Environmental Research Communications

PAPER

Distribution of polycyclic aromatic hydrocarbons in Woji Creek, in the Niger Delta

Owhonda Chikeru Ihunwo1, Amir Reza Shahabinia1,2, Kufre Solomon Udo1,3, Estefanía Bonnail1,4, Mark Obinna Onyema1,2, Amalo Ndu Dibofori-Orji1,2 and Prince Chinedu Mmom1,5

1 Niger Delta Aqua Research Group, Department of Biochemistry and Chemistry Technology, School of Science Laboratory Technology, University of Port Harcourt, Port Harcourt, Nigeria
2 Groupe de Recherche Interuniversitaire en Limnologie (GRIL), Département des Sciences Biologiques, Université du Québec à Montréal (UQAM), Succ. Centre-Ville, Case postale 8888 Montréal, Québec H3C 3P8, Canada
3 Department of Chemistry, Faculty of Natural and Applied Sciences. Ignatius Ajuru University of Education, Port Harcourt, Nigeria
4 Centro de Investigaciones Costeras-Universidad de Atacama (CIC-UDA), Avenida Copayapu 485, Copiapó, Atacama, Chile
5 Department of Pure and Industrial Chemistry, University of Port Harcourt, Rivers State, Nigeria

E-mail: owhonda.ihunwo@hotmail.co.uk

Keywords: polycyclic aromatic hydrocarbon (PAH), pollution, creek, Nigeria, rivers state, oil spill

Supplementary material for this article is available online

Abstract

This is the first study related to PAHs distribution in the Woji Creek (Nigeria), that points out potential contaminant sources. The study involved sampling of water and sediment from five stations along the creek monthly (from August to October in 2018). Samples collected were analysed for the concentration of sixteen Polycyclic Aromatic Hydrocarbons (PAHs) using an Agilent 7890B Gas Chromatograph (GC-MS). Eleven (11) PAHs were identified in the water samples with five (5) below detectable limits (Naphthalene, Phenanthrene, Pyrene, Indeno [1, 2, 3-cd] pyrene and Benzo [g, h, i] perylene). Results from the surface water showed that in the month of September, the concentration ranged from 6.029 ppm in S4 to 28.331 ppm in S5. October recorded a PAHs concentration ranging between 6.094 ppm at S1 and 29.257 ppm at S5. In the sediment highest concentration of PAHs was recorded in S5; 1809.08 ppm in August, 1810.05 ppm in September and 1821.5 ppm in October. The concentrations of PAHs in sediment were significantly greater than those in the water. In both sediment and water samples, the highest concentrations of total PAHs were recorded in station 5 and the lowest in station 4. The composition of PAH in water identified the dominance of 2 and 3 rings (Low Molecular Weight (LMW) PAHs) over 4, 5 and 6 rings (High Molecular Weight (HMW) PAHs). In the sediment samples analysed, LMW PAHs (2–3 rings) made up about 30% of the composition, while HMW PAHs (4–6 rings) made up about 70% of PAHs member groups. Cross plots showed that the PAHs could have come from petroleum and combustion.

1. Introduction

Polycyclic Aromatic Hydrocarbons (PAHs) are organic compounds that are among the ubiquitous environmental pollutants. PAHs primarily occur during the incomplete combustion of organic materials such as oil and coal and also naturally originate from coal deposits and volcanic activities [1, 2]. These substances are a class of arenes which also possess substantial energies because they are made up of fused benzene rings [3]. PAHs are insoluble in water, less dense than water and are nonpolar organic compounds with weak intermolecular forces [4]; therefore, PAHs tend to get absorbed and adsorb to aquatic sediments, and also accumulate on the particulate matter for a long time.
The industrial revolution and our increasing ability to use fossil fuels have caused a significant increase in PAHs concentrations in the environment [5]. In addition to this, the risk to the environment is the PAH is a persistent contaminant and tends to linger for a long time when it enters the environment [6,7]. The three major sources of PAHs are from combustion, petroleum and environmental samples such as bush engine oil, gasoline and diesel from cars, among others. They are ubiquitous in the environment with their highest concentrations in urban areas due to the various activities taking place [8].

This group of hydrocarbons is usually classified as the most widely distributed toxic hydrocarbons [9–12]. Its mechanism of toxicity is based on the metabolism of the components of PAHs forming isomers and also interfering with the function of cellular membranes. Multiple researches have shown that PAHs have adverse effects on aquatic organisms including having ability to bind with DNA causing cancer [13,14], accumulating in fish tissues such as gills [15,16] or induce mutations leading to cancerous growth [3]. Due to the hydrophobic nature of PAHs, they can bioaccumulate in the food chain [8]. PAHs not only affects aquatic organisms, but it has also effects on higher-order animals and human causing mutagenicity, carcinogenicity, and genotoxicity [17].

In 2014, distribution of polycyclic aromatic hydrocarbons (PAHs) in sediment cores of selected creeks in Delta State, Nigeria was studied [18], results from this study revealed seasonal variation in PAH concentration. Another study was carried out to perform source and toxicological assessment of polycyclic aromatic hydrocarbons in sediments from Imo river, South-eastern Nigeria [19]. There results revealed PAH concentrations ranging from 409.43 to 41,198 ng g\(^{-1}\) dw with standard deviation of 4,796 ± 1,941. Source analysis revealed that stations were mildly impacted by oil and discriminated among stations that were influenced by pyrogenic sources. Polycyclic aromatic hydrocarbons (PAHs) seasonal variation and sources in Ubeji, Ilfe, and Egbigoko Creeks of the Niger Delta, Nigeria, were predicted using diagnostic ratios (DRs) of parent PAHs (Phe/Phe + Ant; Flu/Flu + Pyr; BaA/BaA + Chry, and Ind/Ind + BghiP) and principal component analysis (PCA) [20]. The diagnostic PAH ratios revealed that PAHs in the sediment cores at the three creeks, in both seasons, mainly stemmed from the combustion process (pyrogenic sources). A study was carried out to investigate the levels of PAH in water and fish of Rivers Niger and Benue confluence Lokoja, Nigeria [21]. The study showed clearly that the levels of PAHs in the samples are of concern due to increasing pollution.

Woji creek is an important fluvial system in the city of Port Harcourt (Nigeria), which serves as a source of food (fishes and other edible aquatic organisms) and transportation. In a study carried out in 2005 [22], they identified 30 benthic fauna species were identified in Woji creek. However, preliminary studies of benthic fauna in this creek did not identify any species which could be as a result of activities taking place in this creek. However, fishes on this creek will either die or migrate to less polluted environments [23], leading to little or no fishes in this stretch of the river. Studies have also revealed that the creek is polluted with heavy metals due to the anthropogenic activities in and around the creek [24]. Therefore, this study aims to determine the concentrations of PAHs in water and sediments of the Woji creek and to investigate the potential sources of PAHs. It is the first study carried out in Woji creek to assess PAH and determine its sources using PAH ratios.

2. Methods

2.1. Study area
The study river is the upstream stretch of the Sambreiro River and it stretches from Rumuibekwe community, passing through Trans Amadi Industrial layout in the city of Port Harcourt and empties in the Bright of Bonny. This is a major navigable river that connects the Bright of Bonny to the city of Port Harcourt (figure 1). This river receives urban and industrial sewage also, few periodic accident oil spillages from illegal and ill-equipped vessels transporting crude to illegal refining production frequently occur. The area is also the site for an abattoir within which the burning of wood, rubbers and cattle skin is carried out. Before the oil spillages, it was a fishing river with different crab species and other benthic invertebrates which provided economic benefits to the community that lay claim to this section of the creek [22]. Woji creek is an intertidal river hence the possibility of the migration of contaminants [24].

Water and sediment samples were collected monthly (from August to October in 2018) during low tide event at five stations (figure 1). There are two sites for boat repairs within the 3 km stretch of this river (S1 and S3) chosen. Samples were collected in both reverse and free flow (that is from upstream to downstream and downstream to upstream). At each station, five samples were collected transversely and mixed together to form a composite sample representing each station [25]. Water samples (N = 5) were collected in 100 ml glass bottles acidified for cleaning purpose to pH 2 with concentrated sulphuric acid and sediment was sampled using a Van Veen Grab Sampler, collecting the top layer soft sediment. Samples were stored in an ice chest (<4 °C) and transported to the laboratory for analysis.
2.2. Analysis
Sample preparation and methodology employed is summarised in Method 8270E: Semi-volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS) [26]. Analysis of the PAHs concentration was determined by the means of the Agilent 7890B Gas Chromatograph (GC-MS). Analysed compounds (abbreviations), chemical formula, molecular weight, and ring numbers are summarized in table 1.

Furthermore, cross plots of An/(An + Pn) versus C0/(C0 + C1) F/P, Fl/(Fl + Py) versus C0/(C0 + C1) F/P and Fl/(Fl + Py) versus C00/(C00 + C1) P/A, as performed by Tobiszewski (2014) and Yunker et al (2002). The ratios of some isomers of PAHs are used in the diagnosis of the source of PAHs in sediment [27–31]. A ratio of An/(An + Pn) higher than 0.1 points out a mainly petrogenic input of PAH, while that less than 0.1 is due to combustion. BaA/(BaA + Ch) ratio below 0.2 indicates PAHs input from petroleum, between 0.2–0.3 indicates a mixed source of input, while a

![Figure 1. Map showing the Rivers State (Nigeria) location, and the sampling stations in the Woji Creek.](image)

| Group name | Abbreviation | Chemical formula | Molecular weight | NO. of rings |
|------------|--------------|------------------|------------------|--------------|
| Low molecular weight PAHs | | | | |
| Naphthalene | Na | C10H8 | 128.174 | 2 |
| Acenaphthylene | Ayl | C10H8 | 152.196 | 3 |
| Acenaphthene | Aen | C12H10 | 154.212 | 3 |
| Fluorene | F | C13H10 | 166.223 | 3 |
| Phenanthrene | Pn | C14H10 | 178.234 | 3 |
| Anthracene | An | C14H10 | 178.234 | 3 |
| High molecular weight PAHs | | | | |
| Fluoranthene | Fl | C16H10 | 202.256 | 4 |
| Pyrene | Py | C16H10 | 202.256 | 4 |
| Benz (a) anthracene | BaA | C18H12 | 228.294 | 4 |
| Chrysene | Ch | C18H12 | 228.294 | 4 |
| Benzo(b) fluoranthene | BF | C20H12 | 252.316 | 5 |
| Benzo(k) fluoranthene | BF | C20H12 | 252.316 | 5 |
| Benzo(a) pyrene | BaP | C20H12 | 252.316 | 5 |
| Indeno(1, 2, 3-cd) pyrene | IP | C22H12 | 276.338 | 6 |
| Benzo[(g), (h), (i)] perylene | Bghi | C22H12 | 276.338 | 6 |
Table 2. Mean ± Standard deviation of PAH in river water and sediment for the months of August September and October.

| Group Name | S1        | S2        | S3        | S4        | S5        | F       | P       |
|------------|-----------|-----------|-----------|-----------|-----------|---------|---------|
| Water (mg l⁻¹) |           |           |           |           |           |         |         |
| Ayl        | 0.818 ± 0.037 | 2.381 ± 0.508 | 1.312 ± 0.148 | 0.730 ± 0.037 | 2.939 ± 0.056 | 50.511 | <0.001 |
| Aen        | 0.839 ± 0.098 | 2.446 ± 0.506 | 1.621 ± 0.275 | 0.763 ± 0.033 | 3.068 ± 0.106 | 42.888 | <0.001 |
| F          | 0.781 ± 0.055 | 2.263 ± 0.287 | 1.56 ± 0.271 | 0.791 ± 0.006 | 3.123 ± 0.056 | 93.331 | <0.001 |
| An         | 0.793 ± 0.036 | 2.378 ± 0.487 | 1.300 ± 0.131 | 0.739 ± 0.034 | 3.161 ± 0.122 | 75.043 | <0.001 |
| Fl         | 0.652 ± 0.041 | 1.848 ± 0.129 | 1.737 ± 0.513 | 0.527 ± 0.022 | 3.0 ± 0.009 | 53.902 | <0.001 |
| BaA        | 0.547 ± 0.092 | 1.666 ± 0.288 | 1.086 ± 0.106 | 0.495 ± 0.024 | 2.932 ± 0.058 | 142.19 | <0.001 |
| Ch         | 0.700 ± 0.038 | 1.934 ± 0.051 | 1.126 ± 0.202 | 0.639 ± 0.02 | 2.918 ± 0.025 | 304.39 | <0.001 |
| BF         | 0.559 ± 0.062 | 1.56 ± 0.113 | 1.023 ± 0.033 | 0.566 ± 0.058 | 2.7 ± 0.171 | 237.92 | <0.001 |
| BF         | 0.474 ± 0.059 | 1.140 ± 0.177 | 0.733 ± 0.069 | 0.375 ± 0.033 | 2.389 ± 0.184 | 135.7 | <0.001 |
| BaP        | 0.452 ± 0.045 | 1.132 ± 0.194 | 0.757 ± 0.125 | 0.486 ± 0.018 | 2.372 ± 0.284 | 69.226 | <0.001 |

Sediment (mg kg⁻¹)

| Na         | 35.9 ± 1.8 | 43.8 ± 0.3 | 39.3 ± 0.2 | 20.5 ± 0.7 | 53.1 ± 0.6 | 501.66 | <0.001 |
| Ayl        | 41.8 ± 0.42 | 44.6 ± 0.36 | 39.3 ± 0.15 | 23.9 ± 0.05 | 64.6 ± 2.78 | 393.58 | <0.001 |
| Aen        | 0.8 ± 0.098 | 2.4 ± 0.506 | 1.6 ± 0.275 | 0.763 ± 0.033 | 3.068 ± 0.106 | 42.888 | <0.001 |
| F          | 53.9 ± 7.15 | 66.6 ± 2.27 | 66.5 ± 0.52 | 28.6 ± 0.30 | 74.63 ± 1.53 | 76.912 | <0.001 |
| An         | 118.7 ± 1.25 | 129.9 ± 1.71 | 119.9 ± 0.31 | 68.6 ± 0.37 | 179.8 ± 0.18 | 4957.5 | <0.001 |
| Fl         | 118.4 ± 1.58 | 129.8 ± 1.17 | 128.8 ± 0.30 | 66.6 ± 0.52 | 176.8 ± 1.96 | 2876.4 | <0.001 |
| Py         | 127.6 ± 1.22 | 119.4 ± 1.30 | 128.9 ± 0.19 | 72.5 ± 0.19 | 192.9 ± 2.74 | 2398.4 | <0.001 |
| BaA        | 105.3 ± 0.62 | 124.7 ± 0.28 | 119.71 ± 0.52 | 60.8 ± 0.78 | 156.1 ± 0.56 | 548.5 | <0.001 |
| Ch         | 97.8 ± 0.81 | 120.0 ± 0.02 | 117.4 ± 0.49 | 57.7 ± 2.07 | 149.6 ± 0.51 | 3180.7 | <0.001 |
| BF         | 98.0 ± 0.88 | 110.0 ± 0.84 | 100.5 ± 0.50 | 56.5 ± 0.06 | 148.9 ± 0.36 | 8733.6 | <0.001 |
| BF         | 119.7 ± 0.56 | 157.4 ± 1.19 | 121.2 ± 0.79 | 69.2 ± 0.78 | 186.1 ± 3.36 | 2130.7 | <0.001 |
| BaP        | 63.5 ± 0.61 | 75.0 ± 0.55 | 78.4 ± 1.49 | 36.8 ± 0.21 | 97.4 ± 2.08 | 1030 | <0.001 |
| IP         | 64.7 ± 0.23 | 92.6 ± 0.47 | 69.4 ± 0.50 | 38.2 ± 0.77 | 99.0 ± 0.82 | 4955.7 | <0.001 |
| Bghi       | 48.2 ± 0.28 | 58.5 ± 0.52 | 66.5 ± 0.40 | 28.5 ± 0.59 | 74.4 ± 0.53 | 4192.9 | <0.001 |

ratio value above 0.3 indicates combustion. Similarly, when IP/(IP + Bghi) value is above 0.5, it indicates a PAHs input from grass, wood and coal combustion, values between 0.2–0.5 indicates petroleum combustion and values below 0.2 indicates PAHs input from petroleum.

3. Results

3.1. PAHs concentration distribution

The PAHs concentrations in water and sediment in the different sampling stations in August, September and October are collected in tables 2. The highest water polluted site along months was determined as S5 (above 28 ppm \( \sum \)PAH), while S4 registered the lowest total concentrations (~6 ppm \( \sum \)PAH). In contrast, concentrations in sediments were notably great, but with a similar distribution of contamination (above 1800 in S5 and below 700 ppm in S4). The major contributors in S5 were pyrene and benz(o)fluoranthene. PAH concentration in this study were higher than those carried out in the study of the distribution of PAHs in sediment sores of selected creeks in Delta State, Nigeria [18].

ANOVA analysis of PAH concentrations in the river water and sediment varied significantly from S1 to S5 with a statistically significant difference of \( p > 0.001 \) (table 3). These variations were not consistent with the activities in each sample site; this inconsistency could be attributed to the fast-flowing nature of the river and other means of dispersion.

The PAHs analysis of water samples showed an absence of naphthalene, phenanthrene, pyrene, indeno (1, 2, 3, -cd) pyrene and benzo (g, h, i) perylene. In August, the PAHs in water samples ranged from 6.089 ppm in S4 to 28.22 ppm in S5. In September, the concentration ranged from 6.029 ppm in S4 to 28.331 ppm in S5. October recorded a PAHs concentration ranging between 6.094 ppm at S1 and 29.257 ppm at S5.

A division attending to the molecular weight was done as low (LMW: two and three rings) and high molecular weight (HMW: four, five and six rings). The percentage LMW about 50% at each sample station, and the high molecular weight PAHs (HMW), which is a combination of four, five and six rings PAHs make up slightly about 50% (figure 2). This was contrary to those obtained in the study of the distribution of PAHs in some sediments in Delta State, Nigeria [18].
In the sediment, all members of the PAHs group were represented in the samples analysed. LMW PAHs (2–3 rings) made up about 30% of the composition, while HMW PAHs (4–6 rings) made up about 70% of PAHs identified in the samples analysed (figure 2). Similar to the results for water analysis, the highest concentration of PAHs was recorded in S5; 1809.08 ppm in August, 1810.05 ppm in September and 1821.5 ppm in October. In contrast, S4 recorded the lowest concentrations of PAHs for all the months (687.93 ppm in August, 691.01 ppm in September, and 689.56 ppm in October).

Due to the absence of some essential PAHs members required to perform the PAHs cross plot in water, this analysis could not be performed. However, a cross plot of An/(An + Pn) versus Fl/(Fl + Py) and BaA/(BaA + Ch) versus Fl/(Fl + Py) showed that the PAHs could have come from petroleum and combustion, while the cross plot of IP/(IP + Bghi) versus Fl/(Fl + Py) shows a majorly petroleum sourced PAHs pollution (figures 3(A)–(C)).

4. Discussion

4.1. PAHs composition

The PAHs composition can be broken down according to the number of rings (2 and 3 rings, 4 rings and 5 and 6 rings), or its molecular weight as Low Molecular Weight PAHs (LMW, 2 and 3 ring PAHs), and High Molecular Weight PAHs (HMW, 4, 5 and 6 ring PAHs). The distribution of PAHs composition in water and sediment is summarized in figure 2. The PAHs in water almost evenly split between the LMW and HMW; meanwhile the PAHs concentration in sediments is dominated by HMW. This determines that PAHs in the water and sediment are from different sources.

In the sediment, all members of the PAHs group were represented in the samples analysed. LMW PAHs (2–3 rings) made up about 30% of the composition, while HMW PAHs (4–6 rings) made up about 70% of PAHs member groups identified in the samples analysed (figure 2). Similar to the results for water analysis, the highest concentration of PAHs was recorded in S5; 1809.08 ppm in August, 1810.05 ppm in September and 1821.5 ppm in October. In contrast, S4 recorded the lowest concentrations of PAHs for all the months (687.93 ppm in August, 691.01 ppm in September, and 689.56 ppm in October).

Due to the absence of some essential PAHs members required to perform the PAHs cross plot in water, this analysis could not be performed. However, a cross plot of An/(An + Pn) versus Fl/(Fl + Py) and BaA/(BaA + Ch) versus Fl/(Fl + Py) showed that the PAHs could have come from petroleum and combustion, while the cross plot of IP/(IP + Bghi) versus Fl/(Fl + Py) shows a majorly petroleum sourced PAHs pollution (figures 3(A)–(C)).

4. Discussion

4.1. PAHs composition

The PAHs composition can be broken down according to the number of rings (2 and 3 rings, 4 rings and 5 and 6 rings), or its molecular weight as Low Molecular Weight PAHs (LMW, 2 and 3 ring PAHs), and High Molecular Weight PAHs (HMW, 4, 5 and 6 ring PAHs). The distribution of PAHs composition in water and sediment is summarized in figure 2. The PAHs in water almost evenly split between the LMW and HMW; meanwhile the PAHs concentration in sediments is dominated by HMW. This determines that PAHs in the water and sediment are from different sources.

The even composition of LMW and HMW PAHs in water shows the influence of both petroleum and the presence of combustion products from low-temperature pyrolytic processes and/or petrogenic sources. This results are similar to a study carried out to assess the composition and source of PAHs in sediments at river mouths and channel in Kaohsiung Harbour, Taiwan [28], they attributed the predominance of low molecular weight PAHs in the surface sediments of the Salt River to indicate recent pollution and/or direct PAHs inputs into the surface water from sources such as shipping, dry and wet atmospheric deposition, and air-water exchange. In the current study, the activities occurring in the area contribute to the input of PAHs in the water. However, the predominance of two and three rings PAHs (>40%) in water indicates that the major source of pollution in the water for all the studied stations comes from petroleum [30] (figure 2). Other sources may come from the burning in the abattoir which releases soot into the atmosphere and leads to direct air-water exchange. They may also have been imputed from the boats that use the river as a means of transport and as a location for
repairs, the direct input of hydrocarbons through spills from inadequate vessels also serve as a means of input [30]. PAH study in Ubeji, Ife, and Egbokodo creeks revealed similar results as those in the present study [20]. In contrast, in sediment samples, the percentage sum of two and three rings PAHs was about 30% (figure 2), while a combination of 4, 5, and 6 rings PAHs made up about 70% of the PAHs composition in all the studied stations. This might be evidence that the PAHs is majorly from a combustion base source with an influence of petroleum combustion [28]. The source of PAH in this creek is similar to those assessed in Imo river [19]. Results from the study was also higher that those obtained in the study of levels and risk assessment of polycyclic aromatic hydrocarbons in water and fish of Rivers Niger and Benue confluence Lokoja, Nigeria [21]. Despite the lower PAH concentrations in the Lokoja, they concluded that the concentration of Benzo[a]pyrene, a known indicator of the presence of carcinogenic PAHs is of health risk concern. It is also safe to also conclude that the present study creek is a health risk concern. Due to the high organic matter in sediment, it is considered as a reservoir for PAH in the environment [32]. This accounts for the significantly higher PAH concentration in the sediment when compared to the surface water. Thus, the persistence may pose a risk of bioaccumulation in sediment dwelling organisms which increases the of a toxic effect to humans who may consume them [6].

4.2. PAHs diagnostic ratios
Results of isomer ratios are plotted in figure 3. The ratio IP/(IP + Bghi) gives a view of grass, wood and coal combustion, therefore, it will help identify input from soot if it applies, which is necessary in our study river due to the activities taking place in this area. When F/(F + Py) is higher than 0.5, it indicates input from the combustion of grass, wood and coal, a ratio between 0.4 and 0.5 indicates input from combustion of petroleum, and a ratio below 0.4 indicates an input of petroleum pollution [27].

Figure 3. PAH cross plots for the ratios of (A) An/(An + Pn) versus Fl/(Fl + Py), (B) BaA/(BaA + Ch) versus Fl/(Fl + Py) and (C) IP/(IP + Bghi) versus Fl/(Fl + Py).
Performing a cross plot of F/(F + Py) and the other ratios (An/(An + Pn), BaA/(BaA + Ch) and IP/(IP + Bghi)) can help to remove misleading results of PAHs input [27, 28]. The results of the cross plots indicate that the PAHs input in the sediments of the study river were mostly from combustion and petroleum (figure 3), similar to some stations in Ubeji, Ilfe, and Egbokodo creeks [20]. This confirms the results from the composition analysis and is in correlation to the activities in the study area as stated above. The same sources of PAHs input applied to every sample station, hence the cluster observed in the plot (figure 3).

5. Conclusion

Our results confirm the presence of PAHs in water and sediments taken from the Woji River. Although the sources of PAHs in the river is mixed, the major source of pollution in the river water has got a predominance of low molecular weight PAHs; the major sources of pollution in the water comes from petroleum, this might be attributed to the oil spill over the river due to the various activities. However, in the sediment, a dominance of high molecular weight PAHs points out a source from the influence of petroleum combustion. This was further confirmed through the PAHs diagnostic ratios.

These results obtained can be used for mitigation purposes, i.e. the identification of courses can help to reduce the consistent input of PAH into this study river. Furthermore, it can help to develop further studies in assessing PAH bioaccumulation in aquatic organisms. This research also opens areas of further studies to be carried out in the amount of petroleum hydrocarbon present in the river and the concentrations of metals present due to the fuel pollution in this river.

Acknowledgments

The research team wishes to thank team also appreciates the support of field and laboratory personnel of the Niger Delta Aqua Research Group, NDARG (www.ndarg.com). This research did not receive any specific funding.

Conflicts of interest

The authors declare no conflicts of interest.

ORCID iDs

Owhonda Chikeru Ihunwo @ https://orcid.org/0000-0003-0676-6886
Amir Reza Shahabinia @ https://orcid.org/0000-0001-8593-5478
Estefanía Bonnail @ https://orcid.org/0000-0003-3190-921X
Mark Obinna Onyema @ https://orcid.org/0000-0002-6984-1751
Amalo Ndu Dibofofi-Orji @ https://orcid.org/0000-0002-7589-0015
Prince Chinedu Mmom @ https://orcid.org/0000-0001-6496-2397

References

[1] Abdel-shafy H I and Mansour M S M 2016 A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation Egypt. J. Pet. 25 107–23
[2] Kumar B et al 2018 Polycyclic aromatic hydrocarbons (PAHs) in inland aquatic ecosystems: perils and remedies through biosensors and Environ. Pollut. 241 212–33
[3] Francis A Cand Robert M G 2014 Organic Chemistry (New York, NY (United States): McGraw-Hill)
[4] Gschwend P M and Schwarzenbach R P 1992 Physical chemistry of organic compounds in the marine environment Mar. Chem. 39 187–207
[5] Wild S R and Jones K C 1995 Polynuclear aromatic hydrocarbons in the United Kingdom environment: a preliminary source inventory and budget Environ. Pollut. 88 91–108
[6] Singare P U 2015 Studies on polycyclic aromatic hydrocarbons in surface sediments of Mithi River near Mumbai, India: assessment of sources, toxicity risk and biological impact Mar. Pollut. Bull. 101 232–42
[7] Basavaiya N, Mohite R D, Singare P U, Reddy A V R, Singhal R K and Blaha U 2017 Vertical distribution, composition profiles, sources and toxicity assessment of PAH residues in the reclaimed mudflat sediments from the adjacent Thane Creek of Mumbai Mar. Pollut. Bull. 118 112–24
[8] Meador J P, Stein J E, Reichert W L and Varanasi U 1995 Bioaccumulation of polycyclic aromatic hydrocarbons by marine organisms Rev. Environ. Contam. Toxicol. 143 79–165
[9] Bamforth S M and Singleton I 2005 Bioremediation of polycyclic aromatic hydrocarbons: current knowledge and future directions 736 723–36
[10] Samanta S K, Singh O V and Jain R K 2002 Polycyclic aromatic hydrocarbons: environmental pollution and bioremediation Trends Biotechnol. 20 243–8
[11] Stanley E M 2003 Toxicological Chemistry and Biochemistry 3rd edn33431 (Boca Raton, Florida: Lewis Publishers)
[12] Zhu L, Lu H, Chen S and Amagi T 2009 Pollution level, phase distribution and source analysis of polycyclic aromatic hydrocarbons in residential air in Hangzhou, China J. Hazard. Mater. 162 1165–70
[13] Mastrangelo G, Fadda E and Marzia V 1996 Polycyclic aromatic hydrocarbons and cancer in man Environ. Health Perspect. 104 1166–70
[14] Korsh J, Shen A, Aliano K and Davenport T 2015 Polycyclic aromatic hydrocarbons and breast Cancer: a review of the literature Breast Care 10 316–8
[15] Frank A P C G, John B W, Ronals W R and Douglas G H 1999 Mechanism of biomagnification in fish under laboratory and field conditions Environ. Sci. Technol. 33 133–41
[16] Van der Oost R, Heida H, Opperhuizen A and Vermeulen N P 1991 Interrelationships between bioaccumulation of organic trace pollutants (PCBs, organochlorine pesticides and PAHs), and MFO-induction in fish Comp. Biochem. Physiol. C. 100 43–7
[17] Dhakad K, Dalal P and Shrivastava J K 2018 A Case Study: Effect of Industrial Effluent Contaminated Water Disposed in Chambal River on Irrigation Land Int. Res. J. Eng. Technol. 5 3–6
[18] Eguvbe P M, Iwegbue C M A, Ogala J E, Nwajie G E and Egboh S H O 2014 Distribution of polycyclic aromatic hydrocarbons (PAHs) in sediment cores of selected creeks in Delta State, Nigeria Environ. Forensics 15 121–33
[19] Oyo-Ita I, Oyo-Ita O, Ugim S, Nnaji N and Elarbaoui S 2017 Source and toxicological assessment of polycyclic aromatic hydrocarbons in sediments from imo river, Southeastern Nigeria Polycycl. Aromat. 39 191–206
[20] Eguvbe P M, Iwegbue C M A, Egboh S H O, Ogala J E and Nwajie G E 2015 Source apportionment and identification of polycyclic aromatic hydrocarbons (PAHs) in sediment cores of selected creeks in Delta State, Nigeria Environ. Forensics 16 51–75
[21] Ekere N R, Yakubu N M, Oparanozie T and Ibedioha J N 2019 Levels and risk assessment of polycyclic aromatic hydrocarbons in water and fish of Rivers Niger and Benue confluence Lokoja, Nigeria J. Environ. Heal. Sci. Eng. 17 383–92
[22] Hart A I and Zabley N 2005 Physico-chemical and benthic fauna of Woji Creek in the Lower Niger Delta Physico-Chemistry and Ekere Fauna of Woji Creek in the Lower Niger Delta, Nigeria Environment Ecol. 23 361–368
[23] William R T D and Jorg F 2015 Lost fishes, who is counting? The extent of threat to freshwater fish biodiversity Conservation of Freshwater Fishes ed P C Gerard, K Martin and D O Julian (Cambridge, United Kingdom: Cambridge University Press) pp 1–36
[24] Amalo N D-O, Owohnda I, Kufre S U, Amir R S, Mark O O and Prince C M 2019 Spatial and temporal distribution and contamination assessment of heavy metal in Woji Creek Environ. Res. Commun. 1 1–10
[25] Patil G P 2002 Composite Sampling Encyclopedia of Environmetrics 1 ed A H El-Shaarawi and W W Piearsch (Chichester: Wiley) pp 387–91
[26] US EPA 2014 Method 8270E: Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS) Hazardous Waste test method SW-846 Revision 6. (Washington, DC: United States: Environmental Protection Agency) p68
[27] Yunker M B, Macdonald R W, Vingarzan R, Mitchell R H, Goyette D and Sylvestre S 2002 PAHs in the Fraser River basin: a critical appraisal of PAH ratios as indicators of PAH source and composition Org. Geochem. 33 489–515
[28] Chen C, Chen C, Dong C and Tu Y 2012 Composition and source apportionment of PAHs in sediments at river mouths and channel in Kaohsiung Harbor, Taiwan J. Environ. Monit. 14 105–15
[29] Kafi zadeh F, Branch J, Shiva A H and Malekpour R 2011 Determination of polycyclic aromatic hydrocarbons (PAHs) in water and sediments of the Kor River, Iran Middle-East J. Sci. Res. 18 01–07
[30] Ping I F, Luo Y M, Zhang H B, Li Q B and Wu L H 2007 Distribution of polycyclic aromatic hydrocarbons in thirty typical soil profiles in the Yangtze River Delta region, east China Environ. Pollut. 147 358–65
[31] Sun C, Zhang J, Ma Q, Chen Y and Hu J 2016 Polycyclic aromatic hydrocarbons (PAHs) in water and sediment from a river basin: sediment – water partitioning, source identification and environmental health risk assessment Environ. Geochem. Health 39 63–74
[32] Pozo K et al 2011 Levels and spatial distribution of polycyclic aromatic hydrocarbons (PAHs) in sediments from Lenga Estuary, central Chile Mar. Pollut. Bull. 62 1572–6