples were collected from three sampling stations in reference to the reception of effluents from Agbara Industrial Estate (Figure 1) using 2.5 L amber glass bottles at the water surface. The samples were stored in a cooler with ice packs before transporting to the laboratory. Sediments were collected with a Van Veen grab sampler. The sediments were quickly transferred into aluminum foil. The samples were each labelled with masking tape and permanent markers and stored in a cooler containing ice. The tools and equipment were washed with methylene chloride and distilled water, and dried before use.

Fishes were collected from Ologe Lagoon with the aid of fishermen using cast nets. The fishes were wrapped in aluminum foil, labeled and placed inside a closed-glass vessel containing ice packs before they were taken for identification and laboratory analysis. All samples were sent to the laboratory for analysis within 8 hours of collection. Identified fish species included *Liza falcipinnis*, *Cynoglossus senegalensis*, *Galeodes decadactylus*, *Chrysichthys nigrodigitatus*, *Tilapia mariae*, *Hemichromis fasciatus*, *Sarotherodon melanotheron*, and *Hyperopisus bebe*. *Sarotherodon melanotheron* was chosen for PAHs analysis based on its abundance at the time of sampling, tolerance to pollution, and economic importance. Five samples of fish tissues were pooled together to form a composite for the analysis.

Extraction and analysis of samples

Polycyclic aromatic hydrocarbons were extracted from water samples by adding 300 ml of dichloromethane, according to the method of Zeng and Vista. Water extracts were
Research

concentrated to 10 ml using a rotary evaporator. Sediment and fish sample extractions were carried out following the method of Sojinu et al. Identification and quantification of PAHs were determined in the extracts by Agilent gas chromatography-7890A with an HP-5MS fused silica column (30 m x 320 μm x 0.25 μm film thickness). Helium was used as the carrier gas. One (1) µl extract was injected with an autosampler in the splitless/split mode with a split time of 1 min after injection, and the injector temperature was set at 270°C. The flow rate was 1.2 ml/min. The column temperature was initiated at 60°C, then increased to 210°C at 12°C/min, and finally increased to 320°C at 10°C/min (held for 5 minutes).

Laboratory bioassay

Juvenile African catfish, *Clarias gariepinus* (weight 34-41 g, total length 16-21 cm), belonging to the same parent stock were acquired from a fish farm. They were transported in aerated bags to the laboratory and kept in 50 L plastic tanks for acclimatization. The acclimatization of the fish was done for 15 days before the exposure period (photoperiod: 12 hours dark, 12 hours light).

Chronic toxicity test

Based on the prevalence of benzo[b]fluoranthene (B[b]F) in the lagoon, the surface water concentration (0.03 mg/L) and 10-fold concentration (0.3 mg/L) of B[b]F were selected for the chronic toxicity test to simulate chronic exposures that are likely to occur in the lagoon and mimic a worst-case scenario that may occur in the future, respectively. Two controls were included, an absolute control and vehicle control (0.2% acetone). A total of 42 acclimatized juvenile fish (six replicates of 7 fish per replicate) were transferred to each test concentration, as well as the controls in glass aquaria (40 cm x 30 cm x 30 cm). The semistatic (renewal) test was employed to renew the test media every 24 hours for a period of 28 days. Physical-chemical parameters of the test media were monitored after each renewal using digital instruments (Jenway). After 28 days of exposure, fish samples were collected for the biomarker studies.

Histopathological analysis

Fish gills were cut open and stored in Bouin's fluid in universal bottles before analysis. The histopathological analysis was conducted following the method employed by Amaeze et al. Determination of metabolic enzymatic activities in the liver

Aspartate aminotransferase (AST) and alanine aminotransferase (ALT) activities were determined following the principle described by Reitman and Frankel.

Micronucleus assay

Blood samples were collected from fish using a 1 ml syringe. After the extraction, a drop of the blood sample was placed on a glass slide. The drop of sample blood on the glass slide was smeared by spreading with another slide at 45°C until the smear became feathered in appearance. The slide was prepared based on the technique of Jiraungkoorskul et al. Once the smear was dried, it was fixed using 70% ethanol for 30 minutes to ensure that the cell structure was not damaged. After the ethanol dried, a follow-up staining was carried out with May-Grünwald stain for 30 minutes which was then rinsed in water and allowed to dry. After the water dried, a counterstaining using 5% Giemsa stain was performed for

| PAH Compound | Point 1 (mg/kg) | Point 2 (mg/kg) | Point 3 (mg/kg) | Mean±SD (mg/kg) |
|--------------|----------------|----------------|----------------|-----------------|
| Low molecular weight | | | | |
| Naphthalene | ND | ND | ND | NA |
| Acenaphthylene | ND | ND | ND | NA |
| Acenaphthene | ND | ND | ND | NA |
| Fluorene | 0.00400 | 0.00354 | ND | 0.00377±0.00032 |
| Phenanthrene | 0.00783 | 0.00708 | 0.00429 | 0.0064±0.0019 |
| Anthracene | ND | ND | ND | NA |
| Subtotal | 0.01183 | 0.01062 | 0.00429 | 0.008913±0.0041 |
| High molecular weight | | | | |
| Fluoranthene | 0.01310 | 0.00466 | 0.00609 | 0.0079±0.0045 |
| Pyrene | 0.00277 | 0.00273 | 0.00156 | 0.0024±0.00069 |
| Benzo(a)anthracene | 0.01991 | 0.02433 | 0.01921 | 0.02115±0.0028 |
| Chrylene | 0.02327 | 0.03134 | 0.02515 | 0.02659±0.00422 |
| Benzo(b)fluoranthene | 0.07657 | 0.11691 | 0.08683 | 0.09344±0.02097 |
| Benzo(k)fluoranthene | 0.00109 | 0.09768 | 0.07264 | 0.05714±0.05013 |
| Benzo(a)pyrene | 0.06262 | 0.08884 | 0.06667 | 0.07573±0.01854 |
| Dibenzo(a,h)anthracene | ND | ND | ND | NA |
| Indeno(1,2,3-cd)pyrene | 0.03443 | ND | 0.02714 | 0.03079±0.00515 |
| Benzo(g,h,i)perylene | 0.10092 | 0.06433 | 0.06314 | 0.08263±0.02587 |
| Subtotal | 0.33468 | 0.43082 | 0.36843 | 0.377977±0.04878 |
| ∑PAHs | 0.34651 | 0.44144 | 0.37272 | 0.38689±0.049025 |

Table 1 — Polycyclic Aromatic Hydrocarbon Levels in Sediments from Ologe Lagoon

Abbreviations: ND, not detected; NA; not available; SD, standard deviation.
Determination of oxidative stress markers in the gills of *Clarias gariepinus*

The levels of glutathione-S-transferase (GST), catalase (CAT), superoxide dismutase (SOD) and malondialdehyde (MDA) were measured in accordance with the methods of Habig and Jakoby, Sinha, Sun and Zigma, and Buege and Aust, respectively.\(^{21-25}\)

**Statistics**

One-way analysis of variance (ANOVA) was used to test for significant difference between means, where differences in means were considered significant when P < 0.05 and significant means were separated using the least significant difference test. All data were analyzed using Statistics Package for Social Sciences (SPSS) version 20 (IBM).

**Results**

Eleven PAH compounds were detected in the sediments from Ologe Lagoon. They include fluorene, phenanthrene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, and benzo[g,h,i]perylene (Table 1). Benzo[b]fluoranthene had the highest concentration with a level of 0.09344 mg/kg. The level of \(\Sigma_{\text{LMW}}\) PAHs in the sediments was less than 1. The mean concentration of \(\Sigma_{\text{PAHs}}\) in the sediments was 0.38689 mg/kg.

Ten PAH compounds including phenanthrene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, and benzo[g,h,i]perylene were detected in the surface water (Table 2). Phenanthrene was the only LMW PAH detected in the surface water. The ratio of \(\Sigma_{\text{LMW}}\) PAHs to \(\Sigma_{\text{HMW}}\) PAHs in the sediments was less than 1. Fluoranthene, pyrene, benzo[a]anthracene, and benzo[a]pyrene levels were above the Canadian Council of Ministers of the Environment’s (CCME) standard limits. The mean concentration of \(\Sigma_{\text{PAHs}}\) in the surface water was 0.15187 mg/L.

| PAH Compound          | Point 1 (mg/L) | Point 2 (mg/L) | Point 3 (mg/L) | Mean±S.D.(mg/L) | CCME standard (mg/L) |
|-----------------------|----------------|----------------|----------------|----------------|----------------------|
|                       | Naphthalene    | Acenaphthylene | Acenaphthene   | ND             | NA                   | 0.00011  |
| Fluorene              | ND             | ND             | ND             | NA             | ND                   | 0.00058  |
| Phenanthrene          | 0.00332        | 0.00468        | 0.00504        | 0.00400±0.00096| 0.004                |
| Anthracene            | ND             | ND             | ND             | NA             | 0.000012             |
| **Subtotal**          | 0.00332        | 0.00468        | 0.00504        | 0.00400±0.00096| 0.000012             |

|                       | ND             | ND             | ND             | NA             | ND                   | 0.000018     |
|                       | Fluorethene    | 0.00425        | 0.00435        | 0.00743        | 0.0043±0.00007       | 0.0004        |
| Pyrene                | 0.00133        | 0.00231        | 0.00269        | 0.00182±0.00069| 0.000025             |
| Benzo[a]anthracene    | 0.00867        | 0.00880        | 0.01370        | 0.01039±0.00287| 0.000018             |
| Chrysene              | 0.00997        | 0.00921        | 0.01428        | 0.01115±0.00273| 0.000018             |
| Benzo(b)fluoranthene  | 0.02923        | 0.01219        | 0.03611        | 0.02584±0.01231| 0.000143             |
| Benzo(k)fluoranthene  | 0.02492        | 0.02761        | 0.02713        | 0.02655±0.00143| 0.000018             |
| Benzo[a]pyrene        | 0.02364        | 0.03080        | 0.02683        | 0.02709±0.00359| 0.000015             |
| Dibenzo(a,h)anthracene| ND             | ND             | ND             | -              | NA                   | 0.14183      |
| Indeno(1,2,3-cd)pyrene| ND             | 0.02253        | ND             | 0.00751±0.0133| 0.000018             |
| Benzo(g,h,i)perylen   | 0.03982        | 0.05477        | ND             | 0.04729±0.01057| 0.000018             |
| **Subtotal**          | 0.14183        | 0.17257        | 0.12817        | 0.147523±0.02274| 0.15187±0.022776      |

*Adapted from Canadian soil quality guidelines for the protection of environmental and human health: benzo[a]pyrene.\(^{26}\)*

Abbreviations: ND, not detected; NA, not available; SD, standard deviation.

**Table 2 — Polycyclic Aromatic Hydrocarbon Levels in Surface Water from Ologe Lagoon**
predominant PAH compound, followed by benzo[a]pyrene.

Micronucleus induction

The results of the micronucleus assay are presented in Table 4. Exposure to 0.3 mg/L of B[b]F significantly (p = 0) induced micronuclei and binuclei in the blood erythrocytes of the fish. On the other hand, 0.03 mg/L of B[b]F did not significantly alter the number of micronucleated and binucleated cells in the blood of the fish (p = 0.198 and 0.061, respectively).

Superoxide dismutase

The results showed that the activity of the enzyme SOD was inhibited (p = 0) in the gills of C. gariepinus exposed to environmentally relevant concentrations (ERCs) (0.03 and 0.3 mg/L) of B[b]F (p = 0.002 and p = 0, respectively; Figure 2a). Gill SOD levels ranged from 3.38 ± 0.58 to 7.69 ± 0.69 U/mg protein in the control and treated groups.

Catalase

Exposure to ERCs (0.03 and 0.3 mg/L) of B[b]F caused a significant (p = 0) modification in the gill tissues of C. gariepinus, in terms of CAT activity (Figure 2b). Gill CAT levels ranged from 14.00 ± 1.29 to 20.12 ± 2.10 U/mg protein in the control and treated groups.

Glutathione-S-transferase

The gill tissues were affected in terms of GST activity by exposure to ERCs of B[b]F (p = 0; Figure 2c). Gill GST levels ranged from 10.94 ± 1.70 to 22.84 to 1.70 U/mg protein in the control and treated groups.

Induction of lipid peroxidation

The results of the lipid peroxidation
assay showed that the level of lipid peroxidation product, MDA, in the gills of *C. gariepinus* exposed to ERCs of B[b]F increased significantly (p = 0) compared to the vehicle control (Figure 2d). Gill MDA levels ranged from 0.04 ± 0.02 to 0.21 ± 0.03 U/mg protein in the control and treated groups.

### Metabolic enzymatic activities in the liver

The effects of ERCs of B[b]F on metabolic enzyme activities in the liver of *C. gariepinus* are presented in Figure 3. Hepatic AST and ALT activities were increased significantly (p = 0) in fish treated with ERCs of B[b]F. Hepatic AST and ALT levels ranged from 35.52 ± 3.16 to 61.03 ± 4.50 IU/L and 36.36 ± 1.82 to 86.75 ± 4.39 IU/L, respectively, in the control and treated groups.
Histology

The gills of control groups showed normal histology, as seen in Figures 4a and 4b. Fish exposed to 0.03 mg/L of B[b]F had epithelial necrosis and lamellae fusion as the major gill histological alterations (Figures 4c and 4d). Epithelial necrosis, shortened lamellae, fused lamellae and desquamation were observed in the gills of fish treated with 0.3 mg/L of B[b]F (Figures 4e and 4f).

Discussion

The distribution of PAHs in Ologe Lagoon suggested that the source of the contamination was of pyrogenic origin. Pyrogenic PAHs could have resulted from incomplete combustion of fossil fuels in the generators used by local industries. Factories close to the lagoon include food and beverage industries, pharmaceutical plants, breweries, metal finishing, chemical plants, and pulp and paper companies.27 These anthropogenic activities indicate that petrogenic sources of PAHs in the lagoon may be limited. Concentrations of fluoranthene, pyrene, benzo[a]anthracene, and benzo[a]pyrene in the water samples were above CCME standard limits. Notably, benzo[a]pyrene, the most studied PAH compound, used as a marker for carcinogenicity of PAHs, was above the limit, raising concerns for human health. There are several studies on the occurrence of PAHs in Nigerian water bodies. Anyakora and Coker, Nwineewi and Marcus, and Asagbra et al. reported a PAH concentration range of 0.00195-0.302 mg/L in the Niger Delta, whereas Anyakora et al., Adedayo et al., and Olayinka et al. reported a range of < 0.00088-0.507 mg/L in Lagos Lagoon.28-33 The concentration of PAHs in the water samples (0.15187 mg/L) detected in the present study was within the range reported in those regions.

Sogbanmu et al. and Amaeze et al. documented that Lagos Lagoon sediments had concentrations of PAHs that varied from 0.365-3.088 mg/kg, whereas Asagbra et al. reported a mean value of 4.5877 mg/kg in the Niger Delta region.30,36,35 In the present study, the mean concentration of ∑PAHs in the Ologe Lagoon sediments was 0.38689 mg/kg. The concentrations were below the threshold effect concentration (1.61 mg/kg) and the probable effect concentration (22.8 mg/kg) for ∑PAHs.36 Previous studies have reported varying concentrations of PAHs in fish from other Nigerian water bodies ranging from 0.0427-1.0985 mg/kg.28,30,37,38 In the present study, the concentration of PAHs in fish was within the range reported by the previous studies. The concentration was lower than the concentration in the sediments. Johnson-Restrepo et al. stated that fishes may metabolize and excrete PAHs, thereby reducing the concentration accumulated in their tissues.39 Micronuclei are usually used as a biomarker for genotoxicity and are formed when there are chromosomal aberrations during cell divisions.40 Therefore, the micronucleus assay can provide information about the
Figure 4a and 4b: ×100 controls (absolute (a) and vehicle (b)) showing normal gill architecture with well-defined primary and secondary lamellae. Abbreviations: PL, primary lamellae; SL, secondary lamellae.

Figure 4c and 4d: ×100 0.03 mg/L of B[b]F exposed fish showing abnormalities which include epithelial necrosis, fused lamellae, and eroded epithelium. Abbreviations: EN, epithelial necrosis; LF, fused lamellae; EE, eroded epithelium.

Figure 4e and 4f: ×100 0.3 mg/L of B[b]F exposed fish showing abnormalities which include fused lamellae, epithelial necrosis, shortened lamellae, and desquamation. Abbreviations: EN, epithelial necrosis; LF, fused lamellae; LS, shortened lamellae; DS, desquamation.
ability of a chemical to interfere with the structure and function of chromosomes. In the present study, the results of the micronucleus assay indicated that 0.3 mg/L of B[b]F induced the formation of micronuclei and binuclei, whereas 0.03 mg/L of B[b]F did not cause a marked increase in micronucleus and binucleus frequency. Thus, it is possible that the present concentration of B[b]F in Ologe Lagoon is not genotoxic or mutagenic to fishes.

The exposure to ERCs of B[b]F probably caused the production of free radicals such as hydrogen peroxide (H$_2$O$_2$), and superoxide anion (O$_2^-$), which oxidatively degrades lipids in cell membranes, resulting in cellular damage as the concentrations increased the levels of MDA in the gills of Clarias gariepinus. Malondialdehyde is produced when the cells are damaged by these free radicals. Therefore, MDA is used as a lipoperoxidation marker. Following the production of free radicals, due to exposure to chemicals or toxicants, anti-oxidative stress enzymes (SOD and CAT) work to transform the free radicals into water and oxygen. However, the high production of free radicals may overwhelm the activities of the enzymes, resulting in cellular damage. Environmentally relevant concentrations of B[b]F inhibited the activities of SOD and CAT. This also points to the occurrence of oxidative stress in the gills of the fish.

Aspartate aminotransferase and ALT are enzymes used to monitor the function of the liver. Fluctuation in the levels of these enzymes is used in toxicological studies to evaluate the impact of toxicants on the liver of test organisms. In the present study, ERCs of B[b]F elevated the levels of AST and ALT in the liver of Clarias gariepinus, which indicates the toxicity of these concentrations to the liver of the fish.

This is in agreement with studies by Kim et al., Wegwu and Omeodu, and Haque et al., who reported a significant increase in the levels of AST and ALT in fishes exposed to PAHs. Polycyclic aromatic hydrocarbon-containing mixtures have been reported to induce histological alterations in the gills of fishes. Fish exposed to petroleum water-soluble fractions and refined products exhibited alterations in the gills, such as the lifting of respiratory epithelium, tissue necrosis, hyperplasia, hypertrophy, hemorrhage, and telangiectasia. In Campos Bay, Brazil, crude oil induced histological effects in the gills of freshwater fish (Astyanax sp.). Gills of Oncorhynchus mykiss chronically exposed to petroleum showed epithelial lifting and damage of secondary lamellae, associated with cellular hypertrophy.

Hyperplasia and hypertrophy of the lamellar epithelium were also observed in three species of marine flatfishes inhabiting an area near an oil refinery. Brand et al. exposed pink salmon fry, Oncorhynchus gorbuscha, to sublethal concentrations of Alaska North Slope crude oil for over 10 days and found morphologic and stress-induced lesions in the gills, such as epithelial lifting, fusion, mucous cell hyperplasia, and vascular constrictions. In the present study, tissue damage was observed in the gills of the fish exposed to ERCs of B[b]F in the form of epithelial necrosis, fused lamellae, shortened lamellae, and desquamation. This could be associated with the effect of oxidative stress caused by this compound.

Conclusions

In Ologe Lagoon, HMW PAHs were more predominant than LMW PAHs, suggesting that the source of the contamination was of pyrogenic origin. The concentrations of fluoranthene, pyrene, benzo[a]anthracene, and benzo[a]pyrene in water were above CCME standard limits, indicating a potential health hazard to humans that utilize water from the lagoon for domestic uses. There is a need for further studies to investigate the sources of PAHs in the lagoon in order to develop a strategic mitigation plan for PAHs contamination in the lagoon. Results from the histological and biochemical studies suggested that environmentally relevant concentrations of B[b]F in Ologe Lagoon elicited deleterious effects in terms of oxidative stress and hepatotoxicity. This study has demonstrated the threat posed by the current concentration of B[b]F in the lagoon to fish and humans that depend on the lagoon for food, as the effects reported may cause a decline in the population of fish resources in the lagoon. Therefore, further studies are required to investigate the impact of aquatic contamination on the population and health status of fishes in the lagoon.

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References

1. Collier TK, Anulacion BF, Arkoosh MR, Dietrich JP, Incardona JP, Johnson LL, Ylitalo GM, Myers MS. Effects on fish of polycyclic aromatic hydrocarbons (PAHs) and naphthenic acid exposures. Fish Physiol [Internet]. 2013 [cited 2019 May 1];33:195-255. Available from: https://doi.org/10.1016/B978-0-12-398254-4.00004-2 Subscription required to view.
2. Masih J, Singhvi R, Kumar K, Jain VK, Tanuja A. Seasonal variation and sources of polycyclic aromatic hydrocarbons (PAHs) in indoor and outdoor air in a semi arid tract of northern India. Aerosol Air Qual Res [Internet]. 2012 [cited 2019 May 1];12(4):515-25. Available from: http://www.acaq.org/article/detail/AAQR-11-11-OA-0192

3. Abdel-Shafy HI, Mansour MS. A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation. Egypt J Pet [Internet]. 2016 Mar [cited 2019 May 1];25(1):107-23. Available from: https://doi.org/10.1016/j.ejpe.2015.03.011

4. Saha M, Togo A, Mizukawa K, Murakami M, Takada H, Zarkia MP, Chiem NH, Tuyen BC, Prudente M, Boonyatumanon R, Sarkar SK, Bhattacharya B, Mishra P, Tana TS. Sources of sedimentary PAHs in tropical Asian waters: differentiation between pyrogenic and petrogenic sources by alkyl homolog abundance. Mar Pollut Bull [Internet]. 2009 Feb [cited 2019 May 2];58(2):189-200. Available from: https://doi.org/10.1016/j.marpolbul.2008.04.049 Subscription required to view.

5. Krauss M, Wilcke W, Martinus C, Bandeira AG, Garcia MV, Amelung W. Atmospheric versus biological sources of polycyclic aromatic hydrocarbons (PAHs) in a tropical rain forest environment. Environ Pollut [Internet]. 2005 May [cited 2019 May 2];135(1):143-54. Available from: https://doi.org/10.1016/j.envpol.2004.09.012 Subscription required to view.

6. Manoli E, Samara C. Polycyclic aromatic hydrocarbons in natural waters: sources, occurrence and analysis. TRAC Trends Anal Chem [Internet]. 1999 Jun [cited 2019 May 2];18(6):417-28. Available from: https://doi.org/10.1016/S0166-6879(99)00111-9 Subscription required to view.

7. Wang D, Feng C, Huang L, Niu J, Shen Z. Historical deposition behaviors of PAHs in the Yangtze River Estuary: role of the sources and water current. Chemosphere [Internet]. 2013 Feb [cited 2019 May 2];90(6):2020-6. Available from: https://doi.org/10.1016/j.chemosphere.2012.10.079 Subscription required to view.

8. Birgul A, Tasdemir Y, Cindoruk SS. Atmospheric wet and dry deposition of polycyclic aromatic hydrocarbons (PAHs) determined using a modified sampler. Atmos Res [Internet]. 2011 Jul [cited 2019 May 2];101(1-2):341-53. Available from: https://doi.org/10.1016/j.atmosres.2011.03.012 Subscription required to view.

9. Qi W, Liu H, Pernet-Coudrier B, Qu J. Polycyclic aromatic hydrocarbons in wastewater, WWTPs effluents and in the recipient waters of Beijing, China. Environ Sci Pollut Res Int [Internet]. 2013 Jun [cited 2019 May 2];20(6):4254-60. Available from: https://doi.org/10.1007/s11356-012-1435-6 Subscription required to view.

10. Krein A, Schoer M. Road runoff pollution by polycyclic aromatic hydrocarbons and its contribution to river sediments. Water Res [Internet]. 2000 Nov 1 [cited 2019 May 2];34(16):4110-5. Available from: https://doi.org/10.1016/S0043-1354(00)00156-1 Subscription required to view.

11. D’adamo R, Pelosi S, Trotta P, Sansone G. Bioaccumulation and biomagnification of polycyclic aromatic hydrocarbons in aquatic organisms. Mar Chem [Internet]. 1997 Feb [cited 2019 May 2];56(1-2):45-9. Available from: https://doi.org/10.1016/S0304-4069(96)00014-2 Subscription required to view.

12. Phillips DH. Polycyclic aromatic hydrocarbons in the diet. Mutat Res [Internet]. 1999 Jul 15 [cited 2019 May 2];443(1-2):139-47. Available from: https://doi.org/10.1016/S0161-3052(99)00016-2 Subscription required to view.

13. IARC monographs on the evaluation of carcinogenic risks to humans. Vol. 92. Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures [Internet]. Lyon, France: International Agency for Research on Cancer; 2010 [cited 2019 May 2]. 688 p. Available from: https://monographs.iarc.fr/wp-content/uploads/2018/06/mono92.pdf

14. Umulor SO, Obanya HE, Amaeze NH, Okoroafor CU. Levels, spatial and seasonal distribution of polycyclic aromatic hydrocarbons in some related exposures [Internet]. Lyon, France: International Agency for Research on Cancer; 2010 [cited 2019 May 2]. 688 p. Available from: https://doi.org/10.1016/S0161-3052(99)00016-2 Subscription required to view.

15. Amaeze NH, Egonmwan RI, Jolaoso AF, Otitoluuid AA. Coastal environmental pollution and fish species diversity in Lagos Lagoon, Nigeria. Int J Environ Prot Res [Internet]. 2012 Nov[2(11):8-16.

16. Zeng EY, Vista CL. Organic pollutants in the coastline environment off San Diego, California. 1. Source identification and assessment by compositional indices of polycyclic aromatic hydrocarbons. Environ Toxicol Chem [Internet]. 1997 Feb [cited 2019 May 2];16(2):179-88. Available from: https://doi. org/10.1002/etc.5620160212 Subscription required to view.

17. Sojinu OS, Wang JZ, Sonibare OO, Zeng EY. Polycyclic aromatic hydrocarbons in sediments and soils from oil exploration areas of the Niger Delta, Nigeria. J Hazard Mater [Internet]. 2010 Feb 15 [cited 2019 May 2];174(1-3):641-7. Available from: https://doi.org/10.1016/j.hazmat.2009.09.099 Subscription required to view.

18. Amaeze NH, Adeyemi RO, Adebesin AO. Oxidative stress, heats shock protein and histopathological effects in the gills of African catfish, Clarias gariepinus induced by bridge runoffs. Environ Monit Assess [Internet]. 2015 Apr [cited 2019 May 2];187(4):172. Available from: https://doi.org/10.1007/s10661-015-4390-6 Subscription required to view.

19. Reitman S, Frankel S. A colorimetric method for the determination of serum glutamic oxaloacetic and glutamic pyruvic transaminases. Am J Clin Pathol. 1957 Jul;28(1):56-63.

20. Jirangkoooskul W, Kosal P, Sahaphong S, Kirtputra P, Chawlaj B, Churucharoen S. Evaluation of micronucleus test's sensitivity in freshwater fish species. Res J Environ Sci. 2007;1(2):56-63.

21. Fenech M, Chang WP, Kirsch-Volders M, Holland N, Bonassi S, Zeiger E. HUMN project: detailed description of the scoring criteria for the cytokinesis-block micronucleus assay using isolated human lymphocyte cultures. Mutat Res [Internet]. 2003 Jan 10 [cited 2019 May 2];534(1-2):65-75. Available from: https://doi.org/10.1016/S0161-3718(02)00249-8 Subscription required to view.

22. Habig WH, Jakoby WB. Assays for differentiation of glutathione S-transferases. Methods Enzymol [Internet]. 1981 [cited 2019 May 2];77:398-405. Available from: https://doi.org/10.1016/S0076-6879(78)52032-6 Subscription required to view.

23. Sinha AK. Colorimetric assay of catalase. Anal Biochem [Internet]. 1972 Jun [cited 2019 May 2];47(2):389-94. Available from: https://doi.org/10.1016/0003-2697(72)90132-7 Subscription required to view.

24. Sun M, Zigma S. An improved spectrophotometric assay for superoxide dismutase based on epinephrine autooxidation. Anal Biochem [Internet]. 1978 Oct 1 [cited 2019 May 2];90(1):81-9. Available from: https://doi.org/10.1016/0003-2697(78)90010-6 Subscription required to view.

25. Buege JA, Aust SD. Microsomal lipid peroxidation. Methods Enzymol [Internet]. 1978 [cited 2019 May 2];52:302-10. Available from: https://doi.org/10.1016/0076-6879(78)52032-6 Subscription required to view.

26. Canadian soil quality guidelines for the protection of environmental and human health: benzo[a]pyrene. Winnipeg, Canada: Canadian Council of Ministers of the Environment; 1997 [updated 2008].

27. Adekeyejo A, Fagbenro O, Adeparusi Y, Emikpe B. Histopathology of African catfish (Clarias gariepinus) from industrially contaminated locations.
of Ologe Lagoon, South-Western, Nigeria. Appl Trop Agric. 2014;19(1):39-43. 

28. Anyakora C, Coker H. Assessment of polynuclear aromatic hydrocarbon content in four species of fish in the Niger Delta by gas chromatography/mass spectrometry. Afr J Biotechnol. 2007 Mar;6(6):737-43. 

29. Nwneewidi JD, Marcus AC. Polycyclic aromatic hydrocarbons (PAHs) in surface water and their toxicological effects in some creeks of South East Rivers State (Niger Delta) Nigeria. J Environ Sci Toxicol Food Technol. 2015 Dec;9(12):27-30. 

30. Asagbna MC, Adebayo AS, Anumudu CI, Ugwumba OA, Ugwumba AA. Polycyclic aromatic hydrocarbons in water, sediment and fish from the Warri River at Ubeji, Niger Delta, Nigeria. Afr J Aquat Sci [Internet]. 2015 [cited 2019 May 2];40(2):193-9. Available from: https://doi.org/10.28998/16085914.2015.1035223 Subscription required to view. 

31. Anyakora C, Ogbecche KA, Uyimandu J, Olayinka K, Alani RA, Alo B. Determination of polynuclear aromatic hydrocarbons in the water sample of the Lagos lagoon, Niger J Pharm. 2004 Jan-Mar;35:35-9. 

32. Adedayo A, Adeyemi D, Uyimandu JP, Chigome S, Anyakora C. Evaluation of the levels of polycyclic aromatic hydrocarbons in surface and bottom waters of Lagos lagoon, Nigeria. Afr J Pharm Sci Pharm. 2012;3(1):58-74. 

33. Olayinka OO, Adewuasi AA, Olarewaju VO, Aladesida AA. Concentration of polycyclic aromatic hydrocarbons and estimated human health risk of water samples around Atlas Cove, Lagos, Nigeria. J Health Pollut [Internet]. 2018 Dec [cited 2019 May 2];8(20):Article 181210 [12 p]. Available from: https://doi.org/10.1056/jhpo.2018.12.181210 

34. Sogbanmu TO, Nagy E, Phillips DH, Arlt VM, Otitoloju AA, Ingersoll CG, Berger TA. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch Environ Contam Toxicol [Internet]. 2000 Jul [cited 2019 May 2];39(1):20-31. Available from: https://doi.org/10.1007/s002440010075 Subscription required to view. 

35. Alani R, Drouillard K, Olayinka K, Alo, B. Bioaccumulation of polycyclic aromatic hydrocarbons in fish and invertebrates of Lagos lagoon, Nigeria. J Emerg Trends Eng Appl Sci. 2012 Apr;3(2):287-96. 

36. Johnson-Restrepo B, Olivero-Verbel J, Lu S, Guette-Fernández J, Baldíris-Avila R, O’Byrne-Hoyos I, Adamson KM, Addink R, Kannan K. Polycyclic aromatic hydrocarbons and their hydroxylated metabolites in fish bile and sediments from coastal waters of Colombia. Environ Pollut [Internet]. 2008 Feb [cited 2019 May 2];151(3):452-9. Available from: https://doi.org/10.1016/j.envpol.2007.04.011 Subscription required to view. 

37. Fenech M. The in vitro micronucleus technique. Mutat Res [Internet]. 2000 Nov 20 [cited 2019 May 2];455(1-2):81-95. Available from: https://doi.org/10.1016/S0027-5107(00)00065-8. Subscription required to view. 

38. Eastmond DA, Balakrishnan S. Genotoxicity of pesticides. In: Krieger R, editor. Hayes’ handbook of pesticide toxicology. Cambridge, MA: Academic Press; 2010. p. 357-80. 

39. Otitoloju AA, Olagoke O. Lipid peroxidation and antioxidant defense enzymes in Clarias gariepinus exposed to water-soluble fraction of North Atlantic rockfish, Sebastes schlegeli (Hilgendorf). Bull Environ Contam Toxicol [Internet]. 2008 Nov [cited 2019 May 2];81(5):470-4. Available from: https://doi.org/10.1007/s00244-008-9499-1 Subscription required to view. 

40. Wegwu MO, Omendu SI. Evaluation of selected biochemical indices in Clarias gariepinus exposed to aqueous extract of Nigerian Crude oil (Bonny Light). J Appl Sci Environ Manag. 2010 Mar;14(1):77-81. 

41. Haque S, Mondal S, Kundu D, Ghosh AR. Effect of multiple polycyclic aromatic hydrocarbons (PAHs) on liver of three teleostean fishes Labeobata, Labeorohita and Cirrhinusmrigala in Burdwan Loco Tank, Burdwan, West Bengal, India. Austin Environ Sci [Internet]. 2017 [cited 2019 May 2];2(1):Article 1017 [8 p]. Available from: https://www.austinpublishinggroup.com/environmental-sciences/fulltext/aes-v2-id1017.php