Research Article
Volume 7:5, 2020

Journal of Environmental Analytical Chemistry

ISSN: 2380-2391 Open Access

Occurrence and Remediation of Polychlorinated Biphenyls in Soil from Jos, Plateau State, Nigeria

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Abstract

Investigation into occurrence and Remediation of Polychlorinated biphenyls in soil from Jos, Plateau State Nigeria was carried out. The polychlorinated biphenyls in the soil was extracted with 40ml hexane-acetone mixture (1:1) in ultrasonic bath for 30 minutes and cleaned with column chromatography packed with silica gel. The polychlorinated biphenyls were quantified using Agilent 6975 Gas chromatography Mass Spectrophotometer with the following results: PCB 18 (0.71), PCB 20 (0.37), PCB 28 (0.38), PCB 29 (0.38), PCB 44 (0.42), PCB 52 (0.66), PCB 101 (0.61), PCB 105 (0.17), PCB 137 (0.64), PCB 142 (0.33), PCB 153 (0.42), PCB 170 (0.13) and PCB 180 (0.21) all in mg/kg. Remediation with *Moringa* seed results in the followings; PCB 20 (0.28), PCB 28 (0.28), PCB 29 (0.28), PCB 52 (0.30), PCB 101 (0.18), PCB 143 (0.91) while the other congeners were completely removed. The *Moringa* seed powder results completely removed the PCBs sake PCB 44. The effectiveness of the powder as compared with the seed in the removal of the PCBs might be attributed to the increased surface area of the seed powder providing for better interaction with the contaminated soil. Whereas the results from the use of activated carbon only removed PCB 105 completely and reduced the concentrations of other congeners as follows: PCB 18 (0.04), PCB 20 (0.011), PCB 28 (0.019), PCB 29 (0.019), PCB 44 (0.021), PCB 52 (0.33), PCB 101 (0.031), PCB137 (0.032), PCB 142 (0.017), PCB 153 (0.021), PCB 170 (0.007) and PCB 180 (0.011) all in mg/kg. The result suggests that *Moringa* seed powder could possibly serve as an excellent means of remediation for Polychlorinated biphenyls in contaminated soil.

Keywords: Remediation • Polychlorinated biphenyl • Mon-oammonium phosphate • Chromatography and soil

Introduction

Polychlorinated biphenyls (PCBs) are persistent and toxic pollutants that have been widely distributed into the environment [1]. They are classified as persistent organic pollutants (POPs) under the Stockholm Convention due to their persistence bioaccumulation, high toxicity and long-range atmospheric transport with potential carcinogenicity [2]. Research evidence has revealed that long range transport is a major source of this contaminant in a remote area [3].

Polychlorinated biphenyls are mainly synthetic chemicals with 2-10 atoms of chlorine attached to the biphenyls molecules and were produced several years ago with annual production estimation of 1.5millions tones [4]. Although banned in most of the countries in 1980, yet its emission still continues from old electrical equipment, inadequate management of wastes and electronic equipment leakage or improper disposal of transformer and capacitor oil [5].

They are 209 compounds often known as PCBs congeners. Their properties such as heat resistance, low electrical conductivity and thermal degradation performance make them excellent in use as insulators mediums, flame retardant agents, plasticizers and pesticides additives since 1930s [6-8]. Out of the 1.5million tones production globally, 48% production of the PCBs is used for transformer oils, 21% for small capacitors, 10% for other closed system, these include heat transfer fluids, hydronic fluids, liquid filled cables and circuit breakers and approximately 21% for open systems as paints and pesticides [4]. They have also been used as organic diluents, plasticizers, adhesives, dust reducing agent cutting oils, flame retardants, sealants and in carbonless copy paper. Some of these PCBs uses have resulted in them directs introduction into the environment.

Contamination of the environmental compartments by polychlorinated biphenyls is a matter of great concern to the environmentalists worldwide. They have been reported to have adverse effects on the environment, human and ecosystem. They enter the environment as a mixture containing different individual congeners [9].

Despite their phase out in 1970, PCBs residues still have been reported in soil, water and air all over the world [10-13] and their levels are not expected to decrease significantly in the next few decades [14].

Soil has been an important sink for PCBs and can also acts as a source of pollution [15]. Soil contamination has led to the reduction of agricultural areas which is a growing problem in many countries. Meijer et al. reported that nearly 21,000 tons of PCBs have been discharged to the soil in the world. This can be accumulated gradually through the food chain and have a detrimental effect on human [16].

The distribution of PCBs in soil can help to assess the level of pollution, infer the source of the emission and evaluate the human health risk [17]. Therefore, the aim of this research is to investigate the occurrence of PCBs in soil and remediate using locally produced activated carbon from Coconut shell and Moringa seed on contaminated soil from Transformer Installation Sites in Jos, Plateau State Nigeria with the objective of evaluating the efficiency of remediation between the activated carbon and the Moringa seed.

Materials and Methods

Sample collection and treatment

The soil samples were collected in March 2019 from transformer

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Received 15 July, 2020; **Accepted** 09 September, 2020; **Published** 18 September, 2020

installation site in Jos, Plateau State, Nigeria within the depth of 15 cm from different sites. The stones, weeds, leave and roots were removed after which it was taken to laboratory. All the samples were dried at ambient temperature crushed through a sieve of 10mm aperture and stored in the refrigerator for further analysis [18].

For the remediation studies the activated carbon was produced according to Soideide with slight modification whereby the final product was air-dried after addition of distilled water for two weeks at room temperature instead of oven drying. This was packed in polyethylene bottles for further use. The Moringa seed was purchased in local market cleaned from debris and crushed with pestle and mortal to obtain the powder seed, which was stored in polythene leather for further use. Ten grams each of the contaminated soil was mixed with five grams each of prepared activated carbon, Moringa seed and Moringa seed powder; and allowed to stand for two weeks, after which it was extracted and analysed.

Sample extraction and cleaned up

Twenty grams of the soil samples (that is moisture free) were mixed thoroughly with 10 g of anhydrous sodium sulphate each sample was ultra-sonicated with 30 mL of n-hexane/acetone (1:1 v/v) for 30 minutes. The extract was cleaned with column chromatography packed with silica gel and concentrated to 2 mL using rotary evaporator.

Instrumental analysis

The final extract of 2.0 ml was analysed for PCBs using a gas chromatograph equipped with 63Ni electron capture detector GC - ECD model CP 3800.

The capillary column used was VF 5ms 30 m × 0.25 mm id × 0.25 µm film thickness. The GC conditions were as follows: injection point temperature: 270°C; oven temperature programme:

70°C (hold 2 min) to 180°C at a rate of 25°C/min (hold 1min) to 300°C at a rate of 5°C/min. Temperature of detector was 300°C; carrier gas-nitrogen at flow rate: 1.0 ml/min; make-up gas flow rate 29.0 ml/min. The total runtime was 31.368 min.

The PCBs congeners were identified by the comparison of retention time of the PCBs in the samples with those of the standard while the quantification of individual congeners in mg/kg was calculated on dry weight basis.

Results and Discussion

The results of the polychlorinated biphenyls in the soil samples (A & A*) collected from Jos, Plateau State, Nigeria and remediation (B, C, D, F, G and H) is shown in Table 1 while the chromatogram for various samples is shown in Figures 1-7.

The results of the concentrations of polychlorinated biphenyls (PCBS) in soil samples from Jos, Plateau State, Nigeria is indicated in Table 1. Sample A is soil sample collected 2 m away from the installed transformer and the PCB concentration ranges from 0.13 to 0.710 mg/kg. PCB 18 has the highest concentration with the value of 0.710 mg/kg and PCB 170 has the least with the value of 0.13 mg/kg while others have various values but all less than 1.00 mg/kg. It can be seen that the concentration is in the order of PCB 18> PCB 52> PCB 137> PCB 101 > PCB 44/153 > PCB 28/29 > PCB 20 >PCB 142 > PCB 180 > PCB 105 > PCB 170. Meanwhile PCBs 118 and 194 were not detected probably their values were below instrument detection limit. The total concentration of the PCBs in the soil in mg/kg of both samples (A and A*) were also indicated in Table 1 (4.30 mg/kg and 159.74 mg/kg) respectively, these values were above 2.0 mg/kg set by United states under the toxic substance control act (TSCA) which regulates the PCBs in the environment, stipulating that any soil or sediments containing PCBs equal or greater than 2 mg/kg that are spilled after 1978 from a source unauthorised for use are regulated as PCB remediation waste [19].

For sample A* appears to be heavily polluted with the polychlorinated biphenyls (PCBs), the least concentration is PCB 118 congener with the concentration of 0.310 mg/kg but highest with PCB 153 with the value of 37.380 mg/kg. The various concentration in this site varies from PCB 153>PCB 137>PCB 52>PCB 28/29>PCB 20>PCB 142>PCB 44>PCB 101>PCB 194>PCB 18>PCB 170>PCB 105>PCB 180>PCB 118. This study agreed with other finding that discovered soil within transformer installed sites in Porthartourt were above the 2.0 mg/kg set by the United States toxic act.

The remediation effiency of the activated carbon, Moringa seed and the Moringa seed powder were compared, and the use of activated carbon was more effective at lower concentration of PCBs, whereas at higher concentration of PCBs the Moringa seed powder appeared more effective (Figure 8). This was obtained by calculating the percentage removal of PCBs by the activated carbon, Moringa seed and the Moringa seed powder using the formula:

$$(\%)\ X = a/b \times 100 \text{ - - - } (1).$$

Table 1. Results of polychlorinated biphenyls in soil.

Sample/congeners	A	B	C	D	A*	F	G	H
PCB 18	0.710	BDL	BDL	0.030	0.790	BDL	BDL	0.040
PCB 20	0.370	0.280	0.280	0.007	13.270	0.280	ND	0.310
PCB 28	0.380	0.270	0.390	0.015	13.770	0.270	ND	0.520
PCB 29	0.380	0.270	0.390	0.015	13.770	0.270	ND	0.520
PCB 44	0.420	ND	1.110	0.005	7.710	ND	ND	0.100
PCB 52	0.660	0.420	0.400	0.004	27.660	0.300	0.180	0.180
PCB 101	0.610	ND	ND	0.030	3.480	0.180	ND	0.170
PCB 105	0.170	ND	ND	0.109	0.500	ND	ND	0.320
PCB 118	BDL	BDL	BDL	BDL	0.31	BDL	ND	BDL
PCB 137	0.640	ND	ND	0.010	27.810	ND	ND	0.420
PCB 142	0.330	0.280	0.430	0.026	9.470	0.910	ND	0.790
PCB 153	0.420	ND	ND	0.006	37.380	ND	ND	0.530
PCB 170	0.130	ND	BDL	0.005	0.540	ND	ND	0.020
PCB 180	0.210	ND	0.150	0.243	0.380	ND	ND	0.440
PCB 194	BDL	ND	ND	BDL	2.900	ND	ND	BDL
TOTAL	5.43	1.52	3.15	0.505	159.74	2.21	0.18	4.36

Keys: A=sample of contaminated soil from Gagere Jos, B=contaminated soil from A + *Moringa* seed powder, C=contaminated soil from A + *Moringa* seed, D=contaminated soil from A + activated carbon. A* =sample of contaminated soil from Unijos old campus, F=sample A* + *Moringa* seed, G=sample A*+ *Moringa* seed powder and H=sample A* + activated carbon. PCB18=2,2,5-Trichlorobiphenyl PCB 20=2,3,3-Trichlorobiphenyl PCB 28=2,4,4-Trichlorobiphenyl, PCB 29=2,4,5-Trichlorobiphenyl, PCB 44=2,2,3,5-Tetrachlorobiphenyl, PCB 52 =2,2,5,5-Tetrachlorobiphenyl PCB 101=2,2,4,5,5-Pentachlorobiphenyl, C105=2,3,3,4,4-Pentachlorobiphenyl, PCB 118=2,3,4,4,5-Pentachlorobiphenyl, PCB 137=2,2,3,4,4,5-Hexachlorobiphenyl,PCB142=2,2,3,4,5,6-Hexachlorobiphenyl,PCB 153=2,2,4,4,5,5-Hexachlorobiphenyl, PCB 170=2,2,3,3,4,4,5-Heptachlorobiphenyl, PCB 180=2,2,3,4,4,5,5-Heptachloribiphenyl, PCB 194=2,2,3,3,4,4,5,5-Octachlorobiphenyl.

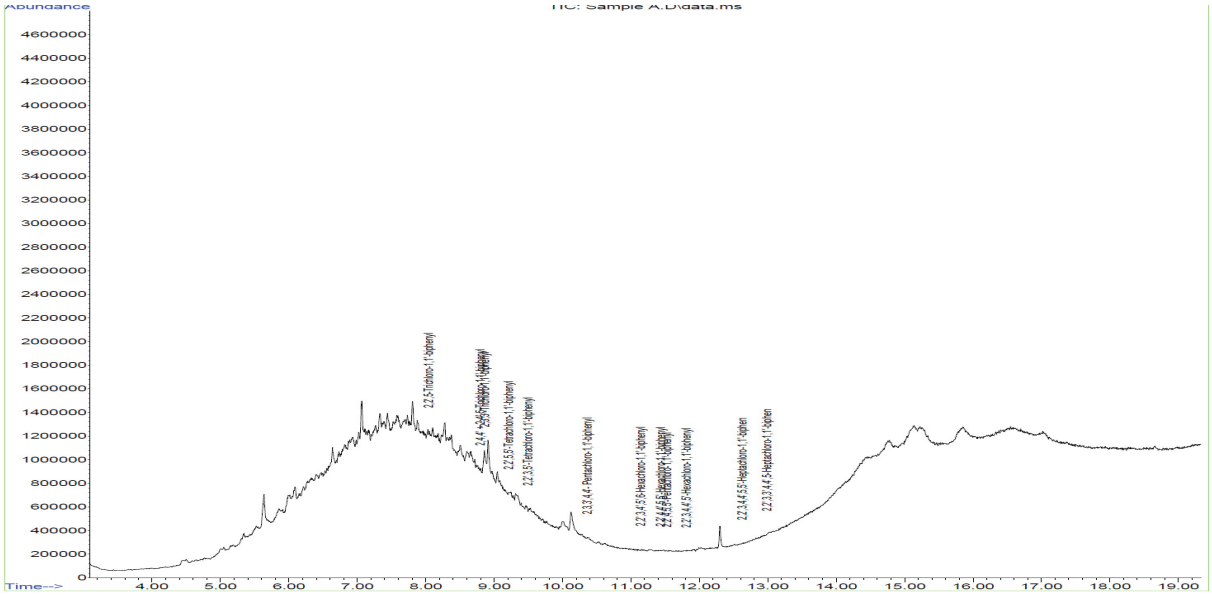

Figure 1. Chromatogram of contaminated soil sample (Sample A).

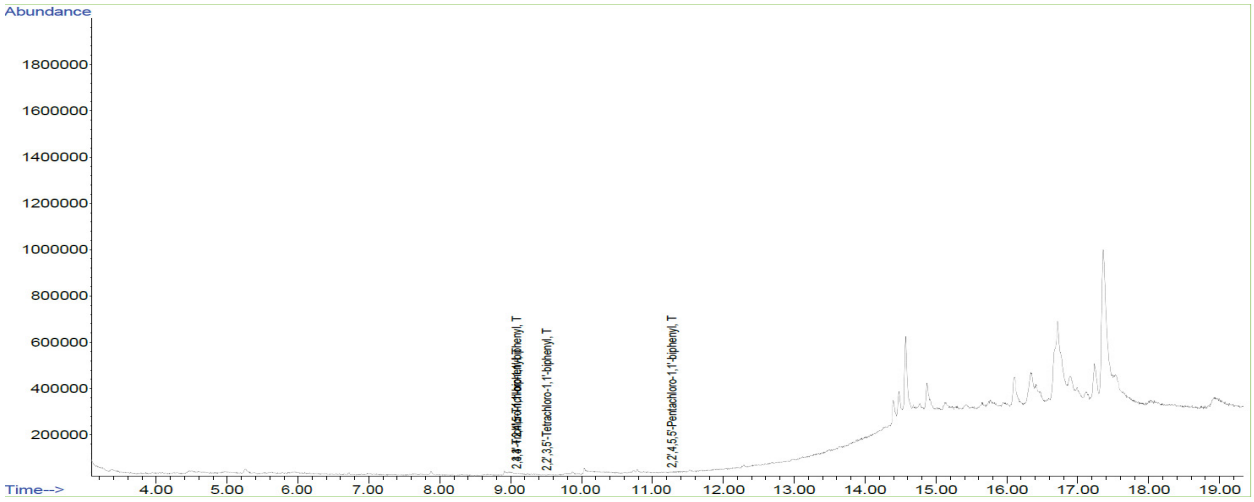

Figure 2. Chromatogram of Sample A + *Moringa* seed powder (Sample B).

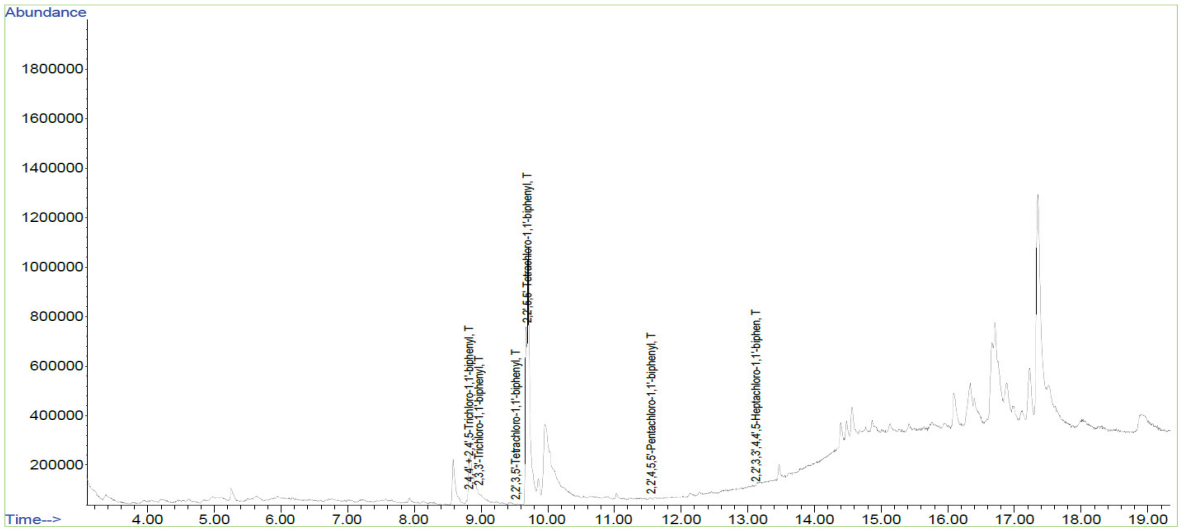

Figure 3. Chromatogram of Sample A + *Moringa* seed (Sample C).

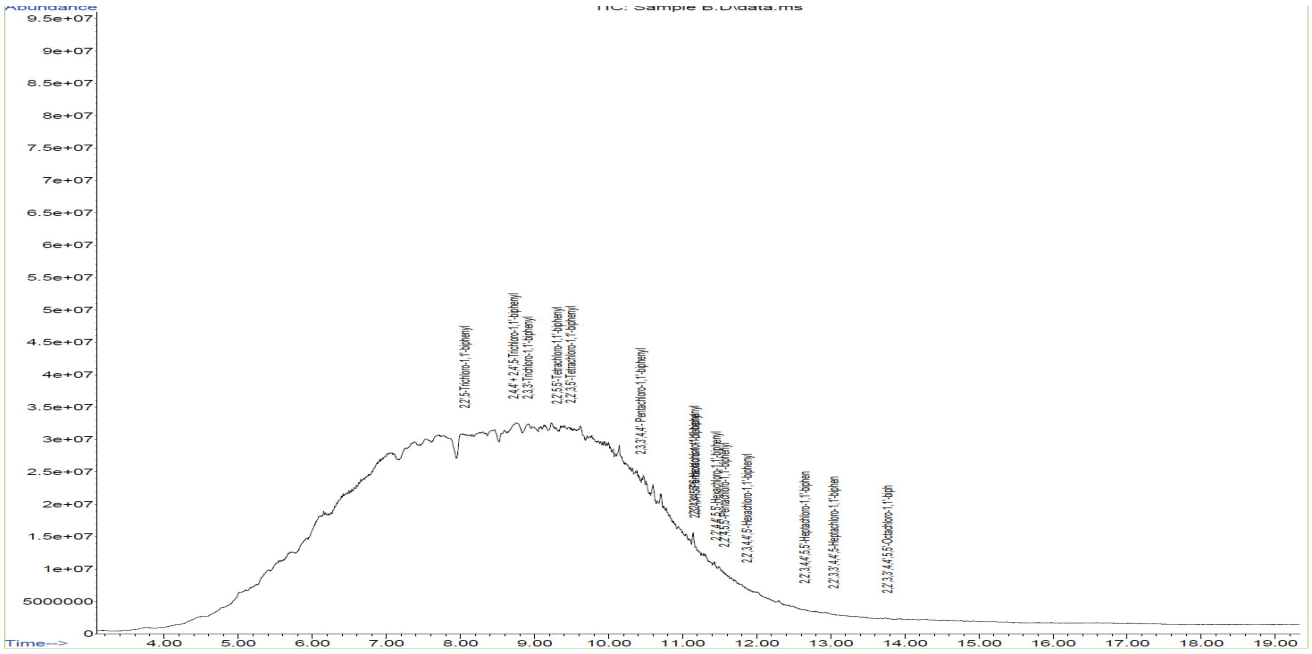

Figure 4. Chromatogram of Sample A*.

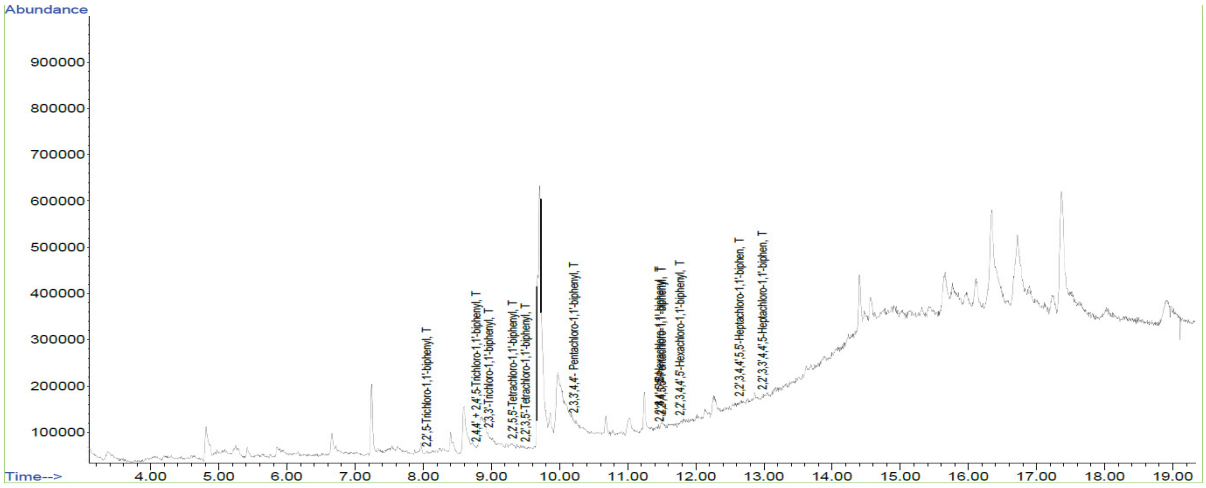

Figure 5. Chromatogram of Sample A* + activated carbon (Sample H).

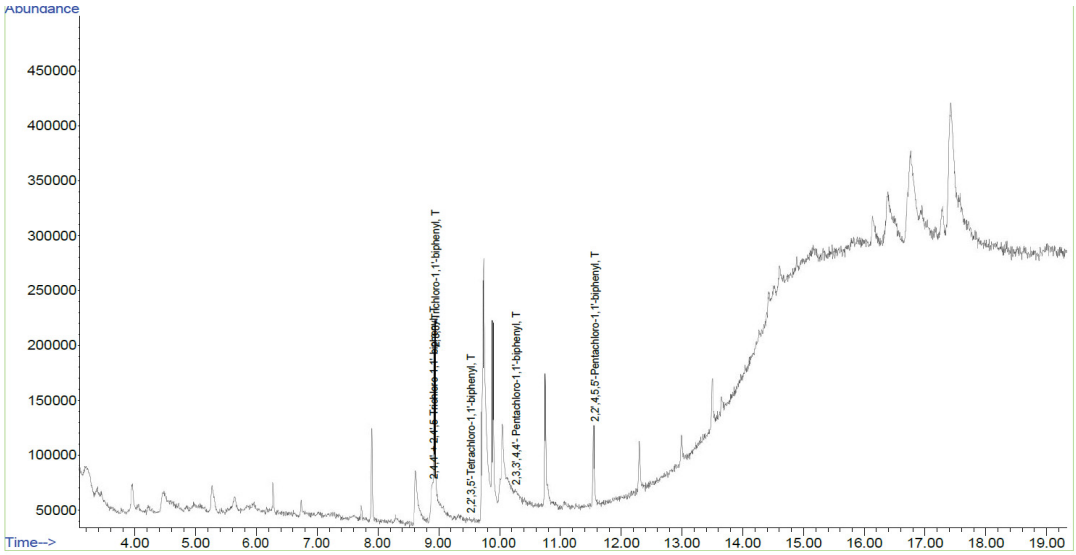

Figure 6. Chromatogram of Sample A* + *Moringa* seed (Sample F).

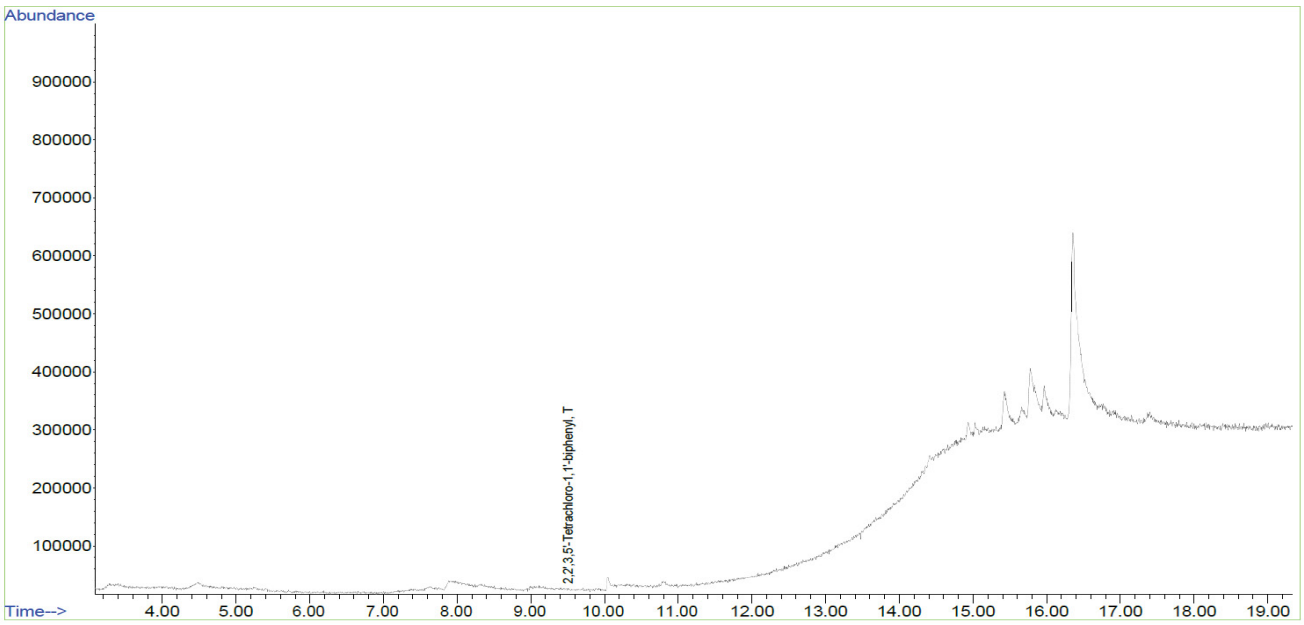

Figure 7. Chromatogram of Sample A* + *Moringa* seed powder (Sample G).

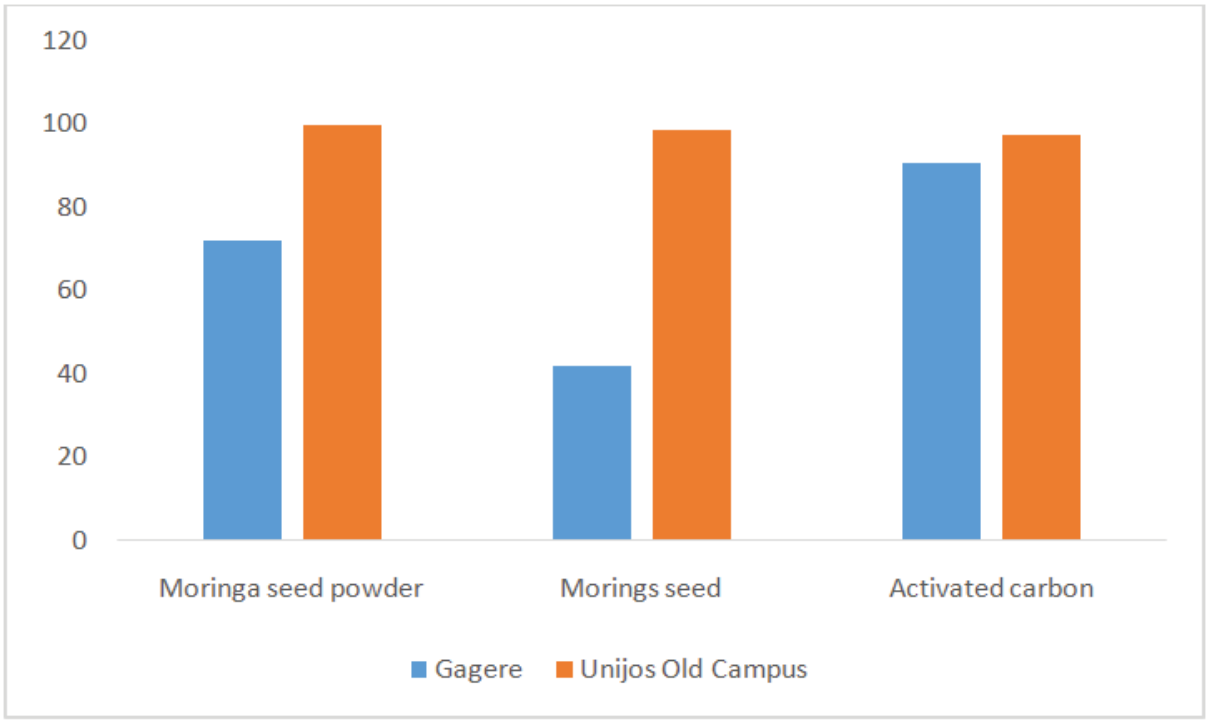

Figure 8. Percentage removal of PCBs by *Moringa* seed powder, *Moringa* seed and activated compared for contaminated soil.

Where X is the percentage of PCBs removed in a particular site, 'a' is the total concentration of PCBs removed in a particular site and 'b' is the total concentration of PCBs in a particular site.

From the results obtained there pose a great danger, studies had shown various toxicological effects of PCBs to includes carcinogenicity, tumor promoter-type effects, endocrine disruption, tetratogenicity and possible impairment of psycho-development in human and animals as well [20].

The best way to estimate accurate toxicity and assessing the carcinogenic risk for PCBs is achieved with the use of congeners form rather than the total PCBs using their toxicity equivalent factor (TEF) [21]. The PCBs dioxin like play important role in the evaluation of risk associated to PCBs release and in the development of PCBs cleanups level, this is because evaluation of total PCBs would not give accurate information on the environmental matrix.

To achieve the compliance with cleanup and remediation levels for environmental matrix like soil for PCBs under the Model Toxic Control Act (MTCA) cleanup regulation, the soil matrix is considered a single hazardous substance and the target cancer risk level of one in one million (10^{-6}) is used in estimating cleanup level under method B. The 1998 and 2006 toxicity equivalent factor was used to evaluate the carcinogenicity of four dioxin like PCBs (PCB 105, PCB 118, PCB 170 and PCB 180). The cancer potency factor of the dioxin like PCBs with a method B cleanup level 1.3×10^{-6} mg/kg is used as shown in equation (2) below:

$$TTEC/TEQ=\sum Cn \times TEFn \text{- - - - (2)}$$

Table 2. Changes in TEFs values for human risk assessment of Dioxin-like PCBs.

Congener	TEFaTETb
PCB 77 0.0001	0.0001
PCB 810.0001	0.0003
PCB 1050.0001	0.00003
PCB 1140.0005	0.00003
PCB 1180.0001	0.00003
PCB 1230.0001	0.00003
PCB 1560.0005	0.00003
PCB 1570.0005	0.00003
PCB 1670.0001	0.00003
PCB 1700.0001	-
PCB 1800.00001	-
PCB 1890.0001	0.00003

PCB: Polychlorinated Biphenyl, a=Van der Berg et al. (1998): b=Van der Berg et al. (2006).

where Cn is the concentration of individual congener in the soil matix, TEFn is the toxic equivalent factor of individual congener, TTEC is the total toxicity equivalent concentration and TEQ is the toxicity equivalence.

The 2005 and 2006 Van Der Berg TEF was used in this work (Table 2). The PCB congeners that are affected in the whole fifteen detected are PCB 105, PCB 118, PCB 170 and PCB 180 out of these PCB 170 and PCB 180 toxicity equivalent factors has not been established in the 2006 but have values for 1998. Applying their respective TEF values for 1998 and 2006 and computing using equation (2) the cancer factor (TTEC/TEQ) for site A is 3. 21×10^{-5} mg/kg, A* is 1.39×10^{-4} mg/kg for 1998 and site A is 5.10×10^{-6} mg/kg, A* is 2.43×10^{-5} mg/kg for 2006 respectively.

Again the values for both sites exceeded the method B cleanup levels for dioxin like PCBs i.e., 1.3×10^{-6} mg/kg and therefore the sites needed massive cleanup for carcinogenic dioxin like PCBs. It is patient for the relevant authorities to remediate and cleanup the transformer locations to avoid further direct human contact and toxicity. This lead the researchers to carry out remediation study having seen the danger posed by this class of pollutants to human and animals. The finding now revealed both Moringa seed and activated carbon can be use for PCBs remediation. However Moringa seed powder in this study serves as an excellent means of PCBs remediation in PCBs contaminated soil of higher degree [22-27].

Conclusion

The results of the total PCBs concentration in the soil from the two sites of the transformer installations exceeded the maximum required baseline of 2 mg/kg for cleanup. Both activated carbon and Moringa seed can be used for remediation, preferably Moringa seed powder probably due to increased in the surface area. Due to the economic importance of Moringa seed which served as a source of immune boaster the researcher recommend that PCB transformer should be replaced with non PCB releasing transformers.

Acknowledgement

The authors express their appreciation to TETFUND University of Jos Institution Based Research through the Office of Research and Development (ORD) for their financial support in this research work, Ikukplasi Laboratory Services (Nig.) Ltd for their facilities and Jos Electricity Distribution Company for availing us opportunity to use their facilities.

Authors Contributions

E.G. Ibrahim performed the experiment, wrote the manuscript and collect the samples, S.J. Salami designed the experiment, J.S. Gushit analysed the data and contributed in provision of materials, M.B. Dalen contributed reagents/analysis tools and M.A. Gube-Ibrahim proof read and edit the manuscript.

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How to cite this article: Ezekiel Gube Ibrahim, Salami SJ, Gushit JS, Dalen MB and Gube-Ibrahim MA. "Occurrence and Remediation of Polychlorinated Biphenyls in Soil from Jos, Plateau State, Nigeria." *J Environ Anal Chem* 7 (2020): 277