# Effect of Phytoremediation on PAHs Levels of Agricultural Soil around Mechanic Village Wukari, Nigeria

**Itodo AU[1], Sha Ato R[1], Wuana RA[1] and Emmanuel A Yerima[2*]**

[1]*Department of Chemistry, Federal University of Agriculture, Makurdi, PMB 2373, Benue State, Nigeria*

[2]*Department of Chemical Sciences, Federal University Wukari, PMB 1020, Taraba State, Nigeria*

## Abstract

This study evaluates the PAHs composition in agricultural soils around Mechanic village, Wukari using standard procedures by means of GC-MS. The possible source of the PAHs in the soil was deduced, using the diagnostic ratio analysis for PAH origin. Risk assessment was based on the incremental life cancer risk of PAHs proposed by Provisional Guidance for Quantitative Risk Assessment of the United States Environmental Protection Agency. Effect of phyto-remediation using *Zea mays* inter-planted with *Striga hermonthica* (SMV-MS), *Zea mays* alone (SMV-M), *Zea mays* inter-planted with *Striga hermonthica* alongside the application of fertilizer (SMV-MSF) and *Zea mays* alone alongside fertilizer application (SMV-MF). The result reveals that the PAHs composition based on ring prevalence in agricultural soils around Mechanic village Wukari was in the order $\Sigma 5 > \Sigma 6 > \Sigma 4 > \Sigma 3 > \Sigma 2$ ring. Dibenz [a,h] anthracene 4.52 μg/kg (39.09%) has the highest percentage abundance but was less than the 100 μg/kg and 700 μg/kg Canadian soil quality guideline for agricultural and commercial layout while acenaphthene 0.111 μg/kg (0.90%) was the least abundant. The source of the PAHs in the soil was basically pyrogenic based on the diagnostic ratio analysis while phytoremediation of the soil using *Zea mays* inter-planted with *Striga hermonthica* significantly reduce the PAHs content of the soil.

**Keywords:** PAHs • Composition • Source • Toxicity • Phytoremediation

## Introduction

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous organic pollutants which enters the environment through natural processes such as forest fires, volcanic activity and anthropogenic means via incomplete combustion of fossil fuels and accidental leakages of petroleum products such as coal tars [1]. PAHs have been reported to have carcinogenic activity and they have been included in the European Union (EU) and the Environmental Protection Agency (EPA) lists of priority pollutant. A lot of studies has carried on Benzo (a) pyrene (BaP) due to its carcinogenicity and is now use as a reference to ascertain the carcinogenic potency of other polycyclic aromatic Hydrocarbons (PAHs) [2]. Transport and distribution of PAHs in the environment are mainly governed by their physicochemical properties. Low molecular weight PAHs (2 to 3 fused aromatic rings) are more soluble in water than those with higher molecular weight PAHs (more than 3 fused aromatic rings) and are usually distributed in soil and groundwater more readily than the later. These low molecular weight PAHs may occur in the atmosphere mainly as vapor due to greater values of Henry's law constant. They are prone to degradation process in the environment. High molecular weight PAHs, due to less water soluble and high lipophilic characters are usually adsorbed to particles in the environments [3]. Soil is the primary steady reservoir and sinks for PAHs in the terrestrial environment, because PAHs are readily absorbed by organic matter in soil where they remain relatively stable [4]. The accumulated PAHs in soil organic matter provides potential for PAHs to find its way into food chains where toxic PAHs may exert their toxic effect on human health [5-7].

In view of the ubiquitous nature and toxicity of PAHs, various techniques have been employed to reduce and control PAHs and other organic pollutants in the environment such as chemical degradation [8], photo degradation, which has been reportedly enhanced using nano-composites catalyst [9,10]. As well as biodegradation for instance rhizospheric biodegradation which is based on the secretion by plants root exudates which supports the growth and metabolic activities of diverse fungal and bacterial communities in the rhizosphere capable of degrading varied pollutants. The secreted enzymes can transform the chemicals around the rhizosphere without the need for uptake of the pollutants for detoxification. Rhizospheric microorganisms have been reported to decontaminate areas by volatilizing pollutants or by increasing the production of humic substances from the organic pollutants [11,12].

This study intends to evaluate the PAHs composition in agricultural soils around Mechanic village Wukari, the possible source of the PAHs in the soil using the diagnostic ratio analysis, the incremental life cancer risk of PAHs and the effect of phytoremediation using *Zea mays* inter-planted with *Striga hermonthica*.

## Materials and Methods

### Study area and sample collection

Mechanic village Wukari with the geographical coordinate 7°51'17.208"N and 9°47'40.374"E is situated in Wukari local government area of Taraba state, Nigeria. The facility has been in existence for about two decades now where activities such as car repairs, car spraying, car electrical components fittings, car battery repairs and others are carried out on daily basis thereby

generating a lot of waste where in most cases such waste are done away with by means of incineration.

Stratified sampling technique was used for soil sample collection where the sampling site was broken into four (4) stratums (small areas) north, south, east and west with respect to Mechanic village Wukari. Each stratum was further subdivided into four quadrants of equal size before five (5) samples were taken randomly by grab method within the depth of 0-15 cm in the individual quadrant (smaller area) making a total of twenty (20) samples per strata (small area) and a total of eighty (80) samples from the four stratums situated at the north, south, east and west of the industry to enable detailed representation of variability within the study area. The 80 sample units of approximately equal size were pooled together to form the composite and a representative sample for the entire area labeled SMV [13,14].

The representative soil sample obtained was sorted to eliminate pebbles and coarse materials and then air-dried at room temperature over three days with occasional breaking of aggregated materials with wooden roller; followed by sieving through a nonmetallic sieve with mesh hole of 2 mm diameter to remove stones, plants and animal's debris. The pH and soil textural class were determined by standard methods described by the United State Department of Agriculture [15,16] while the soil organic carbon content was determined by titrimetry after wet oxidation of soil sample using potassium dichromate and concentrated sulphuric acid. Since the average content of carbon in soil organic matter is equal to 58% the conversion factor 1.724 was used to calculate the percentage of organic matter from the content of organic carbon [17,18] (Figure 1).
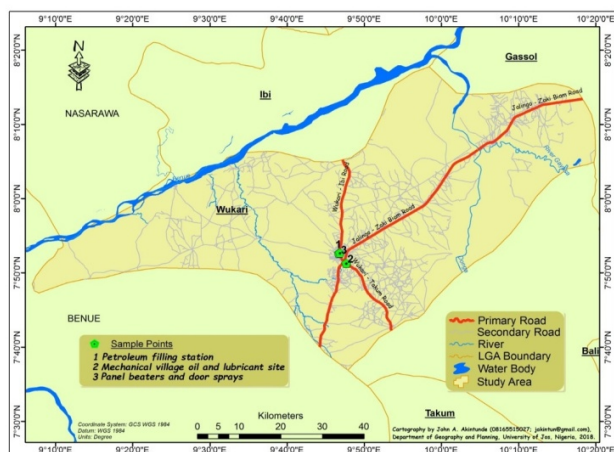


**Figure 1.** GPS Map of Mechanic Village Wukari, Nigeria.

## Phytoremediation experiment

The composite soil sample collected from the farmlands around mechanic village Wukari labelled SMV before remediation was further divided into four portions of about 4.0 L each in a pot and were placed in the greenhouse. To about 4.0 L of the first portion of soil in a pot, 5 seeds of maize were sown to about 2-3 cm depth of soil without striga and about 1.884 g of NPK fertilizer was applied as amendment after 3 weeks of planting to aid the development of maize plant. After harvesting the maize, the soil was labeled SMV-MF, to the second portion of the soil in a pot, 5 seeds of maize were sown to a depth of about 2-3 cm without amendment after 3 weeks of planting to serve as control. After harvesting the maize, the soil was labeled SMV-M. To the third portion of the soil in a pot, 50 g of the striga seed in 50 g of the soil were homogenized to help serve as carrier since the striga seed is extremely tiny before sprinkling them onto the soil followed by sowing of 5 seeds of maize to about 2-3 cm depth of the soil in the pot. About 1.884 g of NPK fertilizer was applied as amendment after 3 weeks of planting to aid the development of maize plant as describe by Berner in striga research methods manual [19]. After harvesting plant tissues even though striga could not germinate, the soil was labeled SMV-MSF. Likewise, to the last soil portion in a pot, 50 g of the

striga seed in 50 g of the soil were homogenized before sprinkling them onto the soil followed by sowing of 5 seeds of maize to about 2-3 cm depth of soil in the pot, without amendment after 3 weeks of planting to serve as control. After harvesting the maize plant tissues as striga could germinate, the soil was labeled: SMV-MS.

## PAHs analysis

**Chemicals:** All solvents and reagents used were of trace analysis (TA) and chromatographic grade. Standards of 16 PAHs were obtained from Sigma Aldrich Chemical Company. Internal and surrogate standards were used for sample quantification. PAHs working standards, internal standard mixture solutions and surrogate standard mixture solutions were properly diluted with GC grade n-hexane and prepared daily before the analysis. Glassware was washed before use with n-hexane and dried in an oven at 105°C.

## Sample preparation for polycyclic aromatic hydrocarbon analysis

Exactly 20 g of the homogenized, sieved and pre dried soil samples was heated at 40-60°C for 4 hours and cool to remove any trace of moisture before extraction. The soil samples were extracted for 30 minutes using solvent by means of ultra-sonication where 2.0 g of the dried soil sample was weighed and transferred into a 50 mL glass conical flask containing 10 mL mixture of acetone and dichloromethane 1:1 (v/v) then capped and placed in an ultrasonic bath (Grant XUBA3) in which four samples could be extracted simultaneously. The extraction step was repeated twice, and the resulting extracts were combined and filtered through a Whatman filter paper No. 41. The combined extract was concentrated to near dryness using rotary evaporator, transferred into amber vial and further concentrated by means of nitrogen concentrator (LabTech E.T. Parallel) [20,21].

The soil extracts containing the PAHs were purified by column chromatography packed with silica gel and anhydrous sodium sulphate after saturation with 2.0 mL of acetone and dichloromethane 1:1 (v/v). Each extract was loaded onto the column and eluted with dichloromethane. The first 1.0 mL of eluate was discarded before 5.0 mL of eluate was collected into an amber coloured vial and the PAHs content analyzed by means of GC-MS [21,22].

## Quality assurance and quality control for PAH analysis

The following PAH compounds (internal standard mixture) was used to pre-spike the sample extracts: Napthalene, 2-methyl Naphthalene, Biphenylene, Acenapthene, Anthracene, Phenanthrene, Triphenylene, Fluorene, Fluoranthene, Pyrene, Benzo(a)anthracene, Benzo(b)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Indeno(1,2,3-cd) pyrene and Benzo(ghi)perylene. The base peak ion was use as the primary ion for quantification of the standard compounds. Where interferences are noted, the next two most intense ions were used as the secondary ions. The internal standard compound was added to all calibration standard solutions and all sample extracts to be analyzed by gas chromatograph.

Three concentration levels calibration standard solutions of PAHs were prepared by adding appropriate volumes of one or more stock standard solutions to a volumetric flask. The stock standard solution was prepared from certified solution of 2000 μg/mL of each analyte of interest. The stock standard solution was prepared at concentrations of 100 μg/mL in toluene and 100 μg/mL of the internal standard added.

The calibration table was constructed from instrument responses for target compounds at concentrations of 25, 50 and 100 μg/mL. To each calibration standard solution, the calibration standard solutions was at a concentration near but not above the maximum detection limit and the other concentrations were ensured to correspond to the expected range of concentrations found in real samples or define by the working range of the

GC system. The working calibration curve was checked each working day by the measurement of one or more calibration standard solutions. Where the response for any analyte varies from the predicted response by more than ± 10%, the test was repeated using afresh calibration standard solution [23].

Limits of detection (LOD) were determined as signals 3 times the background signal. Peaks that were smaller than 3 times the signal-to-noise ratio were not considered. The LOD for PAHs ranged from 10 to 500 pg g$^{-1}$. The average recoveries of PAHs were 80-110% for 10 soil samples.

## GC-MS conditioning

An Agilent Technologies GC-MS comprises of 7890A gas chromatography and MS 5975C mass spectrometer detector was used in this study. The instrument comprises a HP 5 MS column of length 30 m, thickness 0.25 $\mu$m, internal diameter of 0.32 mm and helium as carrier gas at the rate of 1 mL/min. Oven temperature programme of initial temperature at 60°C hold for 1 minute then ramp to 240°C at the rate of 10°C/min to final temperature at 300°C hold for 6 minutes.

## Risk assessment of PAHs in soil

The incremental lifetime cancer risk (ILCR) was employed to evaluate the potential risk of PAHs in agricultural soils around Mechanic village Wukari. The ILCRs for adults in terms of direct ingestion, dermal contact, and inhalation were calculated using the following equations [16,24].

$$ILCR=[CS \times (CSF_{ingestion} \times \{(BW/70)^{1/3})\} \times IR \times EF \times ED]/[BW \times AT \times cf] \ldots\ldots\ldots(1)$$

$$ILCR=[CS \times (CSF_{dermal} \times \{(BW/70)^{1/3})\} \times AS \times AF \times IR \times EF \times ED]/[BW \times AT \times cf] \ldots\ldots\ldots(2)$$

$$ILCR=[CS \times (CSF_{inhalation} \times \{(BW/70)^{1/3})\} \times IR_{air} \times EF \times ED]/[BW \times PEF \times AT \times cf] \ldots\ldots\ldots(3)$$

Where CS is the PAH concentration of soils ($\mu$g kg$^{-1}$), which was obtained by converting concentrations of PAHs according to toxic equivalents of BaP using the toxic equivalency factor (TEF). The carcinogenic slope factor (mg kg$^{-1}$ day$^{-1}$)$^{-1}$ (CSF) was based on the cancer-causing ability of BaP: CSF$_{ingestion}$, CSF$_{dermal}$ and CSF$_{inhalation}$ of BaP were 7.3, 25 and 3.85 (mg kg$^{-1}$ day$^{-1}$)$^{-1}$ respectively [25]. BW is body weight (kg): 70 kg; AT is average life span (year): 70 years; EF is exposure frequency (days year$^{-1}$): 350 days year$^{-1}$; ED is the exposure duration (year): 30 years; IR$_{soil}$ is the soil intake rate (kg day$^{-1}$): 0.0001 kg day$^{-1}$; IR$_{air}$ is the inhalation rate (m$^3$ day$^{-1}$): 20 m$^3$ day$^{-1}$; SA is the dermal surface exposure (cm$^2$ day$^{-1}$): 5000 cm$^2$ day$^{-1}$; cf is the conversion factor: 10$^6$; AF is the dermal adherence factor (kg cm$^{-2}$): 0.00001 kg cm$^{-2}$; ABS is the dermal adsorption fraction (unitless): 0.1; and PEF is the soil dust produce factor (m$^3$ kg$^{-1}$): 1.32 $\times$ 10$^9$ m$^3$ kg$^{-1}$ [7,24,26]. The total risks were the sum of risks of ILCRs in terms of direct ingestion, dermal contact and inhalation.

# Results and Discussion

The pH values of soil around the mechanic village SMV before remediation was 8.20 ± 0.41 and is within the range of moderately alkaline (7.9-8.4) based on USDA classification [16]. Increase rate of bioremediation has been reportedly achieved around pH values of 7 to 8 [27]. High soil pH may result due to calcium carbonate-rich parent material weathering or irrigation with alkaline water and can be adjusted by addition of acidifying fertilizers, such as ammonium sulfate and organic matter.

The textural class of the soil was found to be sandy-loam while the percentage mean organic matter content of soil around the mechanic village SMV was 2.09 ± 0.08%while mean percentage organic carbon content of the soil was 1.215 ± 0.049% and falls within the 1.0-1.5% carbon content classified as moderate base on USDA classification. The organic matter content of the soils correlates positively with the organic carbon content. This imply that the relatively high pH in conjunction with the moderate organic content in a sandy loam soil will provide a relatively good sorption for PAHs and other organic contaminant which are readily absorbed by organic matter in soil and remain fairly stable [4].

## Polycyclic aromatic hydrocarbon composition of soils

The mean concentrations, sum of concentration, percent abundance and ratios of PAHs in agricultural soil sourced around mechanic village reveals that the $\Sigma$5 ring PAHs are the most dominant PAH compounds with concentration of 6.15 $\mu$g/kg (53.20%) where dibenz[a,h] anthracene 4.52 $\mu$g/kg (39.09%) has the highest percentage abundance while Benzo[a]pyrene 0.711 $\mu$g/kg (6.14%) records the least in the group.

The 4.52 $\mu$g/kg concentration of dibenzo[ah]anthracite is greater than the 1.96 $\mu$g/kg recorded in Akpajo, Eleme community of Niger Delta, Nigeria [28] as well as the 0.07-0.20 $\mu$g/kg recorded Igbanko mangrove forest situated in Lagos after the forest fire incident [29]. But less than the 100 $\mu$g/kg and 700 $\mu$g/kg Canadian soil quality guideline for agricultural and commercial layout [30].

Next in the frequency trend is the six membered ring with values of $\Sigma$6 ring PAHs=3.85 $\mu$g/kg (33.29%); where Indeno[1,2,3-cd] pyrene records the highest concentration of 2.61 $\mu$g/kg (22.57%) while the least in the group was Benzo[ghi]perylene 1.24 $\mu$g/kg (10.72%) followed by $\Sigma$4 ring PAHs; 0.68 $\mu$g/kg (5.88%) > $\Sigma$3 ring PAHs; 0.606 $\mu$g/kg (5.24%) and the least dominant is the two membered rings $\Sigma$2 ring PAHs; 0.499 $\mu$g/kg (4.31%) with 2-methyl-Naphthalene 0.140 $\mu$g/kg (1.21%) the least abundant. The low concentrations of alkylated PAH compounds such as 1-methylnaphthalene (1-MN) and 2-methylnaphthalene (2-MN) relative to other PAH suggests non-combusted petroleum sources. Alkylated PAH compounds like 1-methylnaphthalene (1-MN) and 2-methylnaphthalene (2-MN) are important constituents of diesel fuels and are also found in wood smoke, burnt peatlands and unburnt coal in minor amounts [31].

**Table 1.** Mean concentrations of PAHs in soil sample around mechanic village (SMV) before remediation.

| S. No | PAH in soil sample | Abbr | Conc. ($\mu$g/kg) | Abundance (%) | No. Of Aromatic rings | $\Sigma$PAHs ($\mu$g/kg) and (%) |
|---|---|---|---|---|---|---|
| 1 | Naphthalene | NAP | 0.359 ± 0.114 | 3.06 | 2 | |
| 2 | Naphthalene, 2-methyl- | NAP2 | 0.140 ± 0.08 | 1.21 | 2 | 0.499 (4.31) |
| 3 | Biphenylene | BP | 0.131 ± 0.103 | 1.13 | 3 | |
| 4 | Acenaphthene | ACE | 0.111 ± 0.100 | 0.9 | 3 | |
| 5 | Anthracene | ANTH | 0.184 ± 0.125 | 1.59 | 3 | |

| 6 | Phenanthrene | PHE | 0.180 ± 0.179 | 1.55 | 3 | 0.606 (5.24) |
|---|---|---|---|---|---|---|
| 7 | Triphenylene (Chrysene) | TP | 0.143 ± 0.00 | 1.23 | 4 | |
| 8 | Fluorene | FLR | 0.156 ± 0.00 | 1.34 | 4 | |
| 9 | Fluoranthene | FLT | 0.190 ± 0.00 | 0.94 | 4 | |
| 10 | Pyrene | PYR | 0.136 ± 0.00 | 1.17 | 4 | |
| 11 | Benzo[a]anthracene | BaA | 0.137 ± 0.00 | 1.18 | 4 | 0.681 (5.88) |
| 12 | Benzo[b]fluoranthene | BbFA | 0.920 ± 0.270 | 7.95 | 5 | |
| 13 | Benzo[a]pyrene | BaP | 0.711 ± 0.200 | 6.14 | 5 | |
| 14 | Dibenzo[a,h]anthracene | DBahA | 4.520 ± 1.200 | 39.09 | 5 | 6.151 (53.20) |
| 15 | Indeno[1,2,3-cd]pyrene | IP | 2.610 ± 0.200 | 22.57 | 6 | |
| 16 | Benzo[ghi]perylene | BghiP | 1.240 ± 0.100 | 10.72 | 6 | 3.85 (33.29) |
| | $\Sigma$ PAH16 | | 11.562 | | | |

The estimated concentrations of the $\Sigma$ LPAHs; 1.105 μg/kg (9.55%) is 9 times less than the values for $\Sigma$ HPAHs: 10.7 μg/kg (90.45%). The relatively low abundance of low molecular weight PAH (2-3 ring) such as naphthalene, methylnaphthalenes and acenapthylene may be due to their increased susceptibility to weathering by oxidation and increased losses due their higher aqueous solubility [32,33] (Table 1).

The diagnostic ratio of PAHs concentrations and patterns in soils has been used to detect the possible source of PAH. The diagnostic ratio analysis of PAHs in the agricultural soil sampled around mechanic village is presented in Table 2, the diagnostic ratio of PAHs concentrations indicates pyrogenic source since the 0.103 ratios of LMW/HMW is ratio less than 1.0, likewise the 0.97 ratio of PHen/ANth is less than 10. The ratio PYr/FLth is 0.71 which is not greater than 1 implying pyrogenic source likewise the concentration of pyrene is less than that of fluoranthene and evaluation of the expressions IPy/(IPy+BPer) and BaA/(BaA+CHr) were generally greater than 0.2 which implies that the possible source of the PAHs are pyrogenic [34].

**Table 2.** Diagnostic ratio of PAHs in soil around mechanic village [34].

| PAHs Ratio | Value | Origin (source) | PAH Source of Study Area |
|---|---|---|---|
| PHen/ANth | <10 | Pyrogenic | Pyrogenic |
| PHen/ANth | >10 | Petrogenic | Pyrogenic |
| LPAH/HPAH | <1 | Pyrogenic | Pyrogenic |
| LPAH/HPAH | >1 | Petrogenic | Pyrogenic |
| Pyr<Flth | - | Pyrogenic | Pyrogenic |
| FLth>PYr | - | Petrogenic | Pyrogenic |
| PYr/FLth | >1 | Petrogenic | Pyrogenic |
| IPy/(IPy+BPer) | >0.5 | Pyrogenic | Pyrogenic |
| IPy/(IPy+BPer) | <0.2 | Petrogenic | Pyrogenic |
| BaA/(BaA+CHr) | <0.2 | Petrogenic | Pyrogenic |
| $\Sigma$ LPAH | abundant | Petrogenic | Pyrogenic |

## Effect of phytoremediation

The total PAH content of agricultural soil obtained around the mechanic village before remediation was 11.562 μg/kg while after remediation with maize plant with fertilizer application (MF), maize planted without applying fertilizer (M), maize inter-planted with striga applying fertilizer (MSF) and maize inter-planted with striga without applying fertilizer (MS). The PAH level decrease by 94.61%, 87.68%, 81.35% and 99.07% for MF (0.622 μg/kg), M (1.424 μg/kg), MSF (2.156 μg/kg) and MS (0.106 μg/kg) respectively. Were remediation with maize inter-planted with striga without applying fertilizer (MS) was most effective possibly due to the utilization of available PAHs in the absence of available nutrient (fertilizer) while remediation with maize inter-planted with striga with applying fertilizer was the least efficient (Figures 2-7).
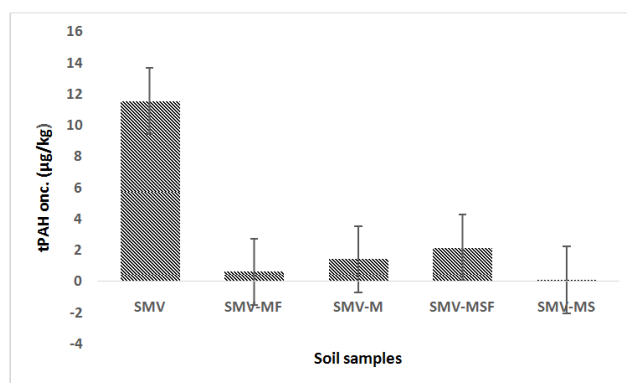


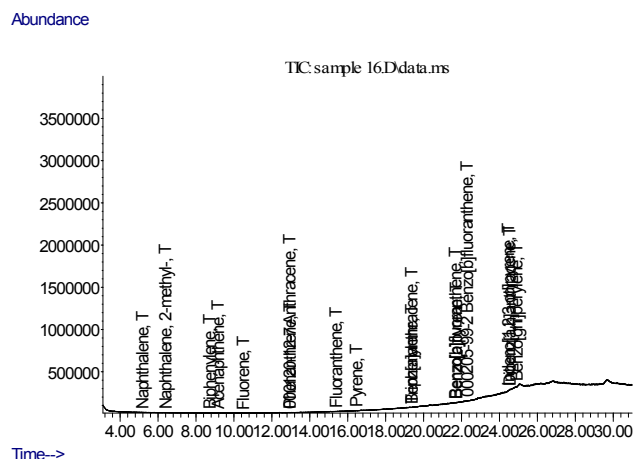**Figure 2.** Effect of phytoremediation on tPAHslevel (μg/kg) in soil sample around mechanic village.

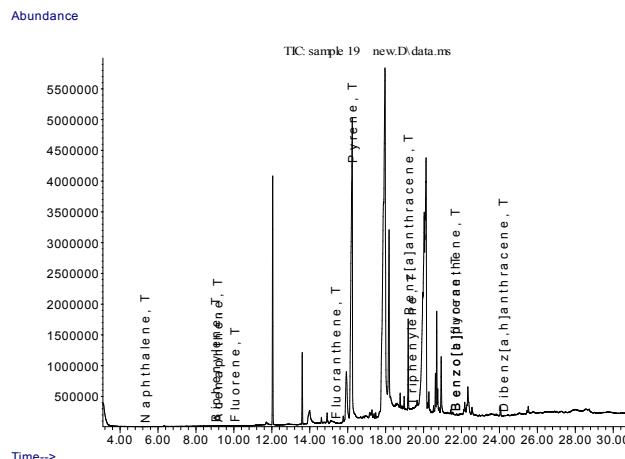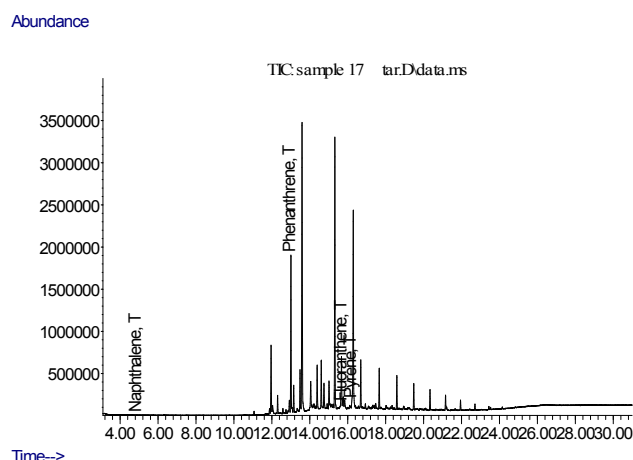**Figure 3.** Chromatogram of PAHs in soil before phytoremediation.



**Figure 4.** Chromatogram of PAHs in soil after remediation with maize plant with fertilizer application (MF).



**Figure 5.** Chromatogram of PAHs in Soil after Remediation with Maize Plant without Fertilizer application (M).
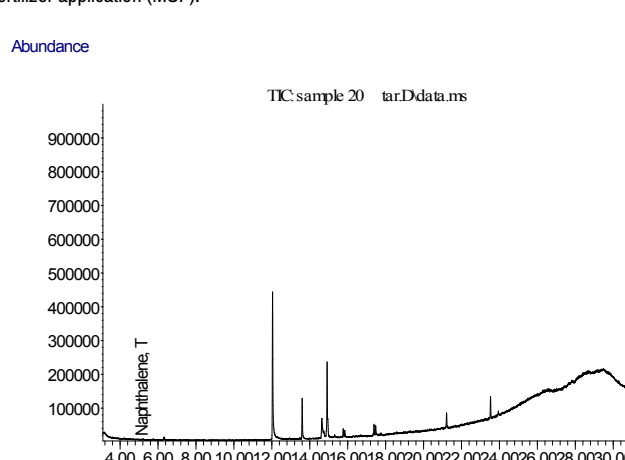


**Figure 6.** Chromatogram of PAHs in Soil after remediation with maize inter-planted with fertilizer application (MSF).



**Figure 7.** Chromatogram of PAHs in soil after remediation with maize inter-planted without fertilizer application (MS).
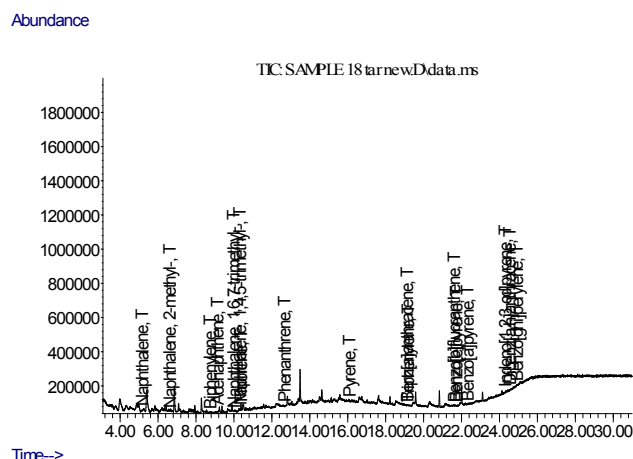
## Incremental life cancer risk

The $9.03 \times 10^{-9}$ ILCRs levels for direct ingestion calculated in the agricultural soils around the mechanic village indicates that there is no human health risk from exposure via direct ingestion likewise, the $1.55 \times 10^{-7}$ ILCRs values for dermal contact and $4.11 \times 10^{-14}$ ILCRs for inhalation indicates no potential risk as well as the $1.64 \times 10^{-7}$ total ILCRs base on the $10^{-6}$ ILCR commonly referenced benchmark for the protection of public health [7,26] (Table 3).

**Table 3.** Risk Assessment indices (BaPeq and ILCR) Values of PAH Concentrations ($\mu$ g/kg) in the Soils. S-MV=mechanic village and TEF=toxic equivalent factor.

| PAH | TEF | S-MV |
|-----|-----|------|
| NAP | 0.001 | $3.59 \times 10^{-4}$ |
| NAP2 | 0.001 | $1.40 \times 10^{-4}$ |
| BP | 0.001 | $1.31 \times 10^{-4}$ |
| ACE | 0.001 | $1.11 \times 10^{-4}$ |
| ANTH | 0.01 | $1.84 \times 10^{-3}$ |
| PHE | 0.001 | $1.80 \times 10^{-4}$ |

| | | |
|---|---|---|
| TP | 0.01 | $1.43 \times 10^{-3}$ |
| FLR | 0.001 | $1.56 \times 10^{-4}$ |
| FLT | 0.001 | $1.90 \times 10^{-4}$ |
| PYR | 0.001 | $1.36 \times 10^{-4}$ |
| BaA | 0.1 | 0.0137 |
| BbFA | 0.1 | 0.092 |
| BaP | 1 | 0.711 |
| DBahA | 1 | 4.52 |
| IP | 0.1 | 0.261 |
| BghiP | 0.01 | 0.0124 |
| SUM | | 5.615 |
| ILCRingestion | | $9.03 \times 10^{-9}$ |
| ILCRdermal | | $1.55 \times 10^{-7}$ |
| ILCRinhalation | | $4.11 \times 10^{-14}$ |
| Total ILCR | | $1.64 \times 10^{-7}$ |

## Conclusion

This study reveals that the PAHs composition in agricultural soils around Mechanic village Wukari was below the Canadian soil quality guideline for agricultural and commercial layout as well as the incremental life cancer risk. The source of the PAHs in the soil was basically pyrogenic based on the diagnostic ratio analysis while phytoremediation of the soil using *Zea mays* inter-planted with *Striga hermonthica* significantly reduce the PAHs content of the soil.

## Competing Interests

Authors have declared that no competing interests exist.

## References

1. Muckian, Lorraine M, Russell J Grant, Nicholas JW Clipson, and Evelyn MDoyle. "Bacterial community dynamics during bioremediation of phenanthrene-and fluoranthene-amended soil." *Int Biodeteriorat Biodegradat* 63 (2009): 52-56.

2. Delgado-Saborit, Juana Maria, Christopher Stark, and Roy MHarrison. "Carcinogenic potential, levels and sources of polycyclic aromatic hydrocarbon mixtures in indoor and outdoor environments and their implications for air quality standards." *Environ Int* 37 (2011): 383-392.

3. Lasson M. " Chemical and Bioanalytical Characteristics of PAH-contaminanted." Studies in Chemistry, Orebro University, pp (2013): 60.

4. Wild, Simon, and Kevin CJones. "Polynuclear aromatic hydrocarbons in the United Kingdom environment: A preliminary source inventory and budget." *Environ Pollut* 88 (1995): 91-108.

5. Jiang, YuFeng, XueTong Wang, MingHong Wu, and GuoYing Sheng, et al. "Contamination, source identification, and risk assessment of polycyclic aromatic hydrocarbons in agricultural soil of Shanghai, China." *Environ Monit Assess* 183 (2011): 139-150.

6. Kipopoulou, Anna Maria, Evangelia Manoli, and Samara C. "Bioconcentration of polycyclic aromatic hydrocarbons in vegetables grown in an industrial area." *Environ Pollut* 106 (1999): 369-380.

7. Yang, Yuyi, Lee Ann Woodward, Qing XLi, and Jun Wang. "Concentrations, source and risk assessment of polycyclic aromatic hydrocarbons in soils from Midway Atoll, North Pacific Ocean." *PLoS One* 9 (2014).

8. Abdel-Shafy, Hussein, and Mona SM Mansour. "Removal of selected pharmaceuticals from urine via fenton reaction for agriculture reuse." *J Sustainable Sanitation Pract* 17 (2013): 20-29.

9. Niu, Junfeng, Ping Sun, and Karl-Werner Schramm. "Photolysis of polycyclic aromatic hydrocarbons associated with fly ash particles under simulated sunlight irradiation." *J Photochemis Photobiol A: Chemis* 186 (2007): 93-98.

10. Ghanbari, Mojgan, Faezeh Soofivand, and Masoud Salavati-Niasari. "Simple synthesis and characterization of Ag2CdI4/AgI nanocomposite as an effective photocatalyst by co-precipitation method." *J Mol Liq* 223 (2016): 21-28.

11. Chatterjee, Soumya, Anindita Mitra, Sibnarayan Datta, and Vijay Veer. "Phytoremediation protocols: an overview." In Plant-Based Remediation Processes, Springer, Berlin, Heidelberg, (2013).

12. Abdel-Shafy, Hussein I, and Mona SM Mansour. "A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation." *Egypt J Petrol* 25 (2016): 107-123.

13. Xuejing, Xie, and Cheng Hangxin. "Global geochemical mapping and its implementation in the Asia–Pacific region." *Appl Geochem* 16 (2001): 1309-1321.

14. Yerima Emmanuel Amuntse, RB Donatus, JI Opara, and GO Egah, et al. "Assessment of heavy metals level of soils around sacks and packaging company, Akwanga Nasarawa State, Nigeria." *J Environ Anal Chem* 5 (2018): 2380-2391.

15. Motsara, MR, and Rabindra Roy. "Guide to laboratory establishment for plant nutrient analysis." Rome: Food and Agriculture Organization of the United Nations. (2008).

16. USDA. "Soil survey division staff (1993) soil survey manual. Soil conservation service." US Dep Agri Handbook. 18 (1993): 315.

17. Walkley, Aldous, and Armstrong Black. "An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method." *Soil Sci* 37 (1934): 29-38.

18. Souza, Diego Mendes de, Pedro Augusto de Oliveira Morais, Ivã Matsushige, and Luismar Alves Rosa. "Development of alternative methods for determining soil organic matter." *Revista Brasileira de Ciência do Solo*. 40 (2016).

19. Berner, Di, MWin Slow, Ad Awad, and KCard Well, et al. "Striga research methods: A manual." (1997).

20. Christensen, Anders, Conny Östman, and Roger Westerholm. "Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in urban dust and diesel particulate matter using ultrasonic assisted extraction and on line LC-GC-MS." *Anal Bioanal Chem*. 381 (2005): 1206-1216.

21. Itodo, AU, TT Akeju, and HU Itodo. "Polycyclic Aromatic Hydrocarbons (PAHs) in Crude Oil Contaminated Water from Ese-Odo Offshore, Nigeria." *Ann Ecol Enviro Sci*. 3 (2019): 12-19.

22. Kumar, Vaneet, and NC Kothiyal. "Distribution pattern and contamination levels of some polycyclic aromatic hydrocarbons along roadside soil at major traffic intercepts during autumn in Jalandhar, India." *Asian J Chem*. 23 (2011): 1363.

23. Kumar, Vaneet, NC Kothiyal, Saruchi Kumari, and RI Mehra, et al. "Determination of some carcinogenic PAHs with toxic equivalency factor along roadside soil within a fast developing northern city of India." *J Earth Sys Sci*. 123 (2014): 479-489.

24. Peng, Chi, Weiping Chen, Xiaolan Liao, and Meie Wang, et al. "Polycyclic aromatic hydrocarbons in urban soils of Beijing: status, sources, distribution and potential risk." *Environ Pollut* 159 (2011): 802-808.

25. Wang, Zhen, Jingwen Chen, Xianliang Qiao, and Ping Yang, et al. "Distribution and sources of polycyclic aromatic hydrocarbons from urban to rural soils: a case study in Dalian, China." *Chemosphere* 68 (2007): 965-971.

26. United States Environmental Protection Agency. "Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons." (1993).

27. Othman, NI, Abdul Talib, and CC Tay. "Optimization of low ring polycylic aromatic biodegradation." In IOP Conference Series: Materials Science and Engineering, 136 (2016).

28. Ana, Gref, Mynepalli KC Sridhar, and Godwin OEmerole. "A comparative assessment of soil pollution by polycyclic aromatic hydrocarbons in two Niger Delta communities, Nigeria." *Afr J Pure Appl Chem*. 3 (2009): 31-41.

29. Sojinu, Olatunbosun, Oluwadayo OSonibare, and Eddy YZeng. "Concentrations of polycyclic aromatic hydrocarbons in soils of a mangrove forest affected by forest fire." *Toxicol Environ Chem* 93 (2011): 450-461.

30. Canadian Council of Ministers of the Environment. "Guidelines for Carcinogenic and Other Polycyclic Aromatic Hydrocarbons (Environmental and Human Health Effects)." Scientific Supporting Document. (2008).

31. Vane, Christopher H, Barry G Rawlins, Alexander W Kim, and Vicky Moss-Hayes, et al. "Sedimentary transport and fate of polycyclic aromatic hydrocarbons (PAH) from managed burning of moorland vegetation on a blanket peat, South Yorkshire, UK." *Sci Tot Environ* 449 (2013): 81-94.

32. Marynowski, Leszek, Slawomir Kurkiewicz, Michał Rakociński, and Bernd RT Simoneit. "Effects of weathering on organic matter: I. Changes in molecular composition of extractable organic compounds caused by paleoweathering of a Lower Carboniferous (Tournaisian) marine black shale." *Chem Geol*. 285 (2011): 144-156.

33. Vane, Christopher, Alexander Kim, Darren Beriro, and Mark Cave, et al. "Polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB) in urban soils of Greater London, UK." *Appl Geochem* 51 (2014): 303-314.

34. Emoyan, OO, A Odagwe, SO Akporido, and PO Agbaire, et al. "Evaluation of polycyclic aromatic hydrocarbons in soil of selected urban areas of delta stat Nigeria." (2018): 266-273.