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Health Risk Assessment of Polycyclic Aromatic Hydrocarbons (PAHs) Concentrations in some Selected Tubers from Three Communities in Rivers State, Nigeria.

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Abstract: Health risk assessment of 16 US environmental protection agency (USEPA) polycyclic aromatic hydrocarbons (PAHs) concentrations in some selected tubers from Umuechem (Etche LGA), Bodo (Gokana LGA), and Obrikom (Ogba/Egbema/Ndoni LGA) communities in Rivers State, Nigeria was determined. Gas chromatography coupled with flame ionization detector (GC-FID) was used for evaluation of PAHs. Total PAHs concentrations in tubers (yam, cocoyam, and cassava) samples were in the range of 1.88E-3-3.31E-3, 1.79E-3-5.98E-3, and 5.02E-4-4.19E-3 respectively. Benzo(a)pyrene concentrations in yam, cocoyam and cassava samples from all the sites were below the European Union (EU) value of 0.002mg/kg. High molecular weight PAHs (HMW-PAHs) were predominant in all the tuber samples compared to low molecular weight PAHs (LMW-PAHs). Estimated daily intakes (EDIs) of PAHs through tubers consumption were below the reference dose (RFD). Toxic equivalents (TEQs) values for all tubers were below the estimated screening value (SV) of 1.59E-1.Hazard quotients (HQs) and hazard index (HIs) for both non-carcinogenic and carcinogenic risk PAHs through non-dietary exposure were below 1 for all tubers. Estimated cumulative excess cancer risk (ECR) PAHs from dietary exposure to cocoyam from Obrikom exceeded the cancer risk guideline value (10^{-6}). Prolong consumption of cocoyam from Obrikom by community dwellers could pose potential PAHs human health cancer risk.

Keywords: Hazard quotient, cancer, hazard index, PAHs, carcinogenic, tubers

1.0 Introduction

Marine and terrestrial environments, in the recent time have been tagged with abundance of persistent organic pollutants. The coastal ecosystem are under threat because of the arthropogenic activities due to PAHs are part of ubiquitous organic pollutants present in the environment for which the sampling sites under consideration in this study belongs.

Polycyclic aromatic hydrocarbons (PAHs) are multi-ringed organic compounds which are ubiquitous in nature. They are derived from both natural processes of biogenic precursors and anthropogenic processes of incomplete combustion of organic matter and emissions of non-combustion-related petrogenic process [1].They are a group of about 10,000 compounds, a few of which occur in considerable amounts in the environment, and in food. Polycyclic aromatic hydrocarbons (PAHs) originate from incomplete combustion of natural deposits (such as oil, coal tar, wood, and petroleum) and artificial sources (such as fuels, vehicle emissions, rubber, plastics, and cigarettes) [2]. The six PAHs listed as carcinogens are benzo[a]anthracene, benzo[b]flouranthene, benzo[k]flouranthene, benzo[a]pyrene, dibenzo[a,h]anthracene, and indeno(1,2,3-cd)pyrene [3]. Benzo(a)pyrene is often used as a marker for total PAHs exposure in industry and in the environment.

Based on physical and biological properties, PAHs are classified into high molecular weight (HMW) and low molecular weight (LMW) types. Those consisting of 4–6 aromatic rings are termed HMW. On the other hand, LMW PAHs consists of 2–3 aromatic rings and although less carcinogenic than HMW type [4].

Human exposure to PAH is over 90% linked to food and can bioaccumulate in food via water and air ([5]; [6]). Epidemiological studies indicate that dietary exposure to PAHs is associated with some human cancers and also elevated levels of DNA adduct, mutation and reproductive effects ([7]; [8]; [9]). In recent years, environmental PAH concentrations have increased in many industrialized and developing countries, leading to high levels of PAHs in foodstuffs [8]. The negative impacts on human health and the ecosystem due to their tetratogenic, carcinogenic and mutagenic characteristics may be caused by the accumulation of high levels of PAHs in the environmental compartments [10].

The magnitude of oil exploration activities in the Niger Delta is so enormous that the toxic effect of oil pollution and spillage of biological species, water contamination and habitat disturbance pose great biochemical and ecological impact. The increased oil and gas activities in recent years make the Niger Delta province most vulnerable to environmental pollution. For instance, in Ogoniland alone, there are over 69 contaminated sites [11]. With the myriads of industries located in Niger Delta region, it is of great concern to research on the level of PAH bioaccumulation in plants grown around these areas.

2.0 Material and Methods

2.1 Study areas

Umuechem, Bodo and Obrikom communities are located in Etche, Gokana and Ogba/Egbema/Ndoni Local Government Area of Rivers State respectively. Umuechem area has borne the hazards of oil and gas exploration. Umuechem is situated 28km and is located at longitude 7°6′45″ East and latitude 5°39′21″ North. The major economic activity of the people is farming. The Bodo area has a tragic history of pollution from oil spills; oil well fires, environmental incidents, such as spills and uncontrolled flares. Gokana is one of the six kingdoms of Ogoniland. Bodo community lies on the coastal low land of Niger Delta, in the southern part of Gokana Local Government Area of Rivers State. Bodo is located between latitude 4°36′ 0″ North and longitude 7°21′0″ East of the equator. The economic activities of the people of Bodo are farming and fishing. Agip gas plant is situated near the Obrikom area. Obrikom is situated 598km north of the equator, and is located at longitude 6°406′.71″ East and latitude 5°23′41.35″ North. The people of Obrikom community are mostly farmers.

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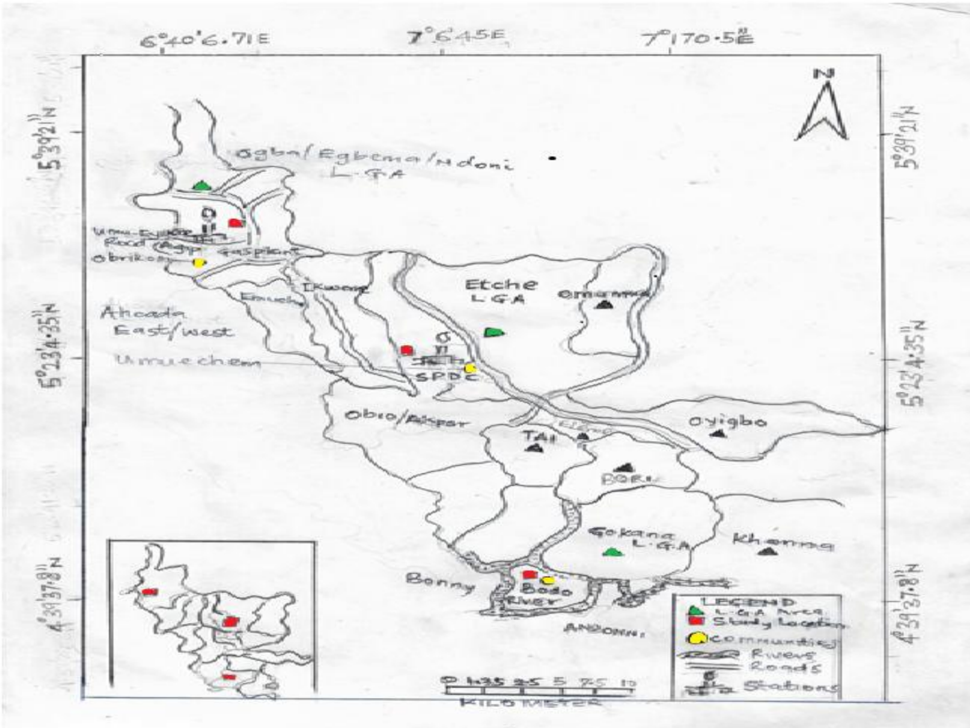

Source: ([12]; [13])

Fig 1.0 Map of Etche, Gokana, and Ogba/Egbema/Ndoni showing sampling areas

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2.2 Sample collection

All three fresh tuber samples, cocoyam (C*olocasia esculenta*), yam (*Dioscorea rotunta*), cassava (*Manihot esculenta*) were collected from three different communities; Bodo community in Gokana Local Government Area (LGA), Umuechem community in Etche Local Government Area (LGA), and Obrikom community in Ogba/Egbema/Ndoni Local Government Area (LGA) of Rivers State, Nigeria. At each study site three tubers samples were collected, cleaned, wrapped, in aluminum foils and transported to the laboratory (Anal Concept) for analysis.

2.3 Chemicals Used

n-Hexana, (BDH Chemical Ltd, GPR, Poole England), dichloromethane (BDH Chemical Ltd, Poole England), anhydrous sodium sulphate (Kernal, India), activated silica gel, 60-120 mesh column chromatography type (Burgoyne Burbidges India). All chemicals used are of analytical grades with high purity.

2.4.0 Determination of polycyclic aromatic hydrocarbons (PAHs) concentrations in borehole water

2.4.1 Principle

The various components are separated inside the column. The detector measures the quantity of the components that exit (eluted) out of the column. To determine a sample with an unknown concentration, a standard sample with known concentration is injected into the instrument (injector) of the GC.

2.4.2 Extraction of sample

For PAHs in solid samples: Two gram (2g) of each samples were weighed into a clean extraction container. A volume of ten milliliter (10ml) of extraction solvent (n-hexane) was added into the samples and mixed thoroughly and allowed to settle.The mixtures were carefully filtered into clean solvent rinsed extraction bottle, using filter paper fitted into Buchner funnels.The extracts were concentrated to 2ml and then transferred for cleanup/separation.

2.4.3 Cleanup/separation

A length of 1cm of moderately packed glass wool was placed at the bottom of 10mm ID *250mm loup chromatographic column. Slury of 2g activated silica in 10ml dichloromethane was prepared and placed into the chromatographic column. To the top of the column was added 0.5cm of sodium sulphate . The column was rinsed with additional 10ml of dichloromethane and pre-eluted with 20ml of n-hexane, this was allowed to flow through the column at a rate of about 20 minutes until the liquid in the column was just above the sulphate layer. Immediately 1ml of the extracted sample was transfer into the column. The extraction bottle was rinsed with 1ml of n-hexane and added to the column as well. The stop-cork of the column was opened and the eluent was collected with a 10ml graduated cylinder.

Just prior to exposure of the sodium sulphate layer to air, n-hexane was added to the column in 1-2ml increments. Accurately measured volume of 8-10ml of the eluent was collected and labeled aromatic.

2.4.4 Gas chromatographic analysis

The concentrated aromatic fraction was transferred into labeled glass vials with teflon rubber crimp caps for GC analysis. A volume (1µl) of the concentrated sample was injected by means of hypodermic syringe through a rubber septum into the column. Separation occurs as the vapour constituent partition between the gas and the liquid phases. The sample was automatically detected as it emerges from the column (at a constant flow rate) by the FID detector whose response is dependent upon the composition of the vapour.

2.4.5 Chromatographic conditions

The gas chromatography was Hewlett Packed 5890 series II, gas chromatography apparatus, coupled with flame ionization detector (FID) (Hewlett Packard, Wilmington, DE, USA), powered with HP chemstation Rev. A09:01 (10206) software to identify and quantify compounds. The GC operating conditions were as specified by the procedural manual.

2.5 Human Health risk assessment of polycyclic aromatic hydrocarbons (PAHs)

2.5.1 The guideline value

The exposure risk associated with PAHs concentrations in tubers (yam, cocoyam, and cassava) was assessed through comparison of the observed concentrations with guideline values. Concentrations of PAHs in tubers were assessed for individual PAH and total PAH concentrations (sum of all the assessed PAH congeners). Concentrations of Benzo(a)pyrene (B(a)P), which has been accepted as an indicator for the occurrence and effect of carcinogenic PAHs in food such as tubers (yam, cocoyam and cassava) as specified in the maximum acceptable limit of 0.002mg/kg for benzo(a)pyrene in tubers [14].

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2.5.2 Non-carcinogenic and carcinogenic polycyclic aromatic hydrocarbons (PAHs) human health risk in tubers

In estimating the non-carcinogenic and carcinogenic human health risk from PAH exposure in tubers, human intake models were used ([15]; [16]). The values for parameterization of human intake models are showed in Table 1. The assessment was determined for adult (60kg).

2.5.3 Risk Assessment of Non-carcinogenic polycyclic aromatic hydrocarbons (PAHs) through Non-dietary Exposure to Tubers

The hazard quotient (HQ) and hazard index (HI) were used to calculate non-carcinogenic risk caused by non-dietary exposure to PAHs in tubers. The HQ ratios greater than 1 indicate potential non-carcinogenic health risk. The risks through consumption of tubers (yam, cocoyam, and cassava), HQ was calculated as the ratio of estimated daily intake (EDI) to the reference dose (RfD) in Eq.3. The EDI was calculated using Eq. 2 [17].

$$\text{Hazard quotient (HQ)} = \frac{EDI}{RfD} \quad (1)$$

$$\text{Estimated Daily Intake (EDI)} = \frac{Ct \times ITR}{BW} \quad (2)$$

To assess the total health risk through exposure to the different PAH mixture, the hazard index (HI) was used. The HI was estimated as the sum of HQs for the individual PAHs as showed in (Eq.3). The risk was assessed if these ratios exceed 1.0 [18].

$$\text{Hazard index (HI)} = \sum_{i=1}^{n} = \text{HQi} \quad (3)$$

2.5.4 Human Health Risk Assessment of Carcinogenic PAHs Through Dietary Exposure to Tubers

The cancer risk due to dietary exposure to PAHs in tubers were assessed using individual PAH carcinogenic risk. Carcinogenic risk PAHs exposure in tubers was determined by multiplying the EDI with the cancer slope factor (SF) [18] in (Eq.4).

$$\text{Carcinogenic risk} = \text{EDI} \times \text{SF} \quad (4)$$

To assess human health risks from dietary exposure to PAHs through ingestion of tubers, the human intake approach was used. Estimated Daily Intake (EDI) concentrations of PAH's from consumption of contaminated tubers and PAHs were determined. The carcinogenic risks were also ascertained by evaluating the carcinogenic potencies of Individual PAH (B(A)Pteq), the carcinogenic toxic equivalents (TEQs) or potency equivalent concentrations (PECs), Screening value (SV) and the excess cancer risk (ECR) index. Carcinogenic potencies of individual PAH B(A)P*teq* was evaluated by multiplying the PAH concentration in the sample with the individual toxicity equivalent factor (TEF) as showed in (Eq.5). TEF is an estimate of the relative toxicity of individual PAH fraction compared to benzo(a)pyrene. The TEFs developed by Nisbet and

LaGoy [19] was used and these values were applied to estimate PAH as benzo[a]pyrene equivalents for a standard adult of 60 kg body weight.

$$(B(A)Pteq) = Ci \times TEFi \qquad (5)$$

The TEQs were estimated as the sum of the carcinogenic potencies of individual PAHs (B(A)Pteq; Eq.6, [15].

$$\text{Carcinogenic toxic equivalents (TEQs)} = \sum B(A)Pteq \qquad (6)$$

Screening value was compared with TEQ value evaluated to ascertain the human health risks associated with PAHs from tubers intake. The screening value (SV) is the threshold concentration of chemicals in edible tissue that is of potential public health concern ([20]; [21]). The screening value was calculated as showed in Eq. 7 ([22]; [19]).

$$\text{Screening value (SV)} = \frac{\left[\left(\frac{RL}{SF}\right) \times BW\right]}{IR} \qquad (7)$$

In dietary exposure to PAHs via tubers (yam, cocoyam, and cassava), the excess cancer risk (ECR) was ascertained as presented in Eq. 8 [23].

$$\text{Excess cancer risk (ECR)} = \frac{\sum Q \times B(A)Pteq \times IR \times ED}{(BW \times ATn)} \qquad (8)$$

For exposure to several carcinogenic substances, the cumulative excess cancer risk assessed was in accordance with the principle of the cumulative effect of carcinogens on the body, by adding the risks calculated for the individual carcinogens as showed in Eq. 9:

$$ELCRtot = \sum_{i=1}^{m} ELCRi \qquad (9)$$

ELCRtotal- the total excess risk of occurrence of carcinogenic effects, caused by all the substances.

ELCRi = the excess risk assessed for the ith substance.

3.0 Results

Table 1: Concentrations of Polycyclic Aromatic hydrocarbons (PAHs) (mg/kg) in Yam from Umuechem, Bodo, and Obrikom Communities in Rivers State, Nigeria.

PAHs components	Code	Umuchem	Bodo	Obrikom
Naphthalene	Nap	ND	3.72E-4	1.52E-4
2-methylnaphthalene	2-MNap	2.65E-5	5.62E-4	1.09E-4
Acenaphthylene	AcPY	1.18E-4	1.01E-4	1.44E-5
Acenaphthene	Acp	4.03E-5	5.79E-5	3.28E-6
Fluorene	Flu	3.44E-5	5.58E-5	7.26E-5
Phenanthrene	Phe	5.90E-5	6.29E-4	1.46E-3
Anthracene	Ant	2.98E-4	5.32E-4	8.59E-4
Fluoranthene	Fl	7.62E-4	9.29E-5	5.03E-4
Pyrene	Pyr	2.53E-4	1.07E-4	9.92E-5
Benzo(a)anthracene	BaA	4.62E-5	5.87E-5	3.89E-6
Chrysene	Chr	ND	9.55E-5	2.59E-6
Benzo(b)fluoranthrene	BbF	1.03E-4	1.78E-4	7.56E-6
Benzo(k)fluoranthrene	BKF	1.45E-5	2.35E-5	1.02E-5
Benzo(a)pyrene	Bap	1.87E-5	9.22E-5	3.38E-6
Indeno(1,2,3-cd)pyrene	Ind	2.14E-5	9.26E-5	4.62E-6
Dibenzo(a,h)anthracene	DBA	8.92E-5	2.44E-4	5.95E-6
Total PAHs		1.88E-3	3.29E-3	3.31E-3
PEC		6.54E-4	1.37E-4	6.79E-3
LMW-PAH/HMW-PAH ratio		1.22	0.55	0.65
BaA/(BaA+Chry) ratio		1.00	0.88	ND

ND= Not detected

Table 2: Concentrations of Polycyclic Aromatic hydrocarbons (PAHs) (mg/kg) in Cocoyam from Umuechem, Bodo, and Obrikom Communities in Rivers State, Nigeria.

PAHs components	Code	Umuechem	Bodo	Obrikom
Naphthalene	Nap	ND	1.62E-5	1.57E-5
2-methylnaphthalene	2-MNap	6.51E-6	3.41E-5	ND
Acenaphthylene	AcPY	2.21E-5	1.44E-5	ND
Acenaphthene	Acp	1.55E-4	2.99E-5	ND
Fluorene	Flu	3.16E-4	2.51E-4	ND
Phenanthrene	Phe	3.67E-4	6.19E-4	2.05E-3
Anthracene	Ant	1.20E-4	3.03E-4	4.05E-4
Fluoranthene	Fl	2.53E-5	2.57E-4	4.06E-4
Pyrene	Pyr	5.01E-6	1.21E-4	3.17E-4
Benzo(a)anthracene	BaA	3.47E-4	9.12E-4	ND
Chrysene	Chr	ND	1.25E-4	ND
Benzo(b)fluoranthrene	BbF	1.84E-4	2.14E-4	9.38E-4
Benzo(k)fluoranthrene	BKF	7.32E-6	2.17E-4	2.38E-5
Benzo(a)pyrene	Bap	2.87E-5	2.06E-4	2.14E-4
Indeno(1,2,3-cd)pyrene	Ind	9.78E-5	3.46E-5	3.20E-4
Dibenzo(a,h)anthracene	DBA	1.12E-4	2.05E-4	1.29E-3
Total PAHs		1.79E-3	3.56E-3	5.98E-3
PEC		6.54E-4	1.37E-3	6.79E-3
LMW-PAH/HMW-PAH ratio		1.22	0.55	0.65
BaA/(BaA+Chry) ratio		1.00	0.88	ND

ND= Not detected

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Table 3: Concentrations of Polycyclic Aromatic hydrocarbons (PAHs) mg/kg in Cassava in Umuechem, Bodo, and Obrikom Communities in Rivers State, Nigeria.

PAHs components	Code	Umuechem	Bodo	Obrikom
Naphthalene	Nap	ND	5.88E-6	ND
2-methylnaphthalene	2-MNap	ND	1.09E-4	ND
Acenaphthylene	AcPY	ND	9.10E-4	ND
Acenaphthene	Acp	ND	1.99E-4	ND
Fluorene	Flu	ND	7.05E-4	ND
Phenanthrene	Phe	ND	5.99E-4	ND
Anthracene	Ant	ND	1.03E-3	ND
Fluoranthene	Fl	7.75E-5	3.94E-4	1.00E-3
Pyrene	Pyr	1.92E-7	1.43E-4	1.64E-4
Benzo(a)anthracene	BaA	6.66E-5	2.78E-6	ND
Chrysene	Chr	3.31E-5	1.23E-5	ND
Benzo(b)fluoranthrene	BbF	1.29E-4	4.02E-6	4.19E-5
Benzo(k)fluoranthrene	BKF	2.01E-5	8.22E-7	1.19E-3
Benzo(a)pyrene	Bap	1.57E-5	1.42E-5	2.77E-4
Indeno(1,2,3-cd)pyrene	Ind	1.87E-5	3.51E-5	2.17E-4
Dibenzo(a,h)anthracene	DBA	1.41E-4	3.41E-5	ND
Total PAHs		5.02E-4	4.19E-3	2.89E-3
PEC		7.48E-4	2.02E-4	4.23E-4
LMW-PAH/HMW-PAH ratio		ND	5.51	ND
BaA/(BaA+Chry) ratio		0.67	0.18	ND

ND = Not detected

Table 4 Total PAHs, PEC. LMW-PAH/HMW-PAHs and BaA/(BaA+Chry) ratios in the three tubers from the three commnities

	UMUECHEM	BODO	OBRIKOM
		YAM	
Total PAHs	**1.88E-3**	**3.29E-3**	**3.31E-3**
PEC	6.54E-4	1.37E-4	6.79E-3
LMW-PAH/HMW-PAH ratio	1.22	0.55	0.65
BaA/(BaA+Chry) ratio	1.00	0.88	ND
		COCOYAM	
Total PAHs	**1.79E-3**	**3.56E-3**	**5.98E-3**
PEC	6.54E-4	1.37E-3	6.79E-3
LMW-PAH/HMW-PAH ratio	1.22	0.55	0.65
BaA/(BaA+Chry) ratio	1.00	0.88	ND
		CASSAVA	
Total PAHs	**5.02E-4**	**4.19E-3**	**2.89E-3**
PEC	7.48E-4	2.02E-4	4.23E-4
LMW-PAH/HMW-PAH ratio	ND	5.51	ND
BaA/(BaA+Chry) ratio	0.67	0.18	ND

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Table 5: Hazard Quotient (HQ) values for non-carcinogenic and carcinogenic risk of PAHs concentration in tuber (yam) from Umuechem

PAHs components	Code	RFD	EDI Ingestion	HQ Non-carcinogenic	Carcinogenic Ingestion
Naphthalene	Nap	0.02	ND	ND	NA
2-methylnaphthalene	2-MNap	0.04	2.60E-7	6.50E-6	NA
Acenaphthylene	AcPY	0.02	1.15E-6	5.75E-5	NA
Acenaphthene	Acp	0.06	3.90E-7	6.50E-6	NA
Fluorene	Flu	0.04	3.40E-7	8.50E-6	NA
Phenanthrene	Phe	NA	5.80E-7	NA	NA
Anthracene	Ant	0.3	2.91E-6	9.70E-6	NA
Fluoranthene	Fl	0.04	7.46E-6	1.87E-4	NA
Pyrene	Pyr	0.03	2.47E-6	8.33E-5	NA
Benzo(a)anthracene	BaA		4.50E-7	NA	8.00E-8
Chrysene	Chr		ND	NA	ND
Benzo(b)fluoranthrene	BbF		1.01E-6	NA	7.37E-8
Benzo(k)fluoranthrene	BKF		1.40E-7	NA	1.02E-8
Benzo(a)pyrene	Bap		1.80E-7	NA	1.31E-6
Indeno(1,2,3-cd)pyrene	Ind		2.10E-7	NA	1.58E-6
Dibenzo(a,h)anthracene	DBA		8.70E-7	NA	6.36E-6
Hazard Index (HI)			1.84E-5	3.59E-4	7.91E-6

NA reference dose (RfD) not available, HQ could not be estimated

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Table 6: Hazard Quotient (HQ) values for non-carcinogenic and carcinogenic risk of PAHs concentration in tuber (yam) from Bodo

PAHs Components	Code	RFD	EDI Ingestion	HQ Non-carcinogenic	Carcinogenic Ingestion
Naphthalene	Nap	0.02	3.64E-6	1.84E-4	NA
2-methylnaphthalene	2-MNap	0.04	5.49E-6	1.37E-4	NA
Acenaphthylene	AcPY	0.02	9.90E-7	4.90E-5	NA
Acenaphthene	Acp	0.06	5.70E-7	9.50E-6	NA
Fluorene	Flu	0.04	5.50E-7	1.38E-5	NA
Phenanthrene	Phe	NA	6.15E-6	NA	NA
Anthracene	Ant	0.3	5.20E-6	1.70E-5	NA
Fluoranthene	Fl	0.04	9.10E-7	2.30E-5	NA
Pyrene	Pyr	0.03	1.05E-6	3.50E-5	NA
Benzo(a)anthracene	BaA		5.70E-7	NA	4.16E-7
Chrysene	Chr		9.30E-7	NA	6.79E-9
Benzo(b)fluoranthrene	BbF		1.74E-6	NA	1.27E-6
Benzo(k)fluoranthrene	BKF		2.30E-7	NA	1.68E-8
Benzo(a)pyrene	Bap		9.00E-7	NA	6.57E-6
Indeno(1,2,3-cd)pyrene	Ind		5.43E-5	NA	3.96E-5
Dibenzo(a,h)anthracene	DBA		2.38E-6	NA	1.74E-5
Hazard Index (HI)			8.56E-5	4.68E-4	6.53E-5

NA reference dose (RfD) not available, HQ could not be estimated

Table 7: Hazard Quotient (HQ) values for non-carcinogenic and carcinogenic risk of PAHs concentration in tuber (yam) from Obrikom

PAHs components	Code	RFD	EDI Ingestion	HQ Non-carcinogenic	Carcinogenic Ingestion
Naphthalene	Nap	0.02	8.91E-5	0.004460	NA
2-methylnaphthalene	2-MNap	0.04	1.07E-6	0.000027	NA
Acenaphthylene	AcPY	0.02	1.40E-7	0.000007	NA
Acenaphthene	Acp	0.06	3.00E-8	0.0000005	NA
Fluorene	Flu	0.04	7.10E-7	0.000018	NA
Phenanthrene	Phe	NA	1.43E-5	NA	NA
Anthracene	Ant	0.3	8.39E-6	0.000028	NA
Fluoranthene	Fl	0.04	2.95E-4	0.007380	NA
Pyrene	Pyr	0.03	5.86E-5	0.001950	NA
Benzo(a)anthracene	BaA		4.00E-8	NA	2.90E-8
Chrysene	Chr		3.00E-8	NA	2.29E-9
Benzo(b)fluoranthrene	BbF		7.00E-8	NA	5.10E-8
Benzo(k)fluoranthrene	BKF		1.00E-7	NA	7.30E-9
Benzo(a)pyrene	Bap		1.98E-6	NA	1.45E-5
Indeno(1,2,3-cd)pyrene	Ind		5.00E-8	NA	3.70E-8
Dibenzo(a,h)anthracene	DBA		3.49E-6	NA	2.55E-5
Hazard Index (HI)			4.73E-4	1.39E-2	4.01E-5

NA reference dose (RfD) not available, HQ could not be estimated

Table 8: Hazard Quotient (HQ) values for non-carcinogenic and carcinogenic risk of PAHs concentration in tuber (cocoyam) from Umuechem

PAHs components	Code	RFD	EDI Ingestion	HQ Non-carcinogenic	Carcinogenic Ingestion
Naphthalene	Nap	0.02	ND	ND	NA
2-methylnaphthalene	2-MNap	0.04	6.36E-8	1.59E-6	NA
Acenaphthylene	AcPY	0.02	2.20E-7	1.08E-5	NA
Acenaphthene	Acp	0.06	1.51E-6	2.52E-5	NA
Fluorene	Flu	0.04	3.09E-6	7.70E-5	NA
Phenanthrene	Phe	NA	3.59E-6	NA	NA
Anthracene	Ant	0.3	1.17E-6	3.91E-6	NA
Fluoranthene	Fl	0.04	2.50E-7	6.30E-6	NA
Pyrene	Pyr	0.03	5.00E-8	1.70E-6	NA
Benzo(a)anthracene	BaA		3.39E-6	NA	2.47E-6
Chrysene	Chr		ND	NA	ND
Benzo(b)fluoranthrene	BbF		1.80E-6	NA	1.31E-6
Benzo(k)fluoranthrene	BKF		7.00E-8	NA	5.11E-9
Benzo(a)pyrene	Bap		2.80E-7	NA	2.04E-6
Indeno(1,2,3-cd)pyrene	Ind		9.56E-7	NA	6.98E-7
Dibenzo(a,h)anthracene	DBA		1.09E-6	NA	7.96E-6
Hazard Index (HI)			1.75E-5	1.27E-4	1.45E-7

NA reference dose (RfD) not available, HQ could not be estimated

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Table 9: Hazard Quotient (HQ) values for non-carcinogenic and carcinogenic risk of PAHs concentration in tuber (cocoyam) from Bodo

PAHs components	Code	RFD	EDI Ingestion	HQ Non-carcinogenic	Carcinogenic Ingestion
Naphthalene	Nap	0.02	1.60E-7	4.00E-4	NA
2-methylnaphthalene	2-MNap	0.04	3.33E-7	1.65E-5	NA
Acenaphthylene	AcPY	0.02	1.41E-7	7.00E-6	NA
Acenaphthene	Acp	0.06	2.92E-7	2.92E-4	NA
Fluorene	Flu	0.04	2.45E-6	6.10E-5	NA
Phenanthrene	Phe	NA	6.05E-6	NA	NA
Anthracene	Ant	0.3	2.96E-6	9.90E-6	NA
Fluoranthene	Fl	0.04	2.51E-6	6.30E-5	NA
Pyrene	Pyr	0.03	1.18E-6	3.90E-5	NA
Benzo(a)anthracene	BaA		8.91E-6	NA	6.50E-6
Chrysene	Chr		1.22E-6	NA	8.91E-9
Benzo(b)fluoranthrene	BbF		2.09E-6	NA	1.53E-6
Benzo(k)fluoranthrene	BKF		2.12E-6	NA	1.55-7E
Benzo(a)pyrene	Bap		2.01E-6	NA	1.47E-5
Indeno(1,2,3-cd)pyrene	Ind		3.40E-7	NA	2.48E-7
Dibenzo(a,h)anthracene	DBA		2.00E-6	NA	1.46E-5
Hazard Index (HI)			3.48E-5	2.01E-4	6.23E-5

NA reference dose (RfD) not available, HQ could not be estimated

Table 10: Hazard Quotient (HQ) values for non-carcinogenic and carcinogenic risk of PAHs concentration in tuber (cocoyam) from Obrikom

PAHs components	Code	RFD	EDI Ingestion	HQ Non-carcinogenic	Carcinogenic Ingestion
Naphthalene	Nap	0.02	1.52E-7	7.50E-6	NA
2-methylnaphthalene	2-MNap	0.04	ND	ND	NA
Acenaphthylene	AcPY	0.02	ND	ND	NA
Acenaphthene	Acp	0.06	ND	ND	NA
Fluorene	Flu	0.04	ND	ND	NA
Phenanthrene	Phe	NA	2.00E-5	NA	NA
Anthracene	Ant	0.3	3.96E-6	1.30E-5	NA
Fluoranthene	Fl	0.04	3.97E-6	9.93E-5	NA
Pyrene	Pyr	0.03	3.10E-6	1.03E-4	NA
Benzo(a)anthracene	BaA		ND	NA	ND
Chrysene	Chr		ND	NA	ND
Benzo(b)fluoranthrene	BbF		9.17E-7	NA	6.69E-7
Benzo(k)fluoranthrene	BKF		2.30E-7	NA	1.68E-7
Benzo(a)pyrene	Bap		2.09E-6	NA	1.53E-5
Indeno(1,2,3-cd)pyrene	Ind		3.13E-6	NA	2.28E-6
Dibenzo(a,h)anthracene	DBA		1.26E-5	NA	9.19E-5
Hazard Index (HI)			4.99E-5	2.15E-4	1.10E-4

NA reference dose (RfD) not available, HQ could not be estimated

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Table 11: Hazard Quotient (HQ) values for non-carcinogenic and carcinogenic risk of PAHs concentration in tuber (cassava) from Umuechem

PAHs Components	Code	RFD	EDI Ingestion	HQ Non-carcinogenic	Carcinogenic Ingestion
Naphthalene	Nap	0.02	ND	ND	NA
2-methylnaphthalene	2-MNap	0.04	ND	ND	NA
Acenaphthylene	AcPY	0.02	ND	ND	NA
Acenaphthene	Acp	0.06	ND	ND	NA
Fluorene	Flu	0.04	ND	ND	NA
Phenanthrene	Phe	NA	ND	ND	NA
Anthracene	Ant	0.3	ND	ND	NA
Fluoranthene	Fl	0.04	7.60E-7	1.90E-4	NA
Pyrene	Pyr	0.03	2.00E-9	7.00E-8	NA
Benzo(a)anthracene	BaA		6.50E-7	NA	4.75E-7
Chrysene	Chr		3.20E-7	NA	2.34E-9
Benzo(b)fluoranthrene	BbF		1.26E-6	NA	9.19E-7
Benzo(k)fluoranthrene	BKF		2.00E-7	NA	1.46E-8
Benzo(a)pyrene	Bap		1.50E-7	NA	1.09E-6
Indeno(1,2,3-cd)pyrene	Ind		1.80E-7	NA	1.31E-7
Dibenzo(a,h)anthracene	DBA		1.38E-6	NA	1.01E-5
Hazard Index (HI)			4.90E-6	1.90E-4	1.27E-5

NA reference dose (RfD) not available, HQ could not be estimated

Table 12: Hazard Quotient (HQ) values for non-carcinogenic and carcinogenic risk of PAHs concentration in tuber (cassava) from Bodo

PAHs components	Code	RFD	EDI Ingestion	HQ Non-carcinogenic	Carcinogenic Ingestion
Naphthalene	Nap	0.02	6.00E-8	0.000003	NA
2-methylnaphthalene	2-MNap	0.04	1.07E-6	0.000027	NA
Acenaphthylene	AcPY	0.02	8.89E-6	0.000445	NA
Acenaphthene	Acp	0.06	1.94E-6	0.000032	NA
Fluorene	Flu	0.04	6.89E-6	0.000172	NA
Phenanthrene	Phe	NA	5.85E-6	NA	NA
Anthracene	Ant	0.3	1.01E-5	0.000034	NA
Fluoranthene	Fl	0.04	3.85E-6	0.000096	NA
Pyrene	Pyr	0.03	1.40E-6	0.000047	NA
Benzo(a)anthracene	BaA		2.72E-8	NA	1.98E-8
Chrysene	Chr		1.20E-7	NA	8.76E-10
Benzo(b)fluoranthrene	BbF		3.90E-8	NA	2.92E-8
Benzo(k)fluoranthrene	BKF		8.03E-9	NA	5.86E-10
Benzo(a)pyrene	Bap		1.40E-7	NA	1.02E-6
Indeno(1,2,3-cd)pyrene	Ind		3.40E-7	NA	2.48E-7
Dibenzo(a,h)anthracene	DBA		3.30E-7	NA	2.48E-6
Hazard Index (HI)			4.11E-5	8.56E-4	3.79E-6

NA reference dose (RfD) not available, HQ could not be estimated

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Table 13: Hazard Quotient (HQ) values for non-carcinogenic and carcinogenic risk of PAHs concentration in tuber (cassava) from Obrikom

PAHs components	Code	RFD	EDI Ingestion	HQ Non-carcinogenic	Carcinogenic Ingestion
Naphthalene	Nap	0.02	ND	ND	NA
2-methylnaphthalene	2-MNap	0.04	ND	ND	NA
Acenaphthylene	AcPY	0.02	ND	ND	NA
Acenaphthene	Acp	0.06	ND	ND	NA
Fluorene	Flu	0.04	ND	ND	NA
Phenanthrene	Phe	NA	ND	ND	NA
Anthracene	Ant	0.3	ND	ND	NA
Fluoranthene	Fl	0.04	9.77E-6	2.44E-5	NA
Pyrene	Pyr	0.03	1.60E-6	5.33E-5	NA
Benzo(a)anthracene	BaA		ND	NA	ND
Chrysene	Chr		ND	NA	ND
Benzo(b)fluoranthrene	BbF		4.10E-7	NA	2.99E-7
Benzo(k)fluoranthrene	BKF		1.16E-5	NA	8.47E-7
Benzo(a)pyrene	Bap		2.71E-6	NA	1.98E-5
Indeno(1,2,3-cd)pyrene	Ind		2.12E-6	NA	1.55E-6
Dibenzo(a,h)anthracene	DBA		ND	NA	ND
Hazard Index (HI)			2.82E-5	7.77E-5	2.25E-5

NA reference dose (RfD) not available, HQ could not be estimated

Table 14: Summary of HI values for non-carcinogenic and carcinogenic risk of PAHs concentrations in yam cocoyam and cassava from Umuechem, Bodo and Obrikom communities

Communities	Tubers	HI/EDI	HI/HQ/Non-carcinogenic	HI/Carcinogenic
Umuechem	Yam	1.84E-5	3.59E-4	7.91E-6
	Cocoyam	1.27E-4	1.27E-4	1.45E-7
	Cassava	4.90E-6	1.90E-4	1.27E-5
Bodo	Yam	8.56E-5	4.68E-4	6.53E-5
	Cocoyam	3.48E-5	2.01E-4	6.23E-5
	Cassava	4.11E-5	8.56E-4	3.79E-6
Obrikom	Yam	4.73E-4	1.39E-2	4.01E-2
	Cocoyam	4.99E-5	2.15E-4	1.10E-4
	Cassava	2.82E-5	7.77E-5	2.25E-5

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Table 15: Toxic equivalent factor (TEF), Toxic equivalent (TEQ), Screening Value (SV) and Excess Cancer Risk(ECR) of PAHs in yam (*Dioscorea rotunta)* from Umuechem.

PAHs components	Code	TEF	CDr(mg/kg)	B(A)Pteq(mg/kg)	SV	ECR(mg/kg)
Naphthalene	Nap	0.001	ND	ND	NA	5.09E-12
2-methylnaphthalene	2-MNap	0.001	2.65E-5	2.65E-8	NA	2.28E-11
Acenaphthylene	AcPY	0.001	1.18E-4	1.18E-7	NA	7.83E-12
Acenaphthene	Acp	0.001	4.03E-5	4.03E-8	NA	6.65E-12
Fluorene	Flu	0.001	3.44E-5	3.44E-8	NA	6.65E-12
Phenanthrene	Phe	0.001	5.90E-5	5.90E-8	NA	1.14E-11
Anthracene	Ant	0.01	2.98E-4	2.98E-6	NA	5.77E-10
Fluoranthene	Fl	0.001	7.62E-4	7.62E-7	NA	1.48E-10
Pyrene	Pyr	0.001	2.53E-4	2.53E-7	NA	4.89E-11
Benzo(a)anthracene	BaA	0.1	4.62E-5	4.62E-6	0.001402	8.94E-10
Chrysene	Chr	0.01	ND	ND	0.140187	NA
Benzo(b)fluoranthrene	BbF	0.1	1.03E-4	1.03E-5	0.001402	1.99E-9
Benzo(k)fluoranthrene	BKF	0.1	1.45E-5	1.45E-6	0.014019	2.81E-10
Benzo(a)pyrene	Bap	1	1.87E-5	1.87E-5	0.000140	3.62E-9
Indeno(1,2,3-cd)pyrene	Ind	0.1	2.14E-5	2.14E-6	0.001402	4.14E-10
Dibenzo(a,h)anthracene	DBA	5	8.92E-5	4.46E-4	0.000142	8.63E-8
				TEQ=4.88E-4	SV=1.59E-1	9.44E-8

Table 16 : Toxic equivalent factor (TEF), Toxic equivalent (TEQ), Screening Value (SV) and Excess Cancer Risk(ECR) of PAHs in yam (*Dioscorea rotunta*) from Bodo.

PAHs components	Code	TEF	CDr(mg/kg)	B(A)Pteq(mg/kg)	SV	ECR(mg/kg)
Naphthalene	Nap	0.001	3.72E-4	3.72E-7	NA	7.20E-11
2-methylnaphthalene	2-MNap	0.001	5.62E-4	5.62E-7	NA	1.09E-10
Acenaphthylene	AcPY	0.001	1.01E-4	1.01E-7	NA	1.95E-11
Acenaphthene	Acp	0.001	5.79E-5	5.79E-8	NA	1.12E-11
Fluorene	Flu	0.001	5.58E-5	5.58E-8	NA	1.08E-11
Phenanthrene	Phe	0.001	6.29E-4	6.29E-7	NA	1.22E-10
Anthracene	Ant	0.01	5.32E-4	5.32E-6	NA	1.03E-9
Fluoranthene	Fl	0.001	9.29E-5	9.29E-8	NA	1.79E-11
Pyrene	Pyr	0.001	1.07E-4	1.07E-7	NA	2.07E-11
Benzo(a)anthracene	BaA	0.1	5.87E-5	5.87E-6	0.001402	1.14E-9
Chrysene	Chr	0.01	9.55E-5	9.60E-7	0.140187	1.86E-10
Benzo(b)fluoranthrene	BbF	0.1	1.78E-4	1.78E-5	0.001402	3.45E-9
Benzo(k)fluoranthrene	BKF	0.1	2.35E-5	2.35E-6	0.014019	4.55E-10
Benzo(a)pyrene	Bap	1	9.22E-5	9.22E-5	0.000140	1.78E-8
Indeno(1,2,3-cd)pyrene	Ind	0.1	9.26E-5	9.26E-6	0.001402	1.79E-9
Dibenzo(a,h)anthracene	DBA	5	2.44E-4	1.22E-3	0.000142	2.36E-7
				TEQ = 1.36E-3	SV = 1.59E-1	ECR = 2.62E-7

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Table 17: Toxic equivalent factor (TEF), Toxic equivalent (TEQ), Screening Value (SV) and Excess Cancer Risk (ECR) of PAHs in yam (*Dioscorea rotunta*) from Obrikom

PAHs components	Code	TEF	CDr (mg/kg)	B(A)Pteq (mg/kg)	SV	ECR (mg/kg)
Naphthalene	Nap	0.001	1.52E-4	1.52E-7	NA	2.94E-11
2-methylnaphthalene	2-MNap	0.001	1.09E-4	1.09E-7	NA	2.11E-11
Acenaphthylene	AcPY	0.001	1.44E-5	1.44E-8	NA	2.79E-12
Acenaphthene	Acp	0.001	3.28E-6	3.28E-9	NA	6.35E-13
Fluorene	Flu	0.001	7.26E-5	7.26E-8	NA	1.41E-11
Phenanthrene	Phe	0.001	1.46E-3	1.46E-6	NA	2.83E-10
Anthracene	Ant	0.01	8.59E-4	8.59E-6	NA	1.66E-9
Fluoranthene	Fl	0.001	5.03E-4	5.03E-7	NA	9.74E-11
Pyrene	Pyr	0.001	9.92E-5	9.92E-8	NA	1.92E-11
Benzo(a)anthracene	BaA	0.1	3.89E-6	3.89E-7	0.001402	7.55E-11
Chrysene	Chr	0.01	2.59E-6	2.59E-8	0.14O187	5.09E-12
Benzo(b)fluoranthrene	BbF	0.1	7.56E-6	7.56E-7	0.001402	8.78E-9
Benzo(k)fluoranthrene	BKF	0.1	1.02E-5	1.02E-6	0.014019	1.97E-10
Benzo(a)pyrene	Bap	1	3.38E-6	3.38E-6	0.000140	6.54E-10
Indeno(1,2,3-cd)pyrene	Ind	0.1	4.62E-6	4.62E-7	0.001402	8.92E-11
Dibenzo(a,h)anthracene	DBA	5	5.95E-6	2.98E-5	0.000142	5.77E-9
				TEQ= 4.68E-5	SV =1.59E-1	ECR = 1.70E-8

Table 18: Toxic equivalent factor (TEF), Toxic equivalent (TEQ), Screening Value (SV) and Excess Cancer Risk (ECR) of PAHs in Cocoyam (*Colocasia esculenta*) from Umuechem.

PAHs components	Code	TEF	CCe (mg/kg)	B(A)Pteq (mg/kg)	SV	ECR (mg/kg)
Naphthalene	Nap	0.001	ND	ND	NA	ND
2-methylnaphthalene	2-MNap	0.001	6.51E-6	6.51E-9	NA	1.17E-12
Acenaphthylene	AcPY	0.001	2.21E-5	2.21E-8	NA	4.31E-12
Acenaphthene	Acp	0.001	1.55E-4	1.55E-7	NA	3.01E-11
Fluorene	Flu	0.001	3.16E-4	3.16E-7	NA	6.10E-11
Phenanthrene	Phe	0.001	3.67E-4	3.67E-7	NA	7.12E-11
Anthracene	Ant	0.01	1.20E-4	1.20E-6	NA	2.32E-10
Fluoranthene	Fl	0.001	2.53E-5	2.53E-8	NA	5.09E-12
Pyrene	Pyr	0.001	5.01E-6	5.01E-9	NA	7.83E-13
Benzo(a)anthracene	BaA	0.1	3.47E-4	3.47E-5	0.001402	1.72E-9
Chrysene	Chr	0.01	ND	ND	0.140187	NA
Benzo(b)fluoranthrene	BbF	0.1	1.84E-4	1.84E-5	0.001402	3.56E-9
Benzo(k)fluoranthrene	BKF	0.1	7.32E-6	7.32E-7	0.014019	1.42E-10
Benzo(a)pyrene	Bap	1	2.87E-5	2.87E-5	0.000140	5.56E-9
Indeno(1,2,3-cd)pyrene	Ind	0.1	9.78E-5	9.78E-6	0.001402	1.89E-9
Dibenzo(a,h)anthracene	DBA	5	1.12E-4	5.60E-4	0.000142	1.08E-7
				TEQ = 6.54E-4	SV = 1.59E-1	ECR = 1.27E-7

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Table 19: Toxic equivalent factor (TEF), Toxic equivalent (TEQ), Screening Value (SV) and Excess Cancer Risk (ECR) of PAHs in Cocoyam (*Colocasia esculenta*) from Bodo.

PAHs components	Code	TEF	CCe (mg/kg)	BAPteq (mg/kg)	SV	ECR (mg/kg)
Naphthalene	Nap	0.001	1.62E-5	1.62E-8	NA	3.14E-10
2-methylnaphthalene	2-MNap	0.001	3.41E-5	3.41E-8	NA	6.65E-12
Acenaphthylene	AcPY	0.001	1.44E-5	1.44E-8	NA	2.74E-12
Acenaphthene	Acp	0.001	2.99E-5	2.99E-8	NA	5.87E-12
Fluorene	Flu	0.001	2.51E-4	2.51E-7	NA	4.85E-11
Phenanthrene	Phe	0.001	6.19E-4	6.19E-7	NA	1.19E-10
Anthracene	Ant	0.01	3.03E-4	3.03E-6	NA	5.87E-10
Fluoranthene	Fl	0.001	2.57E-4	2.57E-7	NA	4.97E-11
Pyrene	Pyr	0.001	1.21E-4	1.21E-7	NA	2.35E-11
Benzo(a)anthracene	BaA	0.1	9.12E-4	9.12E-5	0.001402	1.77E-8
Chrysene	Chr	0.01	1.25E-4	1.25E-6	0.140187	2.42E-10
Benzo(b)fluoranthrene	BbF	0.1	2.14E-4	2.14E-5	0.001402	4.14E-9
Benzo(k)fluoranthrene	BKF	0.1	2.17E-4	2.17E-5	0.014019	4.20E-9
Benzo(a)pyrene	Bap	1	2.06E-4	2.06E-4	0.000140	3.99E-8
Indeno(1,2,3-cd)pyrene	Ind	0.1	3.46E-5	3.46E-6	0.001402	6.69E-10
Dibenzo(a,h)anthracene	DBA	5	2.05E-4	1.03E-3	0.000142	1.98E-7
				TEQ= 1.37E-3	SV = 1.59E-1	ECR = 2.66E-7

Table 20: Toxic equivalent factor (TEF), Toxic equivalent (TEQ), Screening Value (SV) and Excess Cancer Risk (ECR)of PAHs in Cocoyam (*Colocasia esculenta*) from Obrikom.

PAHs components	Code	TEF	CCe (mg/kg)	B(A)Pteq (mg/kg)	SV	ECR (mg/kg)
Naphthalene	Nap	0.001	1.57E-5	1.57E-8	NA	3.04E-12
2-methylnaphthalene	2-MNap	0.001	ND	ND	NA	ND
Acenaphthylene	AcPY	0.001	ND	ND	NA	ND
Acenaphthene	Acp	0.001	ND	ND	NA	ND
Fluorene	Flu	0.001	ND	ND	NA	ND
Phenanthrene	Phe	0.001	2.05E-3	2.05E-6	NA	3.98E-10
Anthracene	Ant	0.01	4.05E-4	4.05E-6	NA	7.84E-10
Fluoranthene	Fl	0.001	4.06E-4	4.06E-7	NA	7.86E-11
Pyrene	Pyr	0.001	3.17E-4	3.17E-7	NA	6.14E-11
Benzo(a)anthracene	BaA	0.1	ND	ND	0.001402	ND
Chrysene	Chr	0.01	ND	ND	0.140187	ND
Benzo(b)fluoranthrene	BbF	0.1	9.38E-4	9.38E-5	0.001402	1.81E-8
Benzo(k)fluoranthrene	BKF	0.1	2.38E-5	2.38E-6	0.014019	4.61E-10
Benzo(a)pyrene	Bap	1	2.14E-4	2.14E-4	0.000140	4.14E-8
Indeno(1,2,3-cd)pyrene	Ind	0.1	3.20E-4	3.20E-5	0.001402	6.19E-9
Dibenzo(a,h)anthracene	DBA	5	1.29E-3	6.45E-3	0.000142	1.25E-6
			5.98E-3	TEQ = 6.79E-3	SV = 1.59E-1	ECR = 1.32E-6

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Table 21: Toxic equivalent factor (TEF), Toxic equivalent (TEQ), Screening Value (SV) and Excess Cancer Risk (ECR) of PAHs in Cassava (*Manihot esculenta*) from Umuechem.

PAHs components	Code	TEF	CMe (mg/kg)	B(A)Pteq(mg/kg)	SV	ECR(mg/kg)
Naphthalene	Nap	0.001	ND	ND	NA	ND
2-methylnaphthalene	2-MNap	0.001	ND	ND	NA	ND
Acenaphthylene	AcPY	0.001	ND	ND	NA	ND
Acenaphthene	Acp	0.001	ND	ND	NA	ND
Fluorene	Flu	0.001	ND	ND	NA	ND
Phenanthrene	Phe	0.001	ND	ND	NA	ND
Anthracene	Ant	0.01	ND	ND	NA	ND
Fluoranthene	Fl	0.001	7.75E-5	7.75E-8	NA	1.49E-11
Pyrene	Pyr	0.001	1.92E-7	1.92E-10	NA	3.72E-14
Benzo(a)anthracene	BaA	0.1	6.66E-5	6.66E-6	0.001402	1.29E-9
Chrysene	Chr	0.01	3.31E-5	3.31E-7	0.140187	6.41E-11
Benzo(b)fluoranthrene	BbF	0.1	1.29E-4	1.29E-5	0.001402	2.49E-9
Benzo(k)fluoranthrene	BKF	0.1	2.01E-5	2.01E-6	0.014019	3.89E-10
Benzo(a)pyrene	Bap	1	1.57E-5	1.57E-5	0.000140	3.04E-9
Indeno(1,2,3-cd)pyrene	Ind	0.1	1.87E-5	1.87E-6	0.001402	3.62E-10
Dibenzo(a,h)anthracene	DBA	5	1.41E-4	7.05E-4	0.000142	1.36E-7
				TEQ = 7.45E-4	SV = 1.59E-1	ECR =1.44E-7

Table 22: Toxic equivalent factor (TEF), Toxic equivalent (TEQ), Screening Value (SV) and Excess Cancer Risk (ECR) of PAHs in Cassava (*Manihot esculenta*) from Bodo.

PAHs components	Code	TEF	CMe (mg/kg)	B(A)Pteq (mg/kg)	SV	ECR (mg/kg)
Naphthalene	Nap	0.001	5.88E-6	5.88E-9	NA	1.14E-12
2-methylnaphthalene	2-MNap	0.001	1.09E-4	1.09E-7	NA	2.11E-11
Acenaphthylene	AcPY	0.001	9.10E-4	9.10E-7	NA	1.76E-10
Acenaphthene	Acp	0.001	1.99E-4	1.99E-7	NA	3.85E-11
Fluorene	Flu	0.001	7.05E-4	7.05E-7	NA	1.36E-10
Phenanthrene	Phe	0.001	5.99E-4	5.99E-7	NA	1.16E-10
Anthracene	Ant	0.01	1.03E-3	1.03E-5	NA	1.99E-9
Fluoranthene	Fl	0.001	3.94E-4	3.94E-7	NA	7.63E-11
Pyrene	Pyr	0.001	1.43E-4	1.43E-7	NA	2.78E-11
Benzo(a)anthracene	BaA	0.1	2.78E-6	2.78E-7	0.001402	5.36E-11
Chrysene	Chr	0.01	1.23E-5	1.23E-7	0.140187	2.39E-11
Benzo(b)fluoranthrene	BbF	0.1	4.02E-6	4.02E-7	0.001402	7.78E-12
Benzo(k)fluoranthrene	BKF	0.1	8.22E-7	8.22E-8	0.014019	1.57E-11
Benzo(a)pyrene	Bap	1	1.42E-5	1.42E-5	0.000140	2.75E-9
Indeno(1,2,3-cd)pyrene	Ind	0.1	3.51E-5	3.51E-6	0.001402	6.79E-10
Dibenzo(a,h)anthracene	DBA	5	3.41E-5	1.71E-4	0.000142	3.30E-8
				TEQ = 2.02E-4	SV = 1.59E-1	ECR = 3.91E-8

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Table 23: Toxic equivalent factor (TEF), Toxic equivalent (TEQ), Screening Value (SV) and Excess Cancer Risk (ECR) of PAHs in Cassava (*Manihot esculenta*) from Obrikom

PAHs components	Code	TEF	CMe (mg/kg)	BAPteq (mg/kg)	SV	ECR (mg/kg)
Naphthalene	Nap	0.001	ND	ND	NA	ND
2-methylnaphthalene	2-MNap	0.001	ND	ND	NA	ND
Acenaphthylene	AcPY	0.001	ND	ND	NA	ND
Acenaphthene	Acp	0.001	ND	ND	NA	ND
Fluorene	Flu	0.001	ND	ND	NA	ND
Phenanthrene	Phe	0.001	ND	ND	NA	ND
Anthracene	Ant	0.01	ND	ND	NA	ND
Fluoranthene	Fl	0.001	1.00E-3	1.00E-6	NA	1.94E-10
Pyrene	Pyr	0.001	1.64E-4	1.64E-7	NA	3.17E-11
Benzo(a)anthracene	BaA	0.1	ND	ND	0.001402	ND
Chrysene	Chr	0.01	ND	ND	0.140187	ND
Benzo(b)fluoranthrene	BbF	0.1	4.19E-5	4.19E-6	0.001402	8.11E-10
Benzo(k)fluoranthrene	BKF	0.1	1.19E-3	1.19E-4	0.014019	2.30E-8
Benzo(a)pyrene	Bap	1	2.77E-4	2.77E-4	0.000140	5.36E-8
Indeno(1,2,3-cd)pyrene	Ind	0.1	2.17E-4	2.17E-5	0.001402	4.20E-9
Dibenzo(a,h)anthracene	DBA	5	ND	ND	0.000142	ND
				TEQ = 4.23E-4	SV = 1.59E-1	ECR = 8.18E-8

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Table 24: Summary of Total Toxic equivalent (TEQ), screening value (SV), and excess cancer risk (ECR) Values of Polycyclic Aromatic Hydrocarbons (PAHs) Concentrations (mg/kg) in Tubers (Yam, Cocoyam, and Cassava) from Umuechem, Bodo and Obrikom Communities.

Communities	Tubers	TEQ (mg/kg)	SV (mg/kg)	ECR (mg/kg)
Umuechem	Yam	4.88E-4	1.59E-1	9.44E-8
	Cocoyam	6.54E-4	1.59E-1	1.27E-7
	Cassava	7.45E-4	1.59E-1	1.44E-7
Bodo	Yam	1.36E-3	1.59E-1	2.62E-7
	Cocoyam	1.37E-3	1.59E-1	2.66E-7
	Cassava	2.02E-4	1.59E-1	3.91E-8
Obrikom	Yam	4.68E-5	1.59E-1	1.70E-8
	Cocoyam	6.79E-3	1.59E-1	1.32E-6
	Cassava	4.23E-4	1.59E-1	8.18E-8

4.0 Discussion

Polycyclic Aromatic Hydrocarbons (PAHs) Concentrations in the three tubers from the three communities in Rivers State, Nigeria.

The concentrations of PAHs in Table 1 revealed the presence of all the 16 PAHs in yam from Bodo and Obrikom communities while all but chrysene and naphthalene were present in cocoyam from Umuechem community. The highest and lowest PAHs concentrations are

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fluoranthene (7.62E-4) and benzo(k)fluoranthene (1.45E-5) from Umuechem, phenanthrene (6.29E-4) and benzo(k)fluoranthene (2.35E-5) from Bodo and phenanthrene (1.46E-3) and chrysene (2.59E-6) from Obrikom. Obrikom (3.31E-3). The highest total PAHs concentrations, followed by Bodo (3.29E-3) and lastly Umuechem (1.88E-3). LMW-PAH/HMW-PAH ratios are 1.22, 0.55 and 0.65 in yam from Umuechem, Bodo and Obrikom respectively. LMW-PAH/HMW-PAH ratios in yam from Umuechem was >1, while that of yam from Bodo and Obrikom are < 1. BaA/(BaA+Chry) ratios was > 0.35 in yam from Umuechem and Bodo, that of Obrikom which was not detected (ND).

In Table 2, Sixteen PAHs were detected in cocoyam from Bodo, while chrysene and naphthalene were not detected in Umuechem and 2-methylnaphthalene, acenaphthyalene, acenaphthene, fluorene, benzo(a)anthracene and chrysene were not detected in cocoyam from Obrikom. The highest and lowest PAHs concentrations are phenanthrene (3.67E-4) and pyrene (5.01E-6) Umuechem, benzo(a)anthracene (9.12E-4) and acenaphthylene (1.44E-5) Bodo and phenanthrene (2.05E-3) and naphthalene (1.57E-5) from Obrikom communities. Cocoyam from Obrikom had the highest total PAHs (5.98E-3) followed by Bodo (3.56E-3) and lastly Umuechem (1.79E-3). LMW-PAH/HMW-PAH ratios in cocoyam were 1.22, 0.55 and 0.65 from Umuechem, Bodo and Obrikom respectively. LMW-PAH/HMW-PAH ratios in cocoyam from Umuechem was >1, Bodo and Obrikom were < 1. BaA/(BaA+Chry) ratios in cocoyam are 1.00 and 0.88 for Umuechem and Bodo respectively, and that of Obrikom was not detected. BaA/(BaA+Chry) ratios in cocoyam was > 0.35 for Umuechem and Bodo, but except in Obrikom which was not detected (ND).

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Table 3 revealed the presence of all the 16 PAHs in cassava from Bodo, while naphthalene, 2-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene and anthracene were not detected in cassava from Umuechem and Obrikom. The highest and lowest PAHs concentrations are dibenzo(a,h)anthracene (1.41E-4) and pyrene (1.92E-7) from Umuechem, anthracene (1.03E-3) and benzo(k)fluoranthrene (8.22E-7) from Bodo and benzo(k)fluoranthrene (1.19E-3) and benzo(k)fluoranthrene (4.19E-5) from Obrikom. Cassava from Bodo had the highest total PAHs (4.19E-3), followed by Obrikom (2.89E-3) and lastly Umuechem (5.02E-4). LMW-PAH/HMW-PAH ratios in cassava was 5.51 from Bodo, but was not detected for Umuechem and Obrikom. LMW-PAH/HMW-PAH ratios in cassava from Bodo was >1. BaA/(BaA+Chry) ratios in cassava are 0.67 and 0.18 in Umuechem and Bodo respectively. BaA/(BaA+Chry) ratios in cassava from Umuechem was > 0.35, while that of Bodo was < 0.35. Obrikom was not detected (ND).

The pathways of PAHs exposure leads to it accumulation in food chain. The relatively highest LMW- PAHs detected in cassava from Bodo community can be attributed to higher arthropogenic fingerprint of human activities in the community. The input of LMW PAHs probably resulted from crude oil/gaseoline spills that may have been transported from distal sources because small-size PAHs are more labile [24].

The LMW-PAH/HMW-PAH ratio showed the predominant of HMW-PAHs to that of LMH-PAHs, and this may be due to the fact that LMH-PAHs are preferentially degraded during PAH transport [25]. Although there was an exception in this trend as the LMW-PAH/HMW-PAH ratio in yam from Umuechem (1.22), cocoyam from Umuechem (1.22) and cassava from Bodo (5.51).

The BaA/(BaA+Chry) ratios in all the tubers from Umuechem and yam and cocoyam from Bodo were > 0.35 which indicated pyrogenic sources, except for cassava from Bodo which was < 0.35,

thereby indicating mixed petrogenic and pyrogenic sources, that is mixed petroleum [26]. BaA/(BaA+Chry) ratios in yam, cocoyam and cassava from Obrikom were not detected (ND).
European Union [14] maximum permissible limit of benzo(a)pyrene was 0.002mg/kg (2ug/kg) in tubers (cocoyam, yam and cassava). The benzo(a)pyrene concentrations for yam, cocoyam and cassava from Umuechem, Bodo and Obrikom communities were below the European Union (EU) limit of 0.002mg/kg indicating low carcinogenic potency.
The highest total PAHS, PEC, LMW-PAH/HMW-PAH and BaA/(BaA+Chry) ratios in tubers from the three communities as shown in Table 4 are cocoyam from Obrikom, yam and cocoyam from obrikom, cassava from Bodo and yam from Umechem respectively.

Human health risk assessment of polycyclic aromatic hydrocarbons (PAHs) through non-dietary exposure to PAHs in tubers
The evaluated hazard quotients (HQ) and hazard index (HI) values for non-carcinogenic and carcinogenic risk of exposure to PAHs in tubers through non-dietary exposure are showed in Tables 5-14. The HI values for non-carcinogenic health risk were 3.59E-4, 4.62E-4, and 1.39E-2 for yam 1.27E-4, 2.01E-4 and 2.15E-4 for cocoyam and 1.90E-4, 8.56E-4 and 7.77E-5 for cassava from Umuechem, Bodo, and Obrikom respectively while carcinogenic health risk were 7.91E-6, 6.53E-5, and 4.01E-5 for yam 1.45E-5, 6.23E-5, and 2.66E-7for cocoyam and 1.27E-5, 3.79E-6 and 2.25E-5 for cassava from Umuechem, Bodo, and Obrikom communities respectively.

Non-carcinogenic risk due to non-dietary exposure to PAHs in tubers was investigated using a hazard quotient approach in order to determined health risk implication. Hazard quotient values were assessed based on reference dose (RfD) for PAHs as proposed by USEPA [27]. Therefore, the HQ and HI values of all the tubers (yam, cocoyam, and cassava) in the present study were below 1, indicating no direct hazard implications to human health despite their presence in the food when ingested.

Human health risk assessment by Estimated Daily Intake (EDI) of PAHs through dietary exposures

Tables 5-14 estimated dietary daily intake of PAHs through consumption of tubers for adult of 60kg body weight. EDI value was applied to assess the health risk of toxicant imperatively through dietary exposure of PAHs. The EDI's values in this study were lower than the recommended reference dose (RFD's) levels, indicating concentrations within acceptable permissible limits for food safety. Implication of the result is dietary exposure of PAHs through ingestion of these tubers may not pose potential health risk to populace consuming these tubers. However, bioaccumulation of these PAHs due to prolonged consumption of these tubers could result to human health hazard.

Carcinogenic human health risk assessment of PAHs
The estimated individual carcinogenic potencies B(A)Pteq, toxic equivalents (TEQs), screening value (SV) and excess cancer risk (ECR) are showed in Tables 15-24. The individual carcinogenic potencies of PAHs (B(A)Pteq) was evaluated, and the result showed that there was no variation in the individual carcinogenic potencies of PAHs in the assessed tubers.

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Dibenz(a,h)anthracene showed highest carcinogenic potency in cocoyam (*Colocasia esculenta*) (6.45E-3mg/kg) from Obrikom compared to yam, and cassava.

Carcinogenic Toxic Equivalents (TEQs) of PAHs

The approach was aimed at directly estimating the carcinogenicity of PAH contamination of the tubers (*Dioscorea rotunda*, *Colocasia esculenta* and *Manihot esculenta*). The screening value (SV) was evaluated to determine the human health risks of PAHs from the ingestion of yam, cocoyam, and cassava. The screening value is the threshold concentration of a chemical in edible tissues that is of potential public health concern ([17]; [19]). The tubers estimated screening value was 1.59E-1mg/kg. The TEQs values were however lower than the calculated screening value (SV) of 1.59E-1mg/kg tuber in all the sites (Tables 15-24), which is the threshold concentration of total PAHs in tubers that is of potential public health concern [19]. Although, TEQ values for tubers from all the communities were below the SV, implying no that consumption of these tubers at rate of 0.5863mg/day may not result to adverse health effects in populace. Hence, there is no potential public health concern.

Excess Cancer Risk (ECR) of PAHs

The excess cancer risk of PAHs through dietary exposure for an adult population with an average body weight of 60kg was determined. Estimated ECR due to lifelong exposure to PAHs through tuber consumption was compared to the acceptable guideline value of 1×10^{-6} [17; 28]. According to the USEPA, lifetime cancer risk of 1 in a million (ECR=10^{-6}) over 70 years lifetime period, is considered acceptable, whereas an additional lifelong cancer risk of 1 in 10,000 or greater (ECR=10^{-4}) is considered serious [29]. In the case of exposure to several carcinogenic PAHs, the total risk was assessed in accordance with the principle of cumulative effect of carcinogens on the body, by adding the risk calculated for the individual carcinogens to evaluate the cumulative excess cancer risk. The cumulative excess cancer risk values estimated for cocoyam (1.32E-6) from Obrikom exceeded the cancer risk guideline value (1×10^{-6}). While others were below the value.

The cumulative ECR value estimated in cocoyam from Obrikom community was observed to have consequential adverse health implication hence people who consume cocoyam fron this community risk the chance of having cancer.

5.0 Conclusion

This study confirmed the presence of polycyclic aromatic hydrocarbons (PAHs) in tubers (yam, cocoyam, and cassava). The estimated health hazard index (HI) for non-carcinogenic and carcinogenic risk exposure showed that tubers pose no health threat, cumulative ECR risk value for cocoyam from Obrikom community exceeded the acceptable cancer risk guideline value of 1×10^{-6} established by USEPA's. This showed that consumption of cocoyam from Obrikom community could pose potential cancer health risk of PAHs to rural dwellers whose staple food is cocoyam.

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Table 1: Human Intake Model Parameters.

Parameters	Unit	Value	Reference
Concentration of tubers (yam, cocoyam and cassava)	mg/kg tubers	Table 1-3	Table 1-3
Reference dose (RfD)	mg/kg/day	Table 4	USEPA (1993)
Tubers ingestion rate (IRt)	kg/capita/day	0.5863kg	(Inter-reseaux, 2010)
Adult body weight (BW)	kg	60	Jiang *et al*.(2005)
Carcinogenic potency of Benzo[a]Pyrene (Q)	mg/ kg/day	7.3 mg/kg/day	Ding *et al*. (2012)
Conversion coefficient (CF)	Kg/mg	1×10^{6}	Huang *et al*. (2014)
Exposure duration (ED)	years	30	Qu *et al*. (2015)
average life span (ATn)	days	25,550	Papadakis *et al*. (2015)
Exposure frequency (EF)	Days/year	365	Qu *et al*. (2015)
Maximum acceptable risk level (RL)	Dimensionless	10^{5}	USEPA (2000)
Toxic equivalent factor (TEF)	No unit	Nisbet and LaGoy (1992)	Nisbet and LaGoy (1992)
Oral slope factor (SF)	mg/kg/day	USEPA (2005)	USEPA (2005)

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