

# **Concentrations of polycyclic aromatic hydrocarbons in samples of soil, feed and food collected in the Niger Delta Region, Nigeria: A probabilistic human health risk assessment**

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## **ABSTRACT**

Polycyclic aromatic hydrocarbons (PAHs) are widely distributed compounds with two or more fused aromatic ring, being some of them classified as carcinogenic. In the present study, we determined the concentrations of 16 PAHs and the sum of them ( $\Sigma$ PAHs), as well as the contributions of various sources (cow meat, goat meat, chicken meat, fish, fish feed, chicken feed, plant and soil) in six different heavily polluted areas (Choba, Khana, Trans Amadi, Eleme, Uyo and Yenagoa) of the Niger Delta Region (Nigeria). Principal component analysis (PCA) was used to identify groups of variables (PAHs) and groups of samples (fish, meat, feed, plant and soil) mainly contributing to the environmental pollution by PAHs in that Region of Nigeria. The results showed that, in several areas, cooked cow meat and chicken-based products were significantly associated to the levels of PAHs. PAHs intake through fish and meat consumption, as well as the derived carcinogenic risks were assessed in a probabilistic way. The high intake of PAHs through meat consumption mean a very high and unassumable carcinogenic risk, which is quite above  $10^{-5}$  for some PAHs, including benzo[*a*]pyrene. The results of the present survey highlight the importance of reducing PAHs content in food, specially in meat, in the Niger Delta region of Nigeria.

**Keywords:** Polycyclic aromatic hydrocarbons; human health; carcinogenic risks; food intake; Niger Delta Region, Nigeria

## 1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a group organic compounds with 2 to 7 fused aromatic rings (Ali et al., 2021). The physicochemical properties of PAHs make them substances highly mobile in the environment, thereby making PAHs easily distributed in water, air and soil (Kryzevicius et al., 2020; Ambade et al., 2021). Some PAHs are mutagens, carcinogens and teratogens, posing serious health risks for humans (He et al., 2020). PAHs are broadly classified into two groups based on their biological and physical properties (high molecular weight (HMW) and low molecular weight (LMW) PAHs.. High molecular weight (HMW) PAHs, which consist of four to seven aromatic rings, are less degradable by microorganisms (Dai et al., 2019; Kryzevicius et al., 2020; Ambade et al., 2021). Consequently, they can persist in environment and accumumulate in animals, and in concequence be more harmful for humans (Li et al., 2020). The low molecular weight (LMW) PAHs consist of less than four aromatic rings. Although they are less carcinogenic, these compounds still poses potential toxicity for a number of species including many marine organisms (Bua et al., 2021). High concentrations of LMW PAHs (e.g., acenaphthene and fluorene) mostly occur in sample matrices that are contaminated with naturally occurring PAHs (petrogenic and biogenic origins) (Pichler et al., 2021). In turn, the PAHs that are generated in combustion processes (pyrolytic origin) have usually elevated levels of HMW (e.g. phenanthrene, fluoranthene, pyrene) and lower levels of LMW PAHs (Davis et al., 2019). PAHs may be present in oil, coal, and tar deposits, and are produced as by-products of indoor and outdoor fuel burning (Alshaarawy et al., 2013, Nováková et al., 2020). Other sources of PAHs include contaminated water and food arising from processing, preparation, and cooking methods (Singh et al., 2020; Iko Afé et al., 2020). Given the diverse sources of PAHs in the environment, exposure to a single PAH compound is unlikely (Alshaarawy et al., 2013).

PAHs are also one of the major petroleum chemicals of interest in oil spill (Farrington, 2020). Therefore, crude oil spills in communities where seafood is harvested generate concerns about the

potential human health risks for the consumers of the seafood (Yitalo et al., 2012). PAHs are considered as the most toxic pollutants of crude oil (Sørensen et al.; 2017). The United States Environmental Protection Agency (US EPA) has classified these compounds as priority toxics due to their persistence in the environment and toxicity to aquatic organisms, being of special interest following oil spills and for periodical environmental monitoring. PAHs have been found in crude oil at significant amounts, with some of them exceeding 2 mg/kg (Ahmad et al., 2006).

Exposure to PAHs is prevalent in the Niger Delta region (Nigeria), as a result of gas flaring, as well as incomplete combustion of fossil fuels and other organic materials (Orisakwe, 2021). Various environmental matrices -especially water- are subjected pollution and degradation due to port activities, crude oil exploration/spills, artisanal and crude oil refining, operations of mechanized boats, deforestation and agricultural practices (Dienye and Sikoki, 2019; Anyanwu et al., 2020; Orisakwe, 2021)

Meat and fish consumption remain high in the Niger Delta region. Fish constitutes approximately 75% of animal protein consumed in the coastal cities of that region (Edun et al., 2010). In fact, some fish species are used mainly as condiments in most meals of that region (Gomna and Rana, 2007). Fishing and hunting, which are the main occupation of the locals in the rural communities of the Niger Delta, predispose them to fish and meat consumption (Babatunde et al., 2015). Data on the levels of PAHs in meat and fish consumed in the Niger Delta region are scarce in the scientific literature.

The present study was focused on measuring the concentrations of 16 PAHs and the sum of them ( $\Sigma$ PAHs) in a number of different kinds of samples collected in the Niger Delta region (Nigeria) and on determining which samples had the highest/lowest influences on PAHs content. The specific objectives were the following. Firstly, to measure the concentrations of 16 selected PAHs and  $\Sigma$ PAHs in different samples (n=26) collected in six areas of that Region: Choba, Khana, Trans Amadi, Eleme, Uyo, and Yenogoa. Secondly, to define the contributions of feed-to-food chain to the levels of PAHs in these areas by using principal component analysis (PCA). PCA should help to identify groups of

variables (i.e., PAHs concentrations) according to the loadings and groups of samples (fish, meat, feed, plant and soil) based on the scores, in order to find common patterns or differences in data distribution, leading to initial dimension reduction of dataset and helping the interpretation (Ahmed et al., 2016; Gergen and Harmanescu, 2012). Finally, PAHs intake through meat and fish consumption was established and the derived carcinogenic risks were assessed.

## **2. Materials and methods**

### *2.1. Study area*

The Niger Delta Region, which includes nine Nigerian states (Cross Rivers, Edo, Abia, Ondo, Imo, Bayelsa, Rivers, Delta, and Akwa Ibom), has an extension around 70,000 km<sup>2</sup> and a population of 35 million inhabitants, 7.5% and 15% of the land area and population of Nigeria, respectively. This region is located between latitude 5°33'N to 8°25'N and longitude 4°15'E to 6°30'E and is the seat of crude oil exploration in Nigeria.

### *2.2. Sampling and treatment*

As recently reported (Okoye et al., 2021), in January 2018, food and feed samples were collected by triplicate in six areas of Niger Delta (Choba, Khana, Trans Amadi, Eleme, Uyo and Yenogoa). Food (cow and goat meat -muscle and liver-, chicken meat, fresh and dried fish) and feed samples (fish and chicken feed) were purchased from markets, sales points, and abattoirs. Fresh *Panicum maximum (Jacq)* (Guinea grass), *Pennisetum purpureum Schumach* (Elephant Grass), *Zea mays (L.)* (Maize) and soil samples were collected. All plant samples were measured as wet weight. Immediately after collection, all samples were packaged in glass petri dishes and kept in the laboratory until subsequent analyses.

### *2.3. Analytical determinations*

PAHs determination was carried out using Gas Chromatography (6890 series and 6890 plus) equipped with a dual detector (FID-ECD), dual column and TriPlus AS auto-sampler with helium carrier gas and a quadrupole Mass Spectrometer (Agilent 5975 MSD) based on the US EPA method 8100 (EPA 1984). Analytical procedure was described elsewhere (Igbiri et al., 2017; Ekhaton et al., 2018; Orisakwe et al., 2015 a,b). Briefly, the extraction of PAHs from the samples was done with a sonicator (Ultrasonic bath-Elmsonic S40H) in accordance with US SW-846 Method 3550. Two grams of each sample were extracted with a 50:50 mixture of acetone and methylene chloride (analytical grade) spiked with 1 ml of PAH internal standard and shaken thoroughly for proper mixing before being placed in an ultrasonic bath (Ekhaton et al., 2018; Orisakwe et al., 2015a,b). Afterwards, the extracts 2.00 µl of extracts were injected into the GC port set at column conditions: HP-5 cross linked PH-ME siloxane, length of 30 m, I.D: 0.25 mm, thickness of 1 µm with helium carrier gas set in the splitless, constant flow mode with 1.2 ml/min flow rate. Other GC and MS operating set-up were done according to the instrument's method development as specified in the operating instruction manual. Identification and quantification of individual PAHs were based on internal calibration standard containing known concentrations of the 16 PAHs (US EPA-16). The specificity of the 16 PAHs sought for in the samples was confirmed by the presence of transition ions (quantifier and qualifier) as shown by their retention times which corresponded to those of their respective standards. The measured peak area ratios of precursor to quantifier ion were in close agreement with those of the standards. The 16 PAHs here analysed were the following: Naphthalene (N), Acenaphthylene (Acy), Acenaphthene (Ace), Fluorene (F), Phenanthrene (P), Anthracene (Ant), Fluoranthene (Fl), Pyrene (Pyr), Benzo[*a*]anthracene (BaAnt), Chrysene (Chr), Benzo[*b*]fluoranthene (BbFl), Benzo[*k*]fluoranthene (BkFl), Benzo[*a*]pyrene (BaPyr), Dibenzo[*ah*]anthracene (DBahAnt), Benzo[*ghi*]perylene (DBghiPer), and Indeno[1,2,3-*cd*]pyrene (Ipyr).

The detection limit (LOD) -estimated as three times the background noise (IUPAC criterion)- was similar for all analysed compounds, being them 0.015 µg/kg dry weight (d.w.) for all analytes. The blank samples remained always below the quantification limit (LOQ): 0.05 µg/kg d.w.

#### 2.4. Human Health risk assessment

As recently reported (Okoye et al., 2021), to deal with the uncertainty of variability of the exposure parameters, individual and total PAHs ingestion through meat and fish were calculated using equation 1 in a probabilistic way (100,000 iterations) using Oracle Crystal ball software (version 11.1.2.4.850).

$$PAH\ ingestion_{ijk} = \frac{IR_{jk} \times [PAH]_{ij}}{BW_k} \quad (1)$$

where PAH ingestion<sub>ijk</sub> is the ingestion of PAH<sub>i</sub>, for age group k -adults or children (6-12 years old)- through consumption of food item j (meat or fish) (in mg/kg/day); IR<sub>jk</sub> is food item j ingestion rate for population k (in g/day); [PAH]<sub>ij</sub> is the PAH<sub>i</sub> concentration in food item j (in mg/g); BW<sub>k</sub> is the body weight for age group k (in kg). The parameters here used are summarized in Table 1.

Benzo[a]pyrene equivalents (BaP<sub>eq</sub>) were calculated using equation 2.

$$BaP_{eq} = \sum_i [PAH_i] \times TEF_i \quad (2)$$

where [PAH] are the concentrations of PAH<sub>i</sub> (in mg/g), being TEF<sub>i</sub> the toxic equivalent factors for the PAH<sub>i</sub>. TEFs were obtained from Nisbet and LaGoy (1992) (Table 1).

Finally, carcinogenic risks due to PAHs ingestion were calculated according to equation 3.

$$Cancer\ risk = \frac{PAH\ ingestion_{ik} \times SF_o \times ED}{AT} \quad (3)$$

where SF<sub>o</sub> is the slope factor oral for each PAHs in (in kg·day/mg) (RAIS, 2021), ED is the exposure time (7 and 45 years for children and adults, respectively) and AT is the life expectancy (75 years) (Table 1).

#### 2.5. Statistics

The PCA data set used in this study comprised 26 samples including fish, meat (goat and cow, liver and muscle), feed (fish and chicken feed), soil and plants (grass and maize) and 17 variables (16 PAHs and the sum of them (ΣPAHs)). The principal component (PC) models were separately

constructed for each area under study (Choba, Khana, Trans Amadi, Eleme, Uyo, Yenagoa). A first model was computed comprising all the PAHs. Unfortunately, the quality of the model was poor, with many of the variables contributing only to decrease the quality. Thus, in order to improve the model, another PCA was constructed through a reduction of the original variables in order to maximize the quality and avoid overfitting. The new PCA models showed a minor number of variables and explained a higher model variance. In the PCA, the eigenvalues give a measure of the variance accounted by the corresponding eigenvectors (components). In the present study, only PCs having eigenvalues greater than 1 were considered. PCA calculated the factor loadings, factor scores and created the PCA biplot graph. The factor loadings showed which PAHs are the major contributors to the model components. The classification of strong, moderate, and weak factor loadings in the range from  $>0.75$ ,  $0.75$  to  $0.5$ , and  $0.5$  to  $0.3$ , respectively, was here used (Liu et al., 2003). Regarding factor scores, a positive score for the sample means that the concentration of the variable (i.e., PAHs) increases along the PC axis, a negative score means that the concentration of PAH decreases along the axis, while a score near zero means that the concentration is poorly linearly related to the PC axis. In the PCA biplot, the direction of the vectors (variables) indicates the direction in which the concentration of the corresponding PAHs increases most, and the length of the vectors equals the rate of change in that direction. Moreover, the narrow angle among the vectors reflected that these variables were positively linked one to each other. PCA was performed by XLSTAT Microsoft Excel statistical software.

### **3. Results and discussion**

Table 2 and Table S1 (supplementary materials), show the individual levels of 16 the PAHs and the sum of them ( $\Sigma$ PAHs) in the 26 samples (cow meat, goat meat, chicken meat, fish, fish feed, chicken feed, plant and soil) from the six areas (Choba, Khana, Trans Amadi, Eleme, Uyo, and Yenagoa) included in the current survey. In Figure 1, mean individual levels PAHs for Niger Delta are depicted. Soil presented levels of  $\Sigma$ PAHs ranging between 6.33 mg/kg in Khana and 8.80 mg/kg

in Uyo. In Choba, Eleme, Trans Amadi and Yenagoa, soil samples presented the following levels of  $\Sigma$ PAHs: 7.42, 6.79, 7.97 and 7.39 mg/kg, respectively. In Lagos (Nigeria), Adetunde et al. (2018) reported total soil PAHs levels ranging from 0.70 to 254 mg/kg, while in Nnewi, a highly industrialized town from eastern Nigeria, the total soil PAHs levels were between 0.017 and 0.047 mg/kg (Ofomatah and Okoye, 2017). In another study, the predominant PAHs were pyrene, naphthalene and benzo[*k*]fluoranthene. Total PAHs levels in Niger Delta soils ranged from 0.182±0.112 to 0.433 ±0.256 mg/kg (Abbas and Brack, 2006). The highest levels of  $\Sigma$ PAHs in fish feed and chicken feed were 28.7 and 15.3 mg/kg, respectively, both collected from Khana, while the lowest levels of fish feed and chicken feed were 6.84 mg/kg (Yenagoa) and 7.40 mg/kg (Choba), respectively. However, plants from Uyo presented the highest level of  $\Sigma$ PAHs (8.42 mg/kg).

There is paucity of information regarding concentrations of PAHs in fish feed. Easton et al. (2002) reported PAHs values of from 0.081 to 1.333 mg/kg, while Tsapakis et al. (2010) found an average (min–max) concentration of 0.316 (0.287–0.351) mg/kg of PAHs in fish feed. The higher PAHs detected in fish feed in the present study may be of public health importance.

Table 3 shows the PCA eigenvalues and factor loadings in the six sampling areas here assessed. The PCA biplot picture of Fig. 2 (a-f) relates the 26 samples to the levels of PAHs in each sampling area (Choba, Khana, Trans Amadi, Eleme, Uyo, and Yenagoa). In the PCA biplot, the red vectors are the PAHs analyzed and the points in Fig. 2 are the 26 samples, colored according to the origin of samples (i.e., cow meat, goat meat, chicken meat, fish, fish feed, chicken feed, plant and soil).

In Choba, the eigenvalues of the PCA model (Table 3) showed that the first two PCs explained the 61.9% of the pattern variation (F1: 43.7% and F2: 18.2%). The PCA biplot (Fig. 2a) showed all the PAHs located in the positive sides of both PC1 and PC2 components. Variables as acenaphthylene (0.844 and 14.8%), phenanthrene (0.826 and 14.2%), acenaphthene (0.748 and 11.6%) and fluorene (0.789 and 12.9%) presented the highest factor loadings and contribution percentages to PC1

component, being closely grouped. In turn, benzo[*k*]fluoranthene (0.791 and 13.0%), benzo[*ghi*]perylene (0.708 and 10.4%) and indeno[1,2,3-*cd*]pyrene (0.758 and 11.9%) formed another strictly linked group of variables, being also relevant contributors to PC1. In addition, the narrow angles among vectors of acenaphthylene-phenanthrene, acenaphthene-fluorene, and benzo[*ghi*]perylene-indeno[1,2,3-*cd*]pyrene-benzo[*k*]fluoranthene reflected that they were positively associated. The positive side of PC2 was dominated by dibenzo[*ah*]anthracene contributing for 32.7% with a high factor loading (0.810). On the other hand, Pyrene was located in the negative sides of PC1 and PC2, and the  $\Sigma$ PAHs in the negative side of PC2, revealing that both Pyrene and  $\Sigma$ PAHs had a reduced influence in the area of Choba. Depending on the samples (Table 2),  $\Sigma$ PAHs in Choba were: 8.06 mg/kg in cow meat; 5.78  $\mu$ g/kg in goat meat; 6.56 mg/kg in fish; 7.42 mg/kg in chicken meat; 8.26 mg/kg in fish feed; 7.40  $\mu$ g/kg in chicken feed; 6.96 mg/kg in plants; and 7.42 mg/kg in soil. In particular, chicken (muscle and gizzard) influenced the levels of benzo[*k*]fluoranthene, benzo[*ghi*]perylene and indeno[1,2,3-*cd*]pyrene, while chicken feed was more associated to phenanthrene and acenaphthylene levels (Fig. 2a). Some cooked meats contributed to the positive PC1 component. Thus, fried meat was mainly associated to acenaphthene and fluorene levels and beef suya barbecued, a very popular meat in Nigeria -usually grilled over an open fire- was linked to fluoranthene. It has been reported that cooking practices as barbecuing, grilling, roasting and frying are associated to higher levels of PAHs in meat (Adeyeye, 2020). In suya meat sampled in selling points from Nigeria, benzo[*a*]pyrene levels ranged between 6.5 and 21.5 mg/kg (Duke and Albert, 2007). Other Nigerian samples that were smoked or grilled using traditional systems (wood fire) were heavily contaminated with benzo[*a*]pyrene (Akpambang et al., 2009). In the current survey, there was a group of samples such as fish (both fresh and dried) and goat meats that were found at the left side of the PCA biplot and distant from all the PAHs, showing therefore a limited association with PAHs pollution in Choba. In fact, among all the samples collected in Choba the lowest levels of PAHs were found in goat meat and fish. According to the scientific literature, due to their ability to rapidly

metabolize PAHs, fish generally contain very low PAH concentrations, except for the highest levels of PAHs observed in smoked fishes and especially in the smoked skin (Adeyeye, 2020).

In Khana, the eigenvalues (Table 3) showed that the first two PCs explained the 60.0% of the variance (F1:39.6% and F2:20.4%). All the PAH vectors were located at the right side of the PCA biplot (Fig. 2b). The  $\Sigma$ PAHs (factor loading of 0.898 and 20.3%) and naphthalene (factor loading of 0.836 and 17.6%) presented the highest contribution to PC1 positive component, reflecting the narrow angles between their vectors a significant relationship. The highest concentration of  $\Sigma$ PAHs in Khana (Table 2) were found in fish feed (28.7 mg/kg), chicken meat (25.4 mg/kg) cow meat (16.7 mg/kg) and chicken feed (15.3 mg/kg). Naphthalene was particularly concentrated in fish feed and chicken feed (2.32 mg/kg and 6.47 mg/kg, respectively). At a lower extent, the levels of pyrene (factor loading 0.752 and 14.3%) and fluorene (factor loading 0.619 and 9.65%) were also associated to the positive F1 axis. Another group of PAHs -formed by benzo[*k*]fluoranthene, acenaphthene and anthracene- contributed positively to both PC1 and PC2 components. In contrast, phenanthrene and dibenzo[*ah*]anthracene decreased along the F2 axis, revealing a limited impact on the contamination of Khana area. Interestingly, pyrene appeared significantly linked to the consumption of kilishi beef, which is a sun-dried, spiced and roasted traditional African meat product. This supports that its presence can be attributed to the contamination resulting from processing methods as drying and roasting. Chicken muscle, chicken feed and fish feed appeared to be associated to acenaphthene, anthracene and fluorene in Khana site, with the highest values of these 3 PAHs (5.31 mg/kg, 2.14 mg/kg and 2.61  $\mu$ g/kg, respectively) especially in fish feed. Other samples such as soil, plants, fish, goat and cow meat were grouped in the left quadrant of the PCA model, providing a clear distance from any PAH.

In Trans Amadi area, the eigenvalues of the PCA model (Table 3) showed the first two PCs explaining 61.3% of the pattern variation. Levels of  $\Sigma$ PAHs (factor loading 0.813 and 18.3%) and Benzo[*ghi*]Perylene (factor loading 0.747 and 15.5%) increased along the positive F1 component (Figure 2c). Another group of PAHs (acenaphthene, acenaphthylene, naphthalene, and

dibenzo[*ah*]anthracene) were located at the positive side of both PC1 and PC2 and were near one to each other, which reveals their common origin (Figure 2c). The concentration of benzo[*a*]anthracene, benzo[*k*]fluoranthene and benzo[*a*]pyrene decreased along the F2 component, highlighting their limited influence on Trans Amadi area contamination. The  $\sum$ PAHs (and also the levels of individual PAHs) (Table 2) were quite similar among the kinds of samples: 7.51 mg/kg in cow meat, 7.40  $\mu$ g/kg in goat meat, 5.65 mg/kg in fish, 8.62  $\mu$ g/kg in chicken meat, 7.12  $\mu$ g/kg in fish feed, 8.27 mg/kg in chicken feed, 7.21 mg/kg in plants, and 7.97 mg/kg in soil. The highest concentration corresponded to pyrene in fish (4.65 mg/kg). The relatively low proximity of PAHs to the analysed samples (Figure 2c) permitted to conclude that no one specific sample or source was able to represent the individual PAHs or their sum in the area of Trans Amadi.

In Eleme area, the first two F1 and F2 components explained a total variance of 48.9% (F1: 32.6% and F2: 16.3%), highlighting a relatively low quality of the model (Table 3 and Fig. 2d). A mixture of compounds: indeno[1,2,3-*cd*]pyrene (0.867 and 17.7%), naphthalene (0.706 and 11.8%), fluorene (0.688 and 11.2%), phenantrene (0.689 and 11.2%), benzo[*a*]pyrene (0.656 and 10.1%), acenaphthene (0.644 and 9.79%) and chrysene (0.610 and 8.77%), contributed to the PC1 component. The only PAHs that contributed to the positive PC2 component were anthracene and benzo[*k*]fluoranthene, with factor loadings of 0.715 and 0.681, and contribution percentages of 24.1% and 21.9%, respectively. These two PAHs were separated one from the other, being clearly differentiated from the rest of PAHs in the PCA plot. In Eleme area, various kinds of samples were located at the positive sides of the two PCs and potentially linked to all the above mentioned PAHs. In Eleme, the levels of  $\sum$ PAHs (and also the levels of individual PAHs) were comparable among samples, ranging from 6.79 mg/kg in soil to 9.91  $\mu$ g/kg in fish feed (Table 2). The most concentrated PAHs were acenaphthylene in fish (1.24 mg/kg), fluoranthene in fish (1.20 mg/kg), benzo[*k*]fluoranthene and pyrene in goat meat (1.04 and 0.99 mg/kg, respectively). Previous studies showed how in Nigeria the exposure to PAHs occur as a mixture of compounds and no one single source may explain all the compounds found in the mixture (Gurjar et al., 2010).

In Uyo sampling area, the sum of the 16 PAHs varied from 1.24  $\mu\text{g}/\text{kg}$  in goat meat to 3.27  $\mu\text{g}/\text{kg}$  in fish and 9.07  $\mu\text{g}/\text{kg}$  in cow meat (Table 2). The PCA results (Table 3 and Figure 2e) explained the 65.6% of the total variation, with the contribution of F1 component (48.4%) higher than F2 (17.2%). The PCA was able to cluster variables into two different groups. The first one formed by naphthalene, acenaphthylene, anthracene and dibenzo[*ah*]anthracene with factor loadings from 0.63 to 0.805 and percentages between 7.5-12%, all of them increasing along the positive PC1 component. The samples that presented an influence on this cluster of PAHs were chicken feed and chicken food, cow meat (barbecued and fried) and soil, but levels of individual compounds were relatively lower (median values below 1.0  $\mu\text{g}/\text{kg}$ ). Another group comprised fluoranthene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, and  $\Sigma\text{PAHs}$  which also positively contributed to PC1 component with loading factors over 0.70 and percentages > 9%. The investigated samples were distant from this second cluster of PAHs and none of them presented a minimal influence on PAHs contamination. The indeno[1,2,3-*cd*]pyrene was separated from the other PAHs and its concentration increased along the PC2 component (factor loading of 0.726 and percentage of 27.8%).

In Yenogoa, the first two PCs explained (Table 3 and Figure 2f) the 64.4 % of the model variance (F1: 48.6% and F2: 15.8%). In this area, many PAHs showed factor loadings > 0.5 along the F1 axis. Among all, the major contributors of PC1 component were fluoranthene, benzo[*k*]fluoranthene, fluorene, acenaphthylene and  $\Sigma\text{PAHs}$  with factor loadings between 0.726-0.796 and percentages between 8.0-10.0%. Cow meat (fried, barbecued and spiced), chicken meat, chicken feed and plant samples were associated to this group of PAHs. Other PAHs like Phenanthrene, dibenzo[*ah*]anthracene, and benzo[*ghi*]perylene increased along the positive F2 axis, but no clear association with any sample was observed. In Yenogoa area, as already observed in Uyo, the lowest content of  $\Sigma\text{PAHs}$  was detected in goat meat (5.50 mg/kg) and fish (4.86 mg/kg) (Table 1) and the highest in chicken feed and plants (8.38 mg/kg and 8.06 mg/kg, respectively). Whilst considering the singol compounds, the most concentrated one (pyrene) was found in fish (2.57 mg/kg), and all the other PAHs were at median levels lower than 1 mg/kg.

Table 4 and 5 summarize the intake of the individual PAHs,  $\Sigma$ PAHs and benzo[a]pyrene equivalents (BaP<sub>eq</sub>) through fish plus meat consumption for adult and child between 6 and 12 years old population of six studied regions. The mean (Percentile 95th (P95)) PAHs intake for adult population through meat plus fish consumption ranged from 0.75 (P95: 1.57)  $\mu\text{g}/\text{kg}/\text{day}$  for naphthalene to 3.53 (P95: 9.66)  $\mu\text{g}/\text{kg}/\text{day}$  for pyrene. Adult BaP<sub>eq</sub> intake through meat plus fish consumption was set at 2.56 (P95: 5.06)  $\mu\text{g}/\text{kg}/\text{day}$ . Regarding children, PAHs intake through meat plus fish consumption were between 1.28 (P95: 2.72)  $\mu\text{g}/\text{kg}/\text{day}$  for naphthalene and 3.35 (P95: 7.88)  $\mu\text{g}/\text{kg}/\text{day}$  for pyrene and BaP<sub>eq</sub> intake for children consumption of meat plus fish was 4.12 (P95: 8.32)  $\mu\text{g}/\text{kg}/\text{day}$ . Children intake was higher for almost all individual PAHs due to higher consumption and body weight ratio than for adults. The only exception was pyrene that presented higher levels in adult than in child population due to the high levels found in fish and the relatively low consumption of fish by children compared to meat. Meat contributes 91% and 96% for BaP<sub>eq</sub> intake through meat plus fish consumption, for adult and children, respectively. Compared with meat, PAHs intake due to fish ingestion is negligible, with the exception of pyrene, whose ingestion through fish consumption was around 3 times higher than through meat for adults, and almost similar than through meat intake for children.

Taking into account location, maximum adult mean intakes of PAH<sub>16</sub> occurred in Khana with levels of 26.8  $\mu\text{g}/\text{kg}/\text{day}$ . However, similar results were obtained in the other 5 areas, with values ranging between 16.1 and 25.6  $\mu\text{g}/\text{kg}/\text{day}$  in Yenagoa and Trans Amadi, respectively (Figure 3). In the same line, BaP<sub>eq</sub> adult intake showed a range of mean levels between 2.17 and 2.96  $\mu\text{g}/\text{kg}/\text{day}$  in Yenagoa and Khana, respectively.

The FAO/WHO JECFA concluded that carcinogenicity is the critical effect of PAHs and as some PAHs are genotoxic, the assumption of a tolerable intake is not possible (JECFA, 2005). However JEFCA established a BDML equivalent of 0.1 mg benzo[a]pyrene/kg/day and EFSA set the 95% lower limit of bench mark dose with 10% effect (BMDL<sub>10</sub>) values for benzo[a]pyrene, PAH<sub>2</sub>, PAH<sub>4</sub> and PAH<sub>8</sub> at 0.07, 0.17, 0.34 and 0.49 mg/kg/day, respectively (JECFA, 2005, EFSA,

2008). In addition, the Panel on Contaminants in the Food Chain (CONTAM), consider the sum of either PAH4 or PAH8 are better indicators of both the occurrence and toxicity of PAHs than PAH 2 or benzo[*a*]pyrene (EFSA, 2008). In addition, CONTAM panel concluded that the toxic equivalent factor approach is not scientifically valid because of the lack of data and studies for mixtures and oral carcinogenicity (EFSA, 2008). As no tolerable intake for PAHs was set by FAO/WHO JECFA and BaPeq seems not being an adequate approach, cancer risks for the 8 carcinogenic PAHs were individually assessed and Margin of exposure (MoE) approach were applied for PAH2, PAH4, PAH8 and benzo[*a*]pyrene according to EFSA (EFSA, 2008). MoE is defined as the quotient between the mean or high intakes and a benchmark dose (EFSA, 2005).

As shown in Figure 4 some of PAHs (naphthalene, benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*a*]pyrene, dibenzo[*ah*]anthracene and indeno[1,2,3-*cd*]pyrene) exceed the  $10^{-5}$  threshold, being for benzo[*a*]pyrene and dibenzo[*ah*]anthracene higher than  $10^{-4}$ . This clearly indicates the high consumption of PAHs through meat and fish deal with very high and unassumible carcinogenic risks ( $>10^{-5}$  and  $>10^{-4}$ ). In addition, the margins of exposure (MoE), the quotient between the mean intakes (PAH2, PAH4, PAH8 and benzo[*a*]pyrene) and  $BDML_{10}$  were 72, 69, 55, and 60 for the, respectively. MoE below 10,000 were considered a intake of cancer, so our mean intake and in consequence also the higher intake for the Niger Delta population were of a really concern (EFSA, 2005, Taghizadeh et al., 2021a,b).

#### **4. Conclusions**

In the current study, taken together, PAHs levels in soil, feed and food are -in general terms- higher than the concentrations reported elsewhere, being of potential public health relevance. PCA was used to find inter-parameter associations existing between different PAHs and different samples in various areas of Nigeria, which is a pollution hotspot dispersing many PAHs in the environment. The pollutants were clustered in various groups of PAHs based on PCA models, and depending on the geographical area. In four areas, some specific samples -as cooked cow meat (fried, barbecued

and dried/spiced) and chicken-based products (food and feed)- mostly contributed to PAHs levels. The results demonstrated that specific cluster of PAHs might identify the study areas in Nigeria, which may have similar sources. It can be used to handle the PAHs pollution reduction strategy and to remark research and monitoring priorities. Carcinogenic risks derived from PAHs ingestion from meat and fish consumption in the Nigerian areas here evaluated are very high and unassumable ( $>10^{-5}$ ). MoE indicated a mean and high intakes of concern for Niger Delta inhabitants. The results of the present survey highlight the importance of reducing PAHs content in food, specially in meat, in the Niger Delta region of Nigeria.

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**Table 1.** Parameters used in Montecarlo simulation for intake of PAHs through meat and fish consumption. PAHs toxic equivalents factors (TEF) and oral slope factors (SFo).

Abbreviation	Parameter		Distribution	Value	Reference
<b>IR</b>	Meat ingestion rate	Adult	LN	116 (18.0) g/day	Ihedioha et al. 2014
		Child	LN	97.7 (16.7) g/day	Ihedioha et al. 2014
<b>IR</b>	Fish ingestion rate	Adult	LN	20.6 (2.1) g/day	Ihedioha et al. 2016
		Child	LN	6.9 (0.7) g/day	Ihedioha et al. 2016
<b>BW</b>	Body weight	Adult	LN	70 (10.3) kg	Ihedioha et al. 2014
		Child	LN	35 (5.9) kg	Ihedioha et al. 2014
<b>[PAH]</b>	Concentrations	PAHs	LN	Pollutant specific	Present study
<b>ED</b>	exposure time	Adult	P	45 year	
		Child	P	7 year	
<b>AT</b>	life expectancy		P	75 year	
Abbreviation	PAHs			TEF <sup>a</sup>	SFo <sup>b</sup> (mg/kg/day) <sup>-1</sup>
<b>N</b>	Napthalene			0.001	0.12
<b>Acy</b>	Acenaphylene			0.001	-
<b>Ace</b>	Acenaphthene			0.001	-
<b>F</b>	Fluorene			0.001	-
<b>P</b>	Phenanthrene			0.001	-
<b>Ant</b>	Anthracene			0.010	-
<b>Fl</b>	Flouranthene			0.001	-
<b>Pyr</b>	Pyrene			0.001	-
<b>BaAnt</b>	Benzo[ <i>a</i> ]anthracene			0.100	0.1
<b>Chr</b>	Chrysene			0.010	0.001
<b>BbFl</b>	Benzo[ <i>b</i> ]fluoranthene			0.100	0.1
<b>BkFl</b>	Benzo[ <i>k</i> ]fluoranthene			0.100	0.01
<b>BaPyr</b>	Benzo[ <i>a</i> ]pyrene			1.000	1
<b>DBahAnt</b>	Dibenzo[ <i>ah</i> ]anthracene			1.000	1
<b>BghiPer</b>	Benzo[ <i>ghi</i> ]perylene			0.010	-
<b>Ipyr</b>	Indeno[1,2,3- <i>cd</i> ]pyrene			0.100	0.1

Values are expressed in means (standard deviation). LN: Log normal. P: Punctual. TEF Toxic equivalent factor. SFo Carcinogenic Slope Factor.  
<sup>a</sup>(Nisbet and LaGoy, 1992); <sup>b</sup>(RAIS, 2021)

**Table 2.** PAHs median levels (mg/kg) in different food, feed and environmental samples analyzed in the six areas studied.

		N	Acy	Ace	F	P	Ant	Fl	Pyr	BaAnt	Chr	BbFl	BkFl	BaPyr	DBahAnt	BghiPer	Ipyr	ΣPAH
<b>Choba</b>	Cow meat	0.18	0.53	0.55	0.53	0.72	0.76	0.25	0.73	0.24	0.63	0.25	0.54	0.51	0.05	0.43	0.21	8.06
	Goat meat	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.018	0.001	0.95	0.001	0.001	0.001	0.001	0.001	0.001	5.78
	Fish	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1.71	0.13	0.001	0.001	0.001	0.001	0.001	0.001	0.001	6.56
	Chicken meat	0.60	0.46	0.29	0.32	0.43	0.62	0.35	0.23	0.23	0.23	0.90	0.61	0.41	0.68	0.53	0.56	7.42
	Fish feed	0.29	0.26	0.41	0.14	0.52	0.98	0.84	0.69	0.12	0.77	0.68	0.52	0.99	0.99	0.04	0.01	8.26
	Chicken feed	0.32	0.65	0.68	0.55	0.47	0.36	0.58	0.49	0.47	0.43	0.78	0.61	0.29	0.18	0.37	0.17	7.40
	Plants	0.48	0.58	0.22	0.28	0.37	0.71	0.54	0.32	0.69	0.53	0.04	0.86	0.36	0.47	0.18	0.16	6.96
	Soil	0.83	0.26	0.73	0.59	0.64	0.56	0.67	0.38	0.08	0.14	0.42	0.20	0.32	0.56	0.72	0.30	7.42
<b>Khana</b>	Cow meat	0.25	0.001	0.001	1.00	0.28	0.001	1.25	0.74	0.46	0.55	0.24	0.6	0.32	0.37	0.35	0.001	16.7
	Goat meat	0.001	0.26	0.36	0.02	0.23	0.38	0.68	0.41	0.66	0.96	0.39	0.95	0.52	0.001	0.001	0.001	8.06
	Fish	0.001	1.60	0.001	0.001	0.001	0.001	0.68	0.001	0.85	0.001	0.001	0.56	0.61	0.001	0.32	0.001	6.42
	Chicken meat	0.25	0.001	0.001	0.69	0.69	0.15	0.87	0.80	0.001	2.65	0.001	1.26	1.46	1.26	0.84	3.25	25.4
	Fish feed	2.32	0.001	5.31	2.14	0.25	2.61	0.001	2.36	2.54	0.001	2.15	6.21	0.001	0.001	0.25	2.56	28.7
	Chicken feed	6.47	0.001	1.15	0.33	0.66	0.7	0.001	0.66	0.37	0.33	0.50	0.33	0.48	2.00	0.66	0.70	15.3
	Plants	0.001	0.001	0.001	0.001	1.62	0.001	0.52	0.49	0.91	0.39	0.13	0.001	0.001	0.001	0.001	0.001	6.58
	Soil	0.001	0.001	0.001	0.001	0.001	0.001	2.82	0.001	0.001	0.001	0.001	3.36	0.14	0.001	0.001	0.001	6.33
<b>Eleme</b>	Cow meat	0.58	0.23	0.67	0.18	0.37	0.56	0.58	0.69	0.83	0.87	0.29	0.55	0.56	0.14	0.42	0.70	9.55
	Goat meat	0.001	0.21	0.17	0.001	0.18	0.13	0.69	0.99	0.17	0.55	0.54	1.04	0.08	0.001	0.53	0.001	9.53
	Fish	0.001	1.24	0.001	0.075	0.004	0.07	1.20	0.21	0.7	0.06	0.65	0.19	0.32	0.001	0.40	0.03	7.72
	Chicken meat	0.54	0.72	0.49	0.72	0.69	0.72	0.39	0.23	0.54	0.71	0.59	0.82	0.53	0.37	0.56	0.72	8.60
	Fish feed	0.89	0.80	0.11	0.46	0.27	0.76	0.98	0.09	0.57	0.96	0.74	0.63	0.81	0.31	0.58	0.97	9.91
	Chicken feed	0.81	0.31	0.34	0.67	0.49	0.24	0.74	0.31	0.61	0.60	0.53	0.53	0.33	0.77	0.77	0.64	8.67
	Plants	0.47	0.38	0.29	0.85	0.3	0.23	0.75	0.35	0.43	0.51	0.73	0.70	0.62	0.81	0.77	0.50	8.22
	Soil	0.20	0.58	0.33	0.18	0.53	0.52	0.36	0.16	0.25	0.92	0.13	0.39	0.83	0.49	0.10	0.83	6.79
<b>Trans Amadi</b>	Cow meat	0.76	0.18	0.16	0.55	0.23	0.42	0.24	0.28	0.29	0.41	0.07	0.45	0.72	0.21	0.39	0.60	7.51
	Goat meat	0.04	0.97	0.001	0.60	0.85	0.27	0.06	0.19	0.31	0.55	0.48	0.32	0.68	0.07	0.001	0.01	7.40
	Fish	0.001	0.014	0.003	0.001	0.001	0.001	0.11	4.65	0.27	0.021	0.078	0.72	0.37	0.001	0.001	0.71	5.65
	Chicken meat	0.60	0.43	0.54	0.79	0.46	0.59	0.56	0.28	0.30	0.51	0.34	0.50	0.66	0.90	0.29	0.44	8.62
	Fish feed	0.80	0.33	0.14	0.31	0.42	0.04	0.33	0.77	0.13	0.37	0.47	0.07	0.82	0.61	0.87	0.65	7.12
	Chicken feed	0.47	0.19	0.44	0.20	0.36	0.75	0.60	0.87	0.84	0.5	0.48	0.72	0.53	0.52	0.382	0.42	8.27
	Plants	0.25	0.63	0.61	0.16	0.47	0.27	0.74	0.74	0.16	0.65	0.46	0.21	0.41	0.67	0.55	0.45	7.21
	Soil	0.82	0.16	0.71	0.23	0.51	0.24	0.77	0.99	0.27	0.03	0.92	0.11	0.46	0.89	0.74	0.11	7.97
<b>Uyo</b>	Cow meat	0.61	0.23	0.26	0.25	0.40	0.32	0.13	0.89	0.75	0.46	0.16	0.67	0.86	0.61	0.33	0.28	9.07
	Goat meat	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.45	0.14	0.001	0.001	0.001	0.03	0.001	0.001	0.51	1.24
	Fish	0.001	0.35	0.15	0.001	0.06	0.001	0.005	0.04	0.49	0.32	0.08	0.40	0.001	0.001	0.17	0.001	3.27
	Chicken meat	0.38	0.61	0.61	0.25	0.71	0.42	0.42	0.39	0.65	0.25	0.26	0.49	0.50	0.51	0.84	0.30	7.45
	Fish feed	0.78	0.19	0.56	0.15	0.83	0.14	0.83	0.63	0.75	0.21	0.01	0.78	1.00	0.05	1.00	0.97	8.88
	Chicken feed	0.71	0.59	0.55	0.63	0.61	0.79	0.63	0.24	0.51	0.57	0.45	0.25	0.80	0.76	0.25	0.71	9.03
	Plants	0.14	0.71	0.78	0.35	0.53	0.69	0.15	0.89	0.50	0.61	0.40	0.96	0.83	0.38	0.43	0.48	8.42
	Soil	0.80	1.00	0.34	0.88	0.08	0.62	0.77	0.91	0.32	0.85	0.40	0.12	0.01	0.38	0.66	0.68	8.80
<b>Yenogoa</b>	Cow meat	0.45	0.47	0.22	0.26	0.18	0.46	0.24	0.53	0.10	0.46	0.66	0.46	0.79	0.39	0.24	0.55	7.98
	Goat meat	0.001	0.04	0.92	0.14	0.001	0.09	0.07	0.001	0.31	0.22	0.8	0.36	0.37	0.001	0.001	0.001	5.50
	Fish	0.001	0.001	0.001	0.001	0.001	0.001	0.001	2.57	0.04	0.001	0.001	0.001	0.001	0.05	0.001	0.001	4.86
	Chicken meat	0.31	0.43	0.50	0.25	0.29	0.60	0.53	0.11	0.25	0.27	0.50	0.53	0.50	0.70	0.83	0.07	7.32

Fish feed	0.05	0.28	0.72	0.71	0.32	0.65	0.40	0.13	0.84	0.08	0.29	0.53	0.81	0.13	0.42	0.12	6.48
Chicken feed	0.81	0.53	0.53	0.74	0.43	0.39	0.19	0.66	0.51	0.31	0.74	0.57	0.31	0.56	0.37	0.74	8.38
Plants	0.32	0.65	0.32	0.78	0.37	0.53	0.47	0.61	0.66	0.65	0.81	0.76	0.48	0.43	0.52	0.18	8.06
Soil	0.59	0.89	0.67	0.12	0.23	0.002	0.29	0.10	0.36	0.17	0.71	0.97	0.85	0.64	0.72	0.07	7.39

N: Napthalene; Acy: Acenaphthylene; Ace: Acenaphthene; F: Fluorene; P: Phenanthrene; Ant: Anthracene; Fl: Fluoranthene; Pyr: Pyrene; BaAnt: Benzo[*a*]anthracene; Chr: Chrysene; BbFl: Benzo[*b*]fluoranthene; BkFl: Benzo[*k*]fluoranthene; BaPyr: Benzo[*a*]pyrene; DBahAnt: Dibenzo[*ah*]anthracene; BghiPer: Benzo[*ghi*]perylene; Ipyr: Indeno[1,2,3-*cd*]pyrene.

**Table 3.** Principal components analysis eigenvalues and factor loadings of PAHs analyzed in the six sampling areas

<b>Choba</b>	<b>F1</b>	<b>F2</b>	<b>Khana</b>	<b>F1</b>	<b>F2</b>
Acenaphthylene	0.844	-0.098	Naphthalene	0.836	-0.111
Acenaphthene	0.748	-0.253	Acenaphthene	0.583	0.588
Fluorene	0.789	-0.316	Fluorene	0.619	-0.165
Phenanthrene	0.826	-0.027	Phenanthrene	0.289	-0.631
Fluoranthene	0.593	0.046	Anthracene	0.696	0.487
Pyrene	-0.096	-0.594	Pyrene	0.752	0.106
Benzo[ <i>k</i> ]Fluoranthene	0.791	0.226	Benzo[ <i>k</i> ]Fluoranthene	0.301	0.674
Dibenzo[ <i>ah</i> ]Anthracene	0.146	0.81	Dibenzo[ <i>ah</i> ]Anthracene	0.418	-0.599
Benzo[ <i>ghi</i> ]Perylene	0.708	0.349	Indeno[1,2,3- <i>cd</i> ]Pyrene	0.581	-0.427
Indeno[1,2,3- <i>cd</i> ]Pyrene	0.758	0.274	∑PAHs	0.898	-0.099
∑PAHs	0.386	-0.754			
<b>Eigenvalue</b>	<b>4.811</b>	<b>2.003</b>	<b>Eigenvalue</b>	<b>3.965</b>	<b>2.037</b>
<b>Variability (%)</b>	<b>43.73</b>	<b>18.21</b>	<b>Variability (%)</b>	<b>39.65</b>	<b>20.37</b>
<b>Cumulative %</b>	<b>43.73</b>	<b>61.94</b>	<b>Cumulative %</b>	<b>39.65</b>	<b>60.02</b>
<b>Trans Amadi</b>	<b>F1</b>	<b>F2</b>	<b>Eleme</b>	<b>F1</b>	<b>F2</b>
Naphthalene	0.538	0.632	Naphthalene	0.706	0.328
Acenaphthylene	0.533	0.43	Acenaphthene	0.644	0.378
Acenaphthene	0.629	0.656	Fluorene	0.688	0.150
Benzo[ <i>a</i> ]Anthracene	0.509	-0.635	Phenanthrene	0.689	0.062
Benzo[ <i>b</i> ]Fluoranthene	0.526	-0.274	Anthracene	0.389	0.715
Benzo[ <i>k</i> ]Fluoranthene	0.519	-0.604	Fluoranthene	0.28	-0.635
Benzo[ <i>a</i> ]Pyrene	0.433	-0.547	Chrysene	0.61	-0.291
Dibenzo[ <i>ah</i> ]Anthracene	0.65	0.518	Benzo[ <i>k</i> ]Fluoranthene	-0.234	0.681
Benzo[ <i>ghi</i> ]Perylene	0.747	-0.316	Benzo[ <i>a</i> ]Pyrene	0.656	0.017
∑PAHs	0.813	-0.079	Dibenzo[ <i>ah</i> ]Anthracene	0.598	-0.228
			Indeno[1,2,3- <i>cd</i> ]Pyrene	0.867	-0.021
			∑PAHs	0.347	-0.523
<b>Eigenvalue</b>	<b>3.604</b>	<b>2.530</b>	<b>Eigenvalue</b>	<b>4.239</b>	<b>2.122</b>
<b>Variability (%)</b>	<b>36.04</b>	<b>25.30</b>	<b>Variability (%)</b>	<b>32.60</b>	<b>16.32</b>
<b>Cumulative %</b>	<b>36.04</b>	<b>61.34</b>	<b>Cumulative %</b>	<b>32.60</b>	<b>48.93</b>
<b>Uyo</b>	<b>F1</b>	<b>F2</b>	<b>Yenogoa</b>		
Naphthalene	0.633	0.615	Acenaphthylene	0.698	-0.201
Acenaphthylene	0.733	0.256	Acenaphthene	0.629	-0.394
Anthracene	0.729	0.456	Fluorene	0.796	-0.154
Fluoranthene	0.786	-0.067	Phenanthrene	0.549	0.631
Chrysene	0.690	-0.371	Anthracene	0.729	-0.414
Benzo[ <i>a</i> ]Anthracene	0.546	-0.622	Fluoranthene	0.791	0.145
Benzo[ <i>b</i> ]Fluoranthene	0.774	-0.254	Benzo[ <i>b</i> ]Fluoranthene	0.748	-0.388
Benzo[ <i>k</i> ]Fluoranthene	0.718	-0.238	Benzo[ <i>k</i> ]Fluoranthene	0.795	-0.058
Dibenzo[ <i>ah</i> ]Anthracene	0.805	0.179	Benzo[ <i>a</i> ]Pyrene	0.573	-0.472
Indeno[1,2,3- <i>cd</i> ]Pyrene	0.153	0.726	Dibenzo[ <i>ah</i> ]Anthracene	0.664	0.562
∑PAHs	0.825	-0.181	Benzo[ <i>ghi</i> ]Perylene	0.670	0.587
			Indeno[1,2,3- <i>cd</i> ]Pyrene	0.636	0.442
			∑PAHs	0.726	-0.123
<b>Eigenvalue</b>	<b>5.328</b>	<b>1.894</b>	<b>Eigenvalue</b>	<b>6.317</b>	<b>2.056</b>
<b>Variability (%)</b>	<b>48.43</b>	<b>17.22</b>	<b>Variability (%)</b>	<b>48.59</b>	<b>15.82</b>
<b>Cumulative %</b>	<b>48.43</b>	<b>65.65</b>	<b>Cumulative %</b>	<b>48.59</b>	<b>64.41</b>

F1 and F2: Factor 1 and 2

**Table 4.** Probabilistic distribution for PAHs and benzo[*a*]pyrene equivalents (BaPeq) intakes ( $\mu\text{g}/\text{kg}/\text{day}$ ) through meat plus fish consumption for adults and children in the six areas studied.

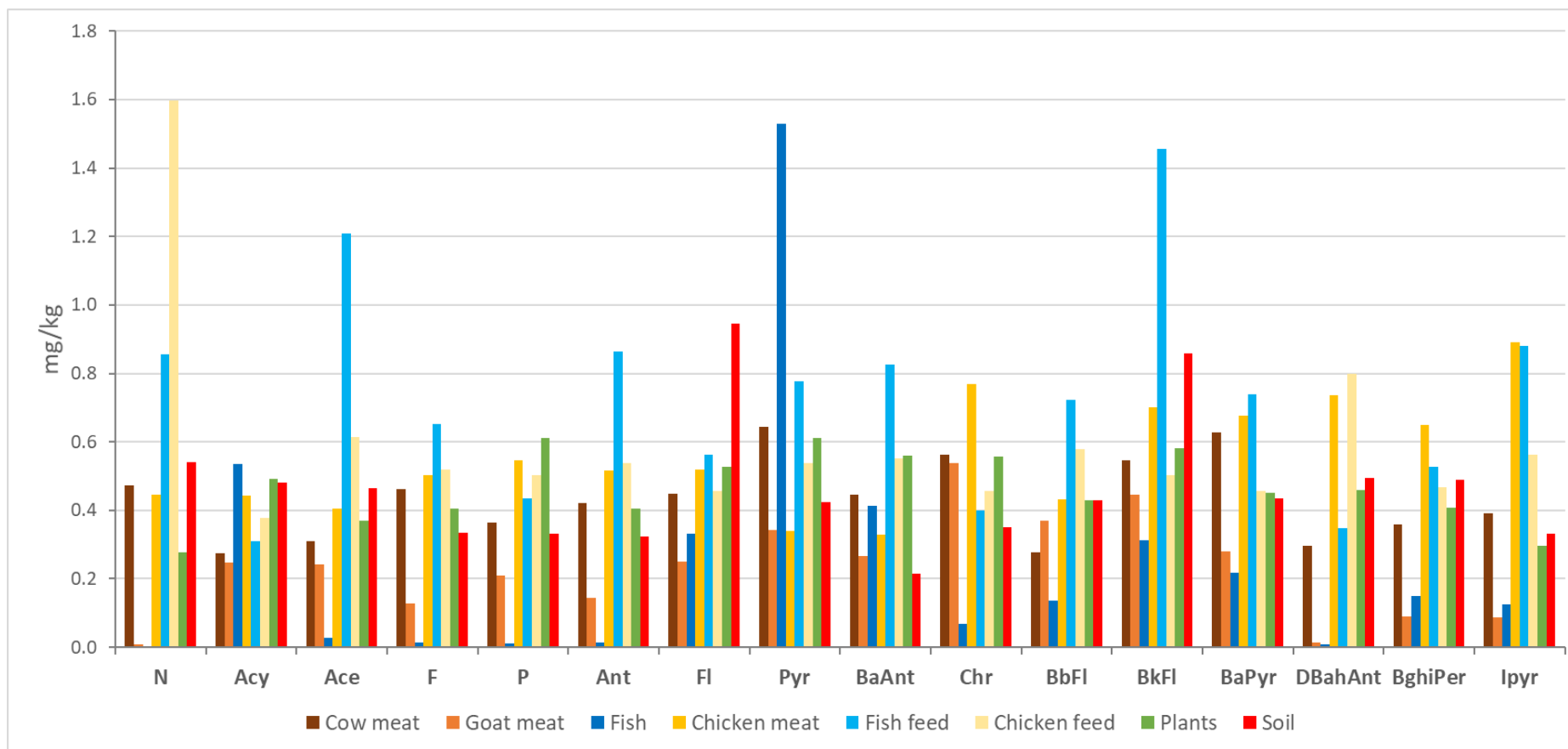
<b>Adult</b>	<b>N</b>	<b>Acy</b>	<b>Ace</b>	<b>F</b>	<b>P</b>	<b>Ant</b>	<b>Fl</b>	<b>Pyr</b>	<b>BaAnt</b>	<b>Chr</b>	<b>BbFl</b>	<b>BkFl</b>	<b>BaPyr</b>	<b>DBahAnt</b>	<b>BghiPer</b>	<b>Ipyr</b>	<b>BaPeq</b>
<b>Mean</b>	0.75	1.00	0.80	0.80	0.89	1.00	1.33	3.53	1.67	1.20	0.87	1.09	1.16	1.01	1.06	0.82	2.56
<b>Standard deviation</b>	0.43	0.46	0.41	0.31	0.63	0.54	2.29	4.53	2.25	1.20	0.39	0.49	0.65	0.69	1.10	0.50	1.24
<b>Minimum</b>	0.12	0.25	0.17	0.24	0.12	0.22	0.07	0.42	0.05	0.11	0.21	0.25	0.27	0.18	0.05	0.16	0.58
<b>5<sup>th</sup> Percentile</b>	0.26	0.48	0.33	0.41	0.27	0.39	0.15	0.77	0.25	0.25	0.38	0.47	0.48	0.31	0.21	0.29	1.07
<b>25<sup>th</sup> Percentile</b>	0.46	0.68	0.53	0.58	0.45	0.64	0.39	1.48	0.57	0.50	0.61	0.76	0.73	0.57	0.44	0.49	1.67
<b>50<sup>th</sup> Percentile</b>	0.66	0.91	0.72	0.74	0.70	0.89	0.69	2.37	1.05	0.83	0.78	1.00	1.00	0.83	0.77	0.69	2.25
<b>75<sup>th</sup> Percentile</b>	0.95	1.19	0.96	0.96	1.11	1.21	1.49	4.01	1.89	1.48	1.05	1.34	1.44	1.24	1.28	1.01	3.15
<b>95<sup>th</sup> Percentile</b>	1.57	1.83	1.57	1.40	2.10	2.05	3.94	9.66	5.10	3.14	1.64	1.96	2.38	2.30	2.90	1.73	5.06
<b>Maximum</b>	3.57	3.83	3.49	2.49	4.78	4.19	32.3	81.9	29.0	11.9	3.05	4.10	6.02	6.69	18.2	5.48	8.21
<b>Child 6-12 years old</b>	<b>N</b>	<b>Acy</b>	<b>Ace</b>	<b>F</b>	<b>P</b>	<b>Ant</b>	<b>Fl</b>	<b>Pyr</b>	<b>BaAnt</b>	<b>Chr</b>	<b>BbFl</b>	<b>BkFl</b>	<b>BaPyr</b>	<b>DBahAnt</b>	<b>BghiPer</b>	<b>Ipyr</b>	<b>BaPeq</b>
<b>Mean</b>	1.28	1.56	1.33	1.35	1.46	1.61	2.19	3.35	2.44	1.96	1.33	1.70	1.85	1.68	1.70	1.33	4.12
<b>Standard deviation</b>	0.76	0.79	0.71	0.57	1.12	0.92	4.26	3.01	3.95	2.23	0.63	0.81	1.11	1.15	1.66	0.88	2.23
<b>Minimum</b>	0.22	0.26	0.25	0.40	0.19	0.29	0.05	0.39	0.08	0.12	0.24	0.25	0.34	0.18	0.07	0.17	0.65
<b>5<sup>th</sup> Percentile</b>	0.43	0.67	0.53	0.66	0.41	0.60	0.20	0.94	0.28	0.39	0.60	0.71	0.71	0.47	0.29	0.43	1.60
<b>25<sup>th</sup> Percentile</b>	0.74	1.01	0.86	0.95	0.74	1.02	0.51	1.67	0.68	0.78	0.90	1.13	1.10	0.88	0.66	0.75	2.55
<b>50<sup>th</sup> Percentile</b>	1.08	1.36	1.17	1.24	1.16	1.42	1.11	2.53	1.36	1.31	1.19	1.54	1.55	1.37	1.17	1.12	3.60
<b>75<sup>th</sup> Percentile</b>	1.60	1.87	1.62	1.61	1.84	1.95	2.49	4.08	2.75	2.28	1.63	2.13	2.29	2.09	2.10	1.64	5.11
<b>95<sup>th</sup> Percentile</b>	2.72	3.06	2.66	2.37	3.46	3.21	6.84	7.88	7.80	5.31	2.47	3.24	3.69	3.87	4.89	2.97	8.32
<b>Maximum</b>	6.47	6.29	6.12	4.80	10.7	9.44	76.6	41.7	53.2	26.9	6.11	7.93	10.1	9.52	15.5	8.53	21.2

N: Naphthalene; Acy: Acenaphthylene; Ace: Acenaphthene; F: Fluorene; P: Phenanthrene; Ant: Anthracene; Fl: Fluoranthene; Pyr: Pyrene; BaAnt: Benzo[*a*]anthracene; Chr: Chrysene; BbFl: Benzo[*b*]fluoranthene; BkFl: Benzo[*k*]fluoranthene; BaPyr: Benzo[*a*]pyrene; DBahAnt: Dibenzo[*ah*]anthracene; BghiPer: Benzo[*ghi*]perylene; Ipyr: Indeno[1,2,3-*cd*]pyrene.

**Table 5.** Probabilistic distribution for PAH2, PAH4, PAH8, PAH16 and benzo[*a*]pyrene equivalents (BaPeq) intakes ( $\mu\text{g}/\text{kg}/\text{day}$ ) through meat plus fish consumption for adults and children, in the six areas studied.

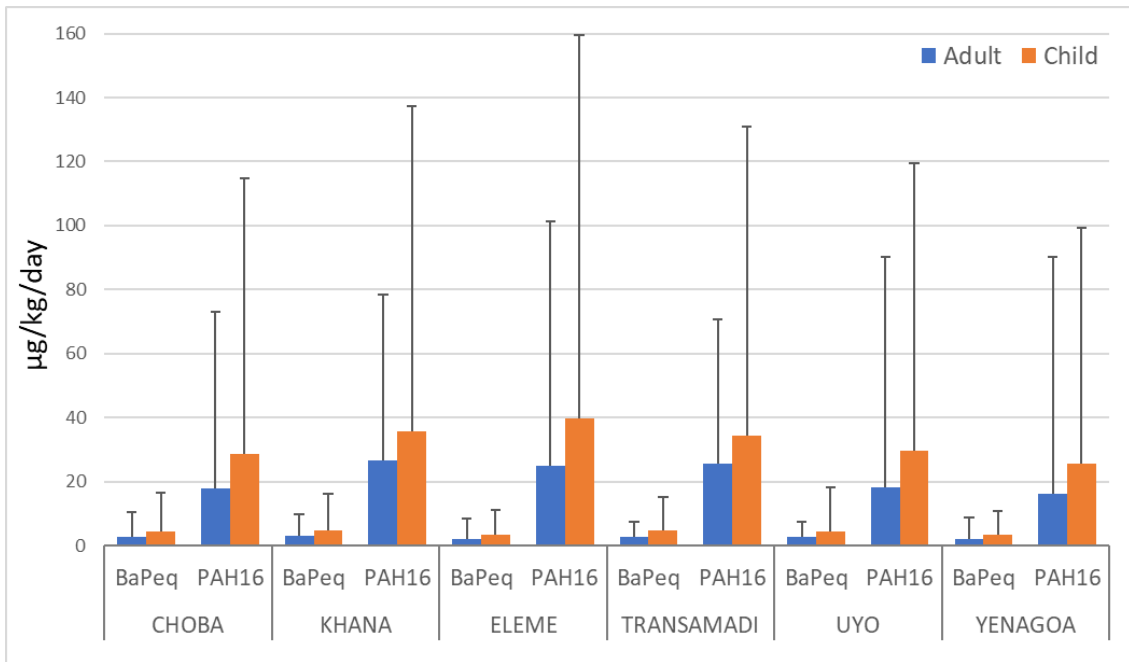
<b>Adult</b>	<b>PAH2</b>	<b>PAH4</b>	<b>PAH8</b>	<b>PAH16</b>	<b>BaPeq</b>
<b>Mean</b>	2.36	4.90	8.88	19.0	2.56
<b>Standard deviation</b>	1.84	4.48	7.26	16.9	1.24
<b>Minimum</b>	0.39	0.65	1.30	2.90	0.58
<b>5<sup>th</sup> Percentile</b>	0.73	1.36	2.63	5.70	1.07
<b>25<sup>th</sup> Percentile</b>	1.23	2.41	4.68	9.90	1.67
<b>50<sup>th</sup> Percentile</b>	1.83	3.66	6.95	14.6	2.25
<b>75<sup>th</sup> Percentile</b>	2.92	5.86	10.7	22.6	3.15
<b>95<sup>th</sup> Percentile</b>	5.52	12.3	21.1	45.3	5.06
<b>Maximum</b>	17.9	50.0	84.4	221	8.21
<b>Child (6-12 years old)</b>	<b>PAH2</b>	<b>PAH4</b>	<b>PAH8</b>	<b>PAH16</b>	<b>BaPeq</b>
<b>Mean</b>	3.82	7.59	14.0	28.1	4.12
<b>Standard deviation</b>	3.34	7.92	12.4	24.5	2.23
<b>Minimum</b>	0.46	0.78	1.46	3.50	0.65
<b>5<sup>th</sup> Percentile</b>	1.11	1.99	3.89	8.30	1.60
<b>25<sup>th</sup> Percentile</b>	1.88	3.46	6.89	14.4	2.55
<b>50<sup>th</sup> Percentile</b>	2.86	5.41	10.6	21.7	3.60
<b>75<sup>th</sup> Percentile</b>	4.57	8.95	16.9	34.0	5.11
<b>95<sup>th</sup> Percentile</b>	9.00	19.3	34.2	66.4	8.32
<b>Maximum</b>	37.1	96.4	138	300	21.2

PAH2: benzo[*a*]pyrene + chrysene  
PAH4: PAH2 + benz[*a*]anthracene + benzo[*b*]fluoranthene  
PAH8: PAH4 + benzo[*k*]fluoranthene + benzo[*ghi*]perylene + dibenzo[*ah*]anthracene + indeno[1,2,3-*cd*]pyrene  
PAH16 the sum of all PAHs here analysed  
BaPeq: Benzo[*a*]pyrene equivalents of PAH16

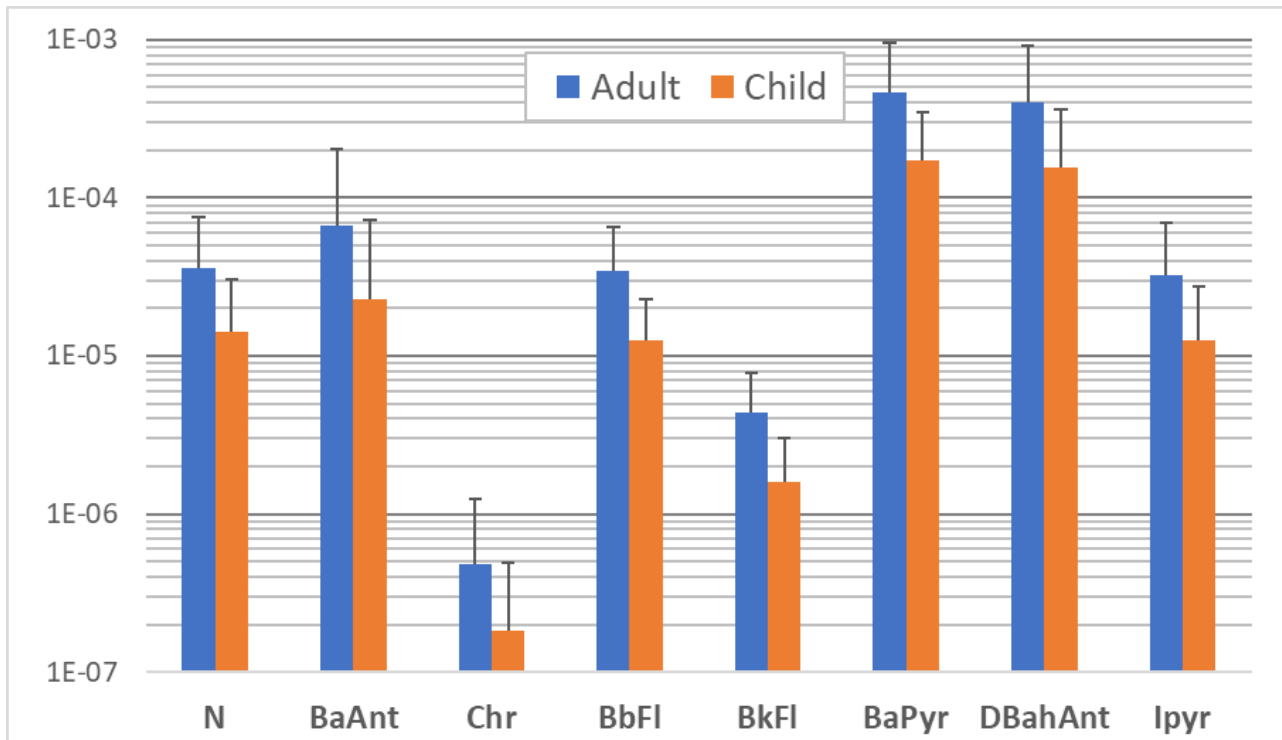


**Figure 1:** Mean PAHs levels (mg/kg) for the six sampling points of Delta Niger. N: Napthalene; Acy: Acenapthylene; Ace: Acenapthene; F: Fluorene; P: Phenanthrene; Ant: Anthracene; Fl: Flouranthene; Pyr: Pyrene; BaAnt: Benzo[a]anthracene; Chr: Chrysene; BbFl: Benzo[b]fluoranthene; BkFl: Benzo[k]fluoranthene; BaPyr: Benzo[a]pyrene; DBahAnt: Dibenzo[ah]anthracene; BghiPer: Benzo[ghi]perylene; Ipyr: Indeno[1,2,3-cd]pyrene.





**Figure 3.** Sum of the 16 PAHs (PAH16) and Benzo[*a*]pyrene equivalents (BaPeq) intakes (µg/kg/day) through meat plus fish consumption for adult and children, in the six areas studied. Error bars indicate 95<sup>th</sup> percentile.



**Figure 4.** Risk due to the intake of carcinogenic PAHs through meat plus fish consumption. Error bars indicate 95<sup>th</sup> percentile. N: Napthalene; BaAnt: Benzo[*a*]anthracene; Chr: Chrysene; BbFl: Benzo[*b*]fluoranthene; BkFl: Benzo[*k*]fluoranthene; BaPyr: Benzo[*a*]pyrene; DBahAnt: Dibenzo[*ah*]anthracene; and Ipyr: Indeno[1,2,3-*cd*]pyrene.