ISSN 2786-7447
EUROPEAN JOURNAL OF THEORETICAL AND APPLIED SCIENCES
OPEN ACCESS
PEER REVIEWED

Effect of Petroleum Illegal Refining Activities on Cassava Plant in the Niger Delta

Iche Harry Dimkpa
Nigerian Upstream Petroleum Regulatory Commission, Warri, Nigeria

Chidi Ahamefule Dimkpa
Centre for Engineering and Technology Management (CETM), Institute of Engineering and Innovation Management (METI), University of Port Harcourt, Nigeria

Suggested Citation
Dimkpa, I.H. & Dimkpa, C.A. (2024). Effect of Petroleum Illegal Refining Activities on Cassava Plant in the Niger Delta. *European Journal of Theoretical and Applied Sciences, 2*(1), 186-198.
DOI: 10.59324/ejtas.2024.2(1).14

Abstract:

The evolution of illegal refining was briefly discussed leading to an experimental research of its effects on cassava plant which is a major staple food in the region. Two deactivated illegal refinery sites were selected for the studies; cassava plant (tubers, stem and leaves) samples were taken from these sites with a control and then analyzed for the concentrations of Heavy Metals, BTEX, PAHs and THC. The results show that the mean concentration of heavy metals in cassava tuber were Pb (5.31±0.17 mg/kg), Cd (6.44±0.23mg/kg), Cr (5.25±0.02 mg/kg), As (9.27±0.04 mg/kg), Zn (5.30±0.17 mg/kg), Cu (4.17±0.06 mg/kg), Ni (13.52±0.01 mg/kg) and Co (40.66±0.00) (mg/kg) for site A; while site B has Pb (0.15±0.03 mg/kg), Cd (0.107±0.06 mg/kg), Cr (0.167±0.03 mg/kg), As (1.83±0.02 mg/kg), Zn (0.063±0.02 mg/kg), Cu (0.079±0.04 mg/kg), Ni (0.113±0.01 mg/kg) and Co (0.082±0.05 mg/kg). The mean concentration values of heavy metals in cassava tuber were higher than the control mean values. Plant Concentration Factor was also calculated from the studies. Result also showed higher mean concentration values of BTEX and PAHs for cassava plant (tuber, stem and leaves) when compared with control values and WHO permissible limits for plants. The overall result indicates the contamination and pollution of cassava plant from both studied sites due to illegal petroleum crude oil refining activities.

Keywords: *Illegal Refineries, Cassava Plant, Petroleum crude oil, Plant Concentration factor, Heavy Metals.*

Introduction

The growing need and desire for energy from petroleum crude oil globally with the attendant unruly exploration and production operations have contributed to the pollution of its operation's environment Kuch and Bavumiragira, (2019). The consequences of these operations are normally and generally attributed to poor production management, pipeline and equipment failures due to aging and faulty designs. Petroleum crude oil refining contributes to extremely harsh surroundings that leads to large amount of waste and residues containing crude oil which eventually leads to environmental degradation. However, a new dimension of the main contributory factor to the environmental degradation and pollution in the Niger Delta region of Nigeria, is the activities of illegal refineries which are virtually dotted across the oil region of the country.

Evolution of Petroleum Illegal Refinery in the Niger Delta

Asimiea and Omokhua, (2013) stated that these illegal refineries came to be as a result of agitation by people of the various communities in the Niger Delta region to the unwholesome oil and gas companies' activities that impacted negatively on their communities and environment due to its exploration and exploitation that climaxed with open arm confrontation against the Nigerian Government in 1999, and despite the huge amount of resources earned from crude oil exploitation activities, nothing was given back to the communities from where these resources came from with serious environmental pollution and degradation which still persist in the communities (Okumagbo, 2019) and the community members could not attain good quality of life for the sustenance of their livelihood (Olawuyi, 2015).

These adverse effects culminating into loss of fishing and farmlands which are predominantly the primary indigenous vocations, leading to indigenes inability to fend for the basic needs of life and therefore gave rise to regional movements, ethnic consciousness and unemployment; thus, became the genesis of the restlessness among the youths and younger generation (Oyewole et al, 2018) leading to expatriates and local indigenous expert staff of International Oil Companies (IOCs) being kidnapped for ransom as experienced in the 1990s with vandalization of crude oil pipelines and oil installations.

As a way out of the situation of the militancy bedeviling the region, the Federal Government granted amnesty to those who dropped their arms and rehabilitated them, while the non-violent and unemployed agitators who were not rehabilitated took to Illegal refining of petroleum products. A new era of illegal petroleum refining was born and is referred to as 'Kpoo Fire' in local parlance.

The illegal refinery operations involve the vandalization of crude oil pipelines, well heads and other oil facilities in order to steal the oil for refining into petroleum products of petrol, diesel and kerosene which is sold to the public since the country relies mostly on the importation of these products as a result of government refineries not functioning. In cause of their operations, spillages occur and its waste and residues are discharged into adjoining farmlands, streams and rivers. Most often than not, there are blow outs with the entire area being a flamed as the products are highly inflammable. This causes environmental pollution of water, land and air as it impacts adversely on the health and livelihood of the communities, nature, plants regeneration, loss of natural wild life habitats, disruption of crops, farming in general, water cycle and in most cases lead to loss of life.

The main problem is the environmental pollution and contamination of the farmlands within the community caused by the activities of these illegal refineries in their areas of operation. This inherently affects the cassava plant which is the most staple food across the region. There are over 142 illegal refineries in Rivers State alone and the State government has destroyed 128 so far while more are still springing up with an estimated total number of over 250 illegal refineries dotted across the Niger Delta region (Onukwe, 2022); with all these creating the same environmental problems in the region.

The cassava plant (Manhot esculenta Crantz) is an important staple food that cuts across the Niger Delta region and indeed the country, very necessary for food security in Nigeria. Therefore, any adverse activity that leads to its contamination like that of petroleum illegal refineries, threatens the food security of the entire nation. Hence, the need to study and analyze the effect of crude oil hydrocarbon contamination of cassava emanating from the activities of these illegal refineries in the Niger Delta region.

The main aim of the study is to investigate, assess and evaluate the concentrations of pollutants arising from illegal petroleum refining in Cassava plant (tuber, stem and leaves); being a staple food that cuts across the region, in two deactivated illegal refinery sites within two oil producing communities in Rivers State of the Niger Delta, with its objectives being to investigate and determine the extent of Polycyclic Aromatic Hydrocarbons (PAHs), Benzene, Toluene, Ethylbenzene and Xylene (BTEX) hydrocarbon and Total Hydrocarbon Content (THC) contaminants in cassava plant (tuber, stem and leaves) from the two sites of illegal refinery compared with a control

The results are expected to create an awareness of the implications of illegal refinery activities on cassava produce and subsequent food insecurity in the region.

Literature Review

As a result of activities of illegal refineries that is being carried out by the breaking and vandalization of crude oil facilities in order to steal petroleum crude oil, oil spillages occur that drastically affect the farmlands and vegetation and more often than not results to fire outbreak with its attendant burning and scotching the vegetation and immediate mangrove environment.

Asimiea and Omokhua, (2013) posited that several other authors reported that living things in the mangrove forest including animals and plants are destroyed as a result of several years of oil spillages experienced in the region with the oil entrapped in the sediments and land requiring several years to naturally recover and restore itself to its original form. This natural process and phenomena of recovery is referred to as attenuation. Cartwright and Atampugre, (2020) reported that due to the oil spillages that occurred in one of the oil producing communities, Bodo city in 2008/2009 that there was a loss of about 1000ha of the mangrove forest belonging to the community and that it is estimated that it will require about 25-30years for the recovery and regeneration of the ecosystem, the remediation work being carried out notwithstanding. Nwaejile et. al, (2017) also reported that the hydrocarbon components in the oil spillage like polycyclic aromatic hydrocarbon (PAH) pollute the soil which results in the loss of quantity and quality of farm products due to loss of soil quality, leaching , erosion and general degradation of the environment, thus; affecting food security and the general wellbeing of the residents as the quality of land is an import characteristic requirement which is needed to maintain the essential land quality for vital sustainable soil and vegetation management. Therefore soil quality is seen in its capability of good quantity and quality of agricultural products including crops when not polluted by petroleum hydrocarbons in the soil which has been associated with essential mineral element depletion in agricultural lands. Egbeja et al, (2019), Funtua et al, (2016) and Opaluwa et al, (2012) all reported that heavy metals naturally occur in soils at varying concentrations but their values tend to be increased by anthropogenic activities like crude oil drilling and illegal refining activities and these pollutants are non-biodegradable and Chiroma et al, (2014), Hector et al (2011) also reported that only heavy metals in soluble form, chelates, exchangeable and in combined states in soil are mobile and required by plants and that bio-accumulation of these heavy metals in plants is a source of transfer into the human food chain when ingested. Although some of these metals like Iron (Fe), Calcium (Ca), and Zinc (Zn) are useful in human metabolic processes at the right concentration and combinations but could be toxic if higher quantities are bio-accumulated by plants and ingested when found within the operational areas of illegal refineries.

The toxic nature of Total Hydrocarbon Content (THC) found in petroleum crude oil has been confirmed of altering the soil chemical characteristics with its attendant effects on farm lands (Yabrade and Tanee, 2016), also crude oil spills decrease land quality leading to low crop yield and financial gain from the sale of their crop due to low yield and further postulated that the annual income of farmers may drop by 5% with a corresponding increase of 10% oil spill leading to 1.3% of reduction in total crop yield (Odjuvwuederhie et al, 2006). This position was supported by Elum et al, (2016) who reported that farmers earnings from agricultural activities in farm lands polluted by hydrocarbons were remarkably less when compared with those that farmed on areas that were not polluted. It was also concluded that childhood malnutrition arise as a result of about 60% reduction in food security which was attributed to spillages from oil and a 36% reduction in ascorbic acid content in vegetables with a corresponding 40% in cassava protein. This is as a result of the contamination of the soil and making the farm land unproductive (Ordinioha and Brisibe, 2013).

Hewelke et al, (2018) and Wei et al, (2020) all reported also that crude oil reduces the ability of soil to retain water by causing the soil to repel water with their pores blocked thereby restricting the flow and motion of water in the soil and Dong et al (2020); Marinescu et al, (2011) and Zhao et al, (2020) also confirmed that the biological, chemical and physical characteristics and properties of soil are being significantly affected by petroleum crude oil. Pathak and Mandalia, (2012) reported of salts associated with drilling fluids during crude oil drilling being absorbed in the soil which affects the physical properties of the soil negatively, thereby negatively affecting general growth of the plant in the oil spill environment.

The toxic compounds or components like Polycyclic Aromatic Hydrocarbons (PAHS) which occur predominantly in petroleum crude oil and main pollutants stabilize within 48hours to 400days for naphthalene and fluoranthene respectively when exposed to the environment (Omozue, 2021) and the PAHs cannot be degraded easily whenever there is an oil spillage, remain in the soil and sediments for a long time with their capability of being also bio-accumulated in tissues of living organisms.

Materials and Methods

Area of Study

The study was carried out in Rivers State in the Niger Delta region which is bounded by the Atlantic Ocean with swampy mangrove terrain. This difficult terrain contributes to the entire area being difficult to police thereby creating an easy avenue for criminals to vandalize crude oil pipes and facilities to steal crude oil for illegal refinery activities.

The two illegal refinery sites being investigated are located in Oshika Community (Site A) and Egbalor Community (Site B) in Eleme all in Rivers State with their coordinates as latitude 5.04 North, longitude 6.51East and latitude 4°46" North, longitude 7°09" East respectively.

Experimental Research

Cassava (leaves, stem and tuber) Sample Preparation

The cassava tuber, stem and leaves from both the polluted site and control were cut and 10grms of the various samples were each put into different 250ml conical flask, digested and chemical elements extracted. Their various solutions were analyzed according to APHA 3111B test method with AAS.

The Agilent 6890N Gas Chromatograph – Flame Ionization Detector (GC-FID) equipment was used for the process for the determination of various hydrocarbon compounds in the prepared

Sample after separation. The various quantities of BTEX were determined at a particular chromatogram in mg/kg for sample. The same procedure was used to resolve THC and PAH in all the various samples from the sites. The various means and standard deviations were separated with the aid of The Duncan's New Multiple Range (DNMR) Test ($p \leq 0.05$).

Results and Discussion

Plant Concentration Factor

This is also referred to as Transfer Factor or ratio and involves the ratio of concentration of metals that is found in the plant to the value of the metal concentration in the soil the plant is grown. Osakwe et al, (2015) in their study stated that heavy metals in plants grown on polluted soil are transferred and accumulated to other parts of the plant by uptake of these metal ions, the equation used in their study was adopted for this study as in Equation 1:

$$\mathrm{PCF} = \frac{\mathrm{C\ plant}}{\mathrm{C\ soil}} \quad (1)$$

Where:

PCF is the plant transfer factor.

C plant; is the metal concentrations in plant.

C soil; is the metal concentrations in soil

Results from cassava plant (tuber, stem and leaf) analysis for Sites A and B with control are shown in Table 1 (Appendix 1).

Table 1 shows that all the heavy metals being investigated were present in the cassava plant comprising the tuber, stem and leaves. Ni has the highest mean values of 13.52±0.01 mg/kg for tuber only while as mean value is next with 9.27±0.04 mg/kg for tuber. Although as has the highest mean value in stem and leaves with 8.76±0.02 mg/kg, 7.62±0.06 mg/kg respectively and Ni with 5.09±0.01 mg/kg and 3.38±0.17 mg/kg for stem and leaves respectively for Site A, however, for the purpose of this research, attention is given to mostly tuber as it is the plant's part mostly used for food. This assumption agrees with other researchers; Harrison et al, (2018); Mbong et al, (2014); Apau et al, (2014) and Harmanescu et al, (2011) that stated that contaminants in soil go into the food chain through tubers and vegetables as a result of plant's ability to bio-accumulate and take up these contaminants which may be toxic and impacting negatively on human health. Other heavy metals indicated in table 4.1 are Cd, Pb, Zn, Cr, Cu and Co with mean values of 6.44±0.23 mg/km, 5.31±0.17 mg/kg, 5.3±0.17 mg/kg, 5.25±0.02 mg/kg, 4.17±0.06 mg/kg and 3.96±0.02 mg/kg respectively for site A in cassava tubers. While table 4.2 for Site B showed Arsenic with the highest mean value of 1.83±0.02 mg/kg in the tuber with 1.63±0.10 mg/kg and 1.32±0.01 mg/kg for stem and leaves respectively. Others are Cr, Pb, Ni, Cd, Co, Cu and Zn with mean values 0.167±0.03 mg/kg, 0.15±0.03 mg/kg, 0.113±0.01 mg/kg, 0.107±0.06 mg/kg, 0.082±0.05 mg/kg, 0.079±0.04 mg/kg and 0.063±0.02 mg/kg. Generally, it could be observed from this study that the heavy metal concentration decreases from tuber to leaves in the order tuber > stem > leaves which indicates that cassava tuber accumulates more than the order parts of the plant. This also agrees with Lichtfouse and Robert, (2014) that reported in their studies that plant accumulate more in tubers than in leaves. However, Aladesanmi et al, (2019) stated that the degree of accumulation of heavy metals in plants is depended on soil texture, cation exchange capacity, plant root flow, pH of soil and the chemical forms of the heavy metals and therefore may affect the general translocation of the metals.

Benzene, Toluene, Ethylbenzene and Xylene (BTEX) Content

Table 1 shows that in site A, Benzene is present in the cassava tuber and stem with mean concentration values of 2.55±0.02 mg/l and 0.73±0.42 mg/l but none in the leaf, while M-Xylene was only detected in the tuber only with a mean value of 1.63±9.36 mg/l. Toluene, Ethylbenzene and Xylene were not detected in the plant. Meanwhile, in site B, Benzene and Ethylbenzene were detected in the tuber with their respective mean concentration values of 1.65±0.35 mg/l and 0.55±0.29 mg/l and none was detected in both stem and leaf. BTEX was not found in the control except only Ethyl benzene found in control tuber (which is within the acceptable WHO standard range) and all the mean values detected on both sites are higher than the WHO permissible values. Studies carried out by Bond et al, (1986); Schnatter et al, (2012); Lan et al, (2012) and Mckenzie et al, (2012) have linked Benzene and Ethylbenzene as cancer causing chemical compounds especially to leukemia and hematopoietic illness, while Toluene and Xylene are not carcinogenic but have been linked to headache, dizziness, vertigo, breathing problems, damage to liver, kidney and heart failure. BTEX produce reproductive adverse effects on chronic exposure at low and high concentrations. Therefore if the cassava tuber from these illegal refinery sites are ingested, it could serious adverse effect on the wellbeing of the community.

Plant Concentration Factor (Transfer Factor)

Table 2 shows the results of the plant concentration factor using Equation (1).

Table 2. Plant Concentration Factor for Cassava plant at sites A and B

Oshika (Site A)					Egbalor (Site B)			
Metal	*Metal Conc. (mg/kg)	Tuber	Stem	Leaf	Metal Conc. (mg/kg)	Tuber	Stem	Leaf
Pb	56.48±0.01	0.094	0.065	0.050	24.23±0.02	0.006	0.003	0.002
Cd	53.49±0.00	0.120	0.095	0.105	17.70±0.01	0.006	0.002	0.001
Cr	46.79±0.12	0.112	0.100	0.084	15.31±0.02	0.011	0.007	0.001
As	84.75±0.01	0.109	0.102	0.090	41.00±0.02	0.045	0.040	0.032
Zn	39.44±9.01	0.134	0.097	0.114	12.77±0.02	0.005	0.002	0.004
Cu	35.46±0.00	0.118	0.084	0.105	9.30±0.00	0.008	0.009	0.004
Ni	66.61±0.03	0.203	0.076	0.051	28.15±0.02	0.004	0.003	0.001
Co	40.66±0.00	0.097	0.065	0.091	8.37±0.12	0.010	0.006	0.011

Note: *Adopted from Achadu et al., 2023

The plant concentration factor is also referred to as transfer factor, which involves the transfer of the metals in its ion or chelate form from the soil to the plant and determined by the ratio of metal concentration in plant to the total metal concentration in soil where the plant is grown. Ni and Zn have the highest plant concentration factor for cassava tuber in site A at values 0.203 and 0.134 while Ar and Cr recorded the highest in site B at 0.045 and 0.011 respectively. Although the plant concentration factor seems lower than that recorded by Sor et al, (2020) , it is an indication that the heavy metals in the crude oil in the soil on both sites of study accumulated in the cassava plant especially the tuber and may impact negatively when its products are ingested as food by the populates

The results of Polycyclic Aromatic Hydrocarbon contaminants in cassava plant from the two sites and control are shown in table 3 (Appendix 1).

Table 3 shows the presence of PAHs in cassava tuber, stem and leaves across the two sites and control with site A having a higher concentration of PAHs. The predominant PAH detected across all samples is Acenaphthene, followed by Naphthalene, Phenanthrene. Fluoranthene and Pyrene were only found in Site A, while Acenaphthylene and Anthracene were detected in the cassava tubers of Sites A and B respectively. The total PAHs present in the various parts of the cassava plant are found to be 47.14 mg/l, 30.65 mg/l and 7.69 mg/l for the tuber in Sites A, B and control respectively, while the stem is 9.66 mg/l, 2.75 mg/l and 2.69 mg/l. The leaves contain a total of 1.45 mg/l, 1.52 mg/l and 0.67 mg/l. It is significant to note that there were no carcinogenic PAHs found in the cassava plants analyzed. The presence of PAHs are consistent with the activities of petroleum crude oil exploitation and production carried out in the Niger Delta and more especially the activities of illegal refineries.

Cancer Illinois Resources (2022) has reported that carcinogenic PAHs, on long exposure to humans have been implicated to causing cataracts, kidney and liver damage, jaundice and breakdown of red blood cells. Long exposure to PAHs may lead to impaired lung functions in asthmatics and thrombotic effects in people affected by coronary heart diseases (KI-Hyun et al, 2013).

The result of the Total Hydrocarbon Content in the cassava plant from the two sites and control are as shown in Table 4 (Appendix 1).

This is usually used to ascertain the quantity of hydrocarbon contaminants and are known to adversely affect plant growth. Table 4.4 shows the amount of hydrocarbon detected from the plant across the study sites and control. The

THC values for Site A are 730.2 mg/l, 20.27 mg/l and 4.79 mg/l for tuber, stem and leaf respectively, while 113.22 mg/l, 6.11 mg/l and 1.6 mg/l in tuber, stem and leaf respectively for Site B. The control values were 7.12 mg/l, 3.10 mg/l and 0.24 mg/l for tuber, stem and leaves respectively. Physical observation showed that the tubers from the study sites were very small in size compared to the control even though they were planted the same period. This observation agrees with Rahbor et al, (2013) who stated that the presence of toxic petroleum hydrocarbons in soils have been known to cause negative effects on plants' development, growth and reduction of carbohydrates in roots which is attributed to reduction of water and decrease in photosynthesis. Soil properties are being altered by the presence of petroleum hydrocarbons to develop hydrophobic behaviours, thereby leading to decrease in water and nutrients availability for the plants and subsequently reduction in its carbohydrates in tubers as a probable means to protect the plant against dehydration and hydrocarbon accumulation (Baker, 1970, Bossert and Bartha, 1985).

Conclusion

The result from this study shows that the studied sites were contaminated from the activities of illegal refineries for the cassava plant with some accumulation of both heavy metals and petroleum hydrocarbons which are detrimental to the human wellbeing when ingested. There is need therefore to enlighten the perpetrators of these illegal refineries, the community and government of the inherent danger and to discourage its proliferation in the Niger Delta region.

Ethical Approval

Approved

Acknowledgement

None

Source of Funding

None

Conflict of Interest

The authors declare no conflict of interest.

References

Achadu, M.A., Dimkpa, I.H. & Dimkpa, C.A. (2023). Evaluation of heavy metal contamination of soil from petroleum crude oil at an illegal refinery site: A case study of Oshika community in the Niger Delta region of Nigeria. *Nigerian Research Journal of Engineering and Environmental Sciences,* *8*(2), 17-24. http://dx.doi.org/10.35182/tses-2019-0008

Aladesanmi, O. T., Oroboade, J. G., Osisiogu, C. P., & Osewole, A. O. (2019). Bioaccumulation Factor of Selected Heavy Metals in Zea mays. *Journal of health & pollution*, *9*(24), 191207. https://doi.org/10.5696/2156-9614-9.24.191207

Apau, J., Acheampong, A., Appiah, J.A. & Ansong, E. (2014). Levels and health risk assessment of heavy metals in tubers from markets in the Kumasi metropolis, Ghana. *International Journal of Science & Technologies, 3*(9), 534–539.

Aminayanaba, A. & Omokhua, G. (2013). Environmental Impact of illegal refineries on the vegetation of the Niger Delta, Nigeria. *Journal of Agriculture and Social Research, 13*(2).

Baker, J.M. (1970). The effects of oils on plants. *Environmental Pollution,* *1*, 27-44. https://doi.org/10.1016/0013-9327(70)90004-2

Bond, G. G., McLaren, E. A., Baldwin, C. L., & Cook, R. R. (1986). An update of mortality among chemical workers exposed to benzene. *British journal of industrial medicine*, *43*(10), 685–691. https://doi.org/10.1136/oem.43.10.685

Bossert, L. & Bartha, R, (1985). Plant growth on soils with a history of oil sludge disposal. *Soil Science, 140*(1), 75-77.

Cartwright, R. & Atampugre, N. (2020). *Organized oil crime in Nigeria; the Delta paradox: organized criminals or community saviours.* Enhancing Africa's response to transnational organized crime (enact), 21.

Chiroma, T.M., Ebewele, R.O. & Hymore, F.K. (2014). The Accumulation of heavy metals in edible crobs is a direct pathway way for their incorporation into human food chain as heavy metals are absorbed from soil, air and water. *International Referred Journal of Engineering and Sciences (IRJES), 3*(2), 01-09.

Dong, Z.L., Wang, B.S., & Li, J. (2020) Effects of petroleum hydrocarbon contamination on soil bacterial diversity in the permafrost region of the Qinghai-Tibetan Plateau. *Soil and Sedim Contamination: An International Journal, 29*(3), 322–339. https://doi.org/10.1080/15320383.2019.1710109

Egbeja, I., Kadiri, J., Onoja, A., & Isah, O. (2019). Determination of heavy metals in water, sediments and tissues of Clarias garipienus and Oreochromis niloticus from Kpata River, Lokoja, Nigeria. *International Journal of Fisheries and Aquatic Studies,* 7(5), 25-29. https://doi.org/10.6084/m9.figshare.9778040.v1

Elum, Z. A., Mopipi, K., & Henri-Ukoha, A. (2016). Oil exploitation and its socioeconomic effects on the Niger Delta region of Nigeria. *Environmental science and pollution research international*, *23*(13), 12880–12889. https://doi.org/10.1007/s11356-016-6864-1

Funtua, M.A., Dailami, S.A., & Onakpa, S.A. (2016). Heavy metal contents of Water, Sediment and Fish from Kpata river Lokoja, Kogi State-Nigeria. *International Journal of Environmental Science and Toxicology Research, 4*(9), 162-168.

Harrison, U.E., Osu, S.R. & Ekanem, J. (2018). Heavy metals accumulation in leaves and tubers of cassava (Manihot esculenta Crantz) grown in crude oil contaminated soil at Ikot Ada Udo, Nigeria. *Journal of Applied Sciences and Environmental Management, 22,* 845. https://doi.org/10.4314/jasem.v22i6.1

Harmanescu, M., Alda, L. M., Bordean, D. M., Gogoasa, I., & Gergen, I. (2011). Heavy metals health risk assessment for population via consumption of vegetables grown in old mining area; a case study: Banat County, Romania. *Chemistry Central journal*, *5*, 64. https://doi.org/10.1186/1752-153X-5-64

Hector, M., Oscar, R.M.V, Enrique, M.S, Ma-Del, C.O.B & Ana, L.B.O. (2011). Heavy metals in agricultural soils and irrigation waste water of Maxquiahinla, Hidalgo, Mexico. *African journal of Agricultural Research, 6*(24), 5505-5511.

Hewelke, E., Szatyłowicz, J., Hewelke, P., Gnatowski, T., & Aghalarov, R. (2018). The Impact of Diesel Oil Pollution on the Hydrophobicity and CO_2 Efflux of Forest Soils. *Water, air, and soil pollution*, *229*(2), 51. https://doi.org/10.1007/s11270-018-3720-6

Ki-Hyun, K., Shamin, A.J., Ehsanul, K., & Brown, R.J.C. (2013). A Review of airborne Polycyclic Aromatic Hydrocarbons (PAHs) and their human health effects. *Environment International, 60,* 71-80. http://dx.doi.org/10.101016/j.envnt.2013.07.019

Kuch, S.G., & Bavumiragira, J.P. (2019). Impacts of crude oil exploration and production on environment and its implications on human health: South Sudan Review. *International Journal of Scientific and Research Publications (IJSRP)*, 9(4), 8836. https://doi.org/10.29322/IJSRP.9.04.2019.P8836

Lan, T. T., & Binh, N. T. (2012). Daily roadside BTEX concentrations in East Asia measured by the Lanwatsu, Radiello and Ultra I SKS passive samplers. *The Science of the total environment*, *441*, 248–257. https://doi.org/10.1016/j.scitotenv.2012.08.086

Lichtfouse, E.J.S. & Robert, D. (2014). *Pollutant Diseases, Remediation and Recycling. Environmental Chemistry for a Sustainable World.* Springer International Publishing Switzerland. https://doi.org/10.1007/978-3-319-02387-8_1

Marinescu, M., Toti, M., Tanase, V., Plopeanu, G.I., Calciu, I., & Marinescu, M. (2011). The effects of crude oil pollution on physical and chemical characteristics of soil. *Research Journal of Agricultural Science, 43*, 125-129.

Mbong, E.O., Akpan, E.E. & Osu, S.R. (2014). Soil-plant heavy metal relations and transfer factor index of habitats densely distributed with Citrus reticulate (tangerine). *Journal of Research Environmental Science and Toxicology, 3*(4), 66–65. http://dx.doi.org/10.14303/jrest.2014.014

McKenzie, L. M., Witter, R. Z., Newman, L. S., & Adgate, J. L. (2012). Human health risk assessment of air emissions from development of unconventional natural gas resources. *The Science of the total environment*, *424*, 79–87. https://doi.org/10.1016/j.scitotenv.2012.02.018

Nwaejije, E.C., Hamidu, I., & Obiosio, E.O.(2017). Early to middle miocenesequence stratigraphy of well-5 (OML 34), Niger Delta, Nigeria. *Journal of African Earth Science, 129*, 519-526. https://doi.org/10.1016/j.jafrearsci.2017.01.026

Odjuvwuederhie, E.L, Douglason, G. & Felicia, N.A. (2006). The effect of oil spillage on crop yield and farm income in Delta State, Nigeria. *Journal of Central European Agriculture, 7*(1), 41-48.

Okumagbo, E.O. (2019). Oil and Gas Pipeline "Vandalism" in Nigeria: Analyzing Alternative Options beyond the Traditional Legal Approach. *International Energy Law Review, 7,* 184.

Olawuyi, D.S. (2015). *The Principles of Nigerian Environmental Law.* Afe Babalola University Press.

Omozue, M. (2021). The destruction of illegal refineries on the Niger Delta environment; An appraisal. *Law and Social Justice Review (LASJURE), 2*(2).

Onukwe, A. (2022). *Nigeria's illegal oil refineries keep killing people.* Quartz Africa.

Opaluwa, O. D., Aremu, M. O., Logbo, L., Imagaji, J., & EOdiba, I. (2012). Assessment of Heavy Metals in Water, Fish and Sediments from UKE Stream, Nasarawa State, Nigeria. Current World Environment, 7, 213-220. https://doi.org/10.12944/CWE.7.2.04

Ordinioha, B., & Brisibe, S. (2013). The human health implications of crude oil spills in the Niger delta, Nigeria: An interpretation of published studies. *Nigerian medical journal : journal of the Nigeria Medical Association*, *54*(1), 10–16. https://doi.org/10.4103/0300-1652.108887

Osakwe, S. A., & Okolie, L. P. (2015). Physicochemical Characteristics and Heavy Metals Contents in Soils and Cassava Plants from Farmlands along a Major Highway in Delta State, Nigeria. Journal of Applied Science and Environmental Management, 19, 695-704. https://doi.org/10.4314/jasem.v19i4.18

Oyewole, S., Adegboye, D. & Durosinmi, S. (2018). Militarisation of Oil and Environmental Politics in Nigeria: Armed Resistance, State Responses and Peace Prospects in the Niger Delta Region. *Covenant University Journal, 6.*

Pathak, C. & Mandalia, H.C. (2012). Petroleum industries: environmental pollution effects, management and treatment methods. *International Journal of Environmental Science, 1*(1), 2163–3851.

Rahbar, F.G., Kiarostami, K. and Shirdam, R. (2012) Effects of Petroleum Hydrocarbons on Growth, Photosynthetic Pigments and Carbohydrate Levels of Sunflower. *Journal of Food, Agriculture and Environment, 10,* 773-776.

Schnatter, A. R., Glass, D. C., Tang, G., Irons, R. D., & Rushton, L. (2012). Myelodysplastic syndrome and benzene exposure among petroleum workers: an international pooled analysis. *Journal of the National Cancer Institute*, *104*(22), 1724–1737. https://doi.org/10.1093/jnci/djs411

Sor, A.L, Edori, O. S., Nwineewii, J. D. (2020). *Concentrations of Heavy Metals in Farmland Soils from selected Oil Bearing Communities in Gokana, Rivers State, Nigeria.*

Tomlinson, D.L., Wilson, J.G., Harris, C.R. and Jeffrey, D.W. (1980) Problems in the Assessment of Heavy-Metal Levels in Estuaries and the Formation of a Pollution Index. *Helgoländer Meeresuntersuchungen, 33,* 566-575. http://dx.doi.org/10.1007/BF02414780

USEPA. (2013). Regulatory Standards for Polycyclic Aromatic Hydrocarbons (PAH) in water, fish and plants.

Wei, Z., Wang, J. J., Gaston, L. A., Li, J., Fultz, L. M., DeLaune, R. D., & Dodla, S. K. (2020). Remediation of crude oil-contaminated coastal marsh soil: Integrated effect of biochar, rhamnolipid biosurfactant and nitrogen application. *Journal of hazardous materials*, *396*, 122595. https://doi.org/10.1016/j.jhazmat.2020.122595

WHO. (1996). Permissible limits of heavy metals in soil and plants. Geneva: World Health Organization, Switzerland.

Yabrade, M., & Tanee, F.B. (2016). Assessing the Impact of Artisanal Petroleum Refining on Vegetation and Soil Quality: A Case Study of Warri South West Salt Wetland of Delta State, Nigeria. *Research Journal of Environmental Toxicology,* *10*, 205-212. https://doi.org/10.3923/RJET.2016.205.212

Zhao, Y., Chen, W., & Wen, D. (2020). The effects of crude oil on microbial nitrogen cycling in coastal sediments. *Environment international*, *139*, 105724. https://doi.org/10.1016/j.envint.2020.105724

Appendix 1

Table 1. Heavy Metals and BTEX: Result of Cassava analysis for Sites A and B

Heavy Metal Content										
Heavy Metals (mg/kg)	Site A			Site B			Control			WHO
	Tuber	Stem	Leaf	Tuber	Stem	Leaf	Tuber	Stem	Leaf	Standard
Pb	5.31 ± 0.17^{b}	3.66 ± 0.03^{b}	2.8 ± 0.06^{b}	0.15 ± 0.03^{a}	0.071 ± 0.04^{a}	0.05 ± 0.01^{a}	0.096 ± 0.01^{a}	0.065 ± 0.02^{a}	0.07 ± 0.01^{a}	2
Cd	6.44 ± 0.23^{a}	5.08 ± 0.05^{a}	5.61 ± 0.17^{a}	0.107 ± 0.06^{a}	0.033 ± 0.02^{a}	0.022 ± 0.001^{a}	0.083 ± 0.01^{a}	0.042 ± 0.02^{a}	0.032 ± 0.02^{a}	0.02
Cr	5.25 ± 0.02^{a}	4.7 ± 0.12^{a}	4.51 ± 0.12^{a}	0.167 ± 0.03^{a}	0.102 ± 0.06^{a}	0.017 ± 0.001^{a}	0.125 ± 0.01^{a}	0.21 ± 0.12^{a}	0.019 ± 0.01^{a}	1.3
As	9.27 ± 0.04^{a}	8.76 ± 0.02^{a}	7.62 ± 0.06^{a}	1.83 ± 0.02^{a}	1.63 ± 0.10^{a}	1.32 ± 0.01^{a}	0.03 ± 0.02^{a}	0.01 ± 0.06^{a}	0.01 ± 0.02^{a}	0.2
Zn	5.3 ± 0.17^{b}	3.82 ± 0.01^{b}	4.5 ± 0.06^{b}	0.063 ± 0.02^{a}	0.025 ± 0.01^{a}	0.05 ± 0.01^{a}	0.052 ± 0.03^{a}	0.345 ± 0.02^{a}	0.15 ± 0.04^{a}	0.6
Cu	4.17 ± 0.06^{b}	2.98 ± 0.32^{b}	3.72 ± 0.01^{b}	0.079 ± 0.04^{a}	0.081 ± 0.01^{a}	0.041 ± 0.02^{a}	0.053 ± 0.02^{a}	0.046 ± 0.02^{a}	0.048 ± 0.02^{a}	10
Ni	13.52 ± 0.01^{b}	5.09 ± 0.01^{b}	3.38 ± 0.17^{b}	0.113 ± 0.01^{a}	0.09 ± 0.01^{a}	0.04 ± 0.01^{a}	0.024 ± 0.01^{a}	0.05 ± 0.01^{a}	0.054 ± 0.01^{a}	10
Co	3.96 ± 0.02^{b}	2.64 ± 0.02^{b}	3.72 ± 0.01^{b}	0.082 ± 0.05^{a}	0.052 ± 0.02^{a}	0.09 ± 0.01^{a}	0.041 ± 0.02^{a}	0.063 ± 0.1^{a}	0.61 ± 0.12^{a}	0.1
Hydrocarbon Content: Benzene, Toluene, Ethylbenzene and Xylene (BTEX) (mg/l)										
	Tuber	Stem	Leaf	Tuber	Stem	leaf	Tuber	Stem	Leaf	Standard
Benzene	2.55 ± 0.02^{a}	0.73±0.42a	-	1.65±0.35a	-	-	-	-	-	0.1 – 0.3
Toluene	-	-	-	-	-	-	-	-	-	0.18 – 0,6
O-Xylene	-	-	-	-	-	-	-	-	-	0.1 – 0.3
M-Xylene	1.63 ± 9.36^{a}	-	-	-	-	-	-	-	-	0.1 – 0.3
P-Xylene	-	-	-	-	-	-	-	-	-	0.1 - 0.3
Ethyl benzene	-	-	-	0.55±0.29 a	-	-	0.15±0.20 a	-	-	0.1 – 0.3

Note: Values represent Mean ± S.E.M at n= 3 and p≤ 0.05. means in the same row with the same superscript alphabets are not significantly different, while means in the same Row with different superscript alphabets are significantly different at p ≤ 0.05

Table 3. PAHs: Result of Cassava analysis for Site A and B

Polycyclic Aromatic Hydrocarbon (PAH) (mg/l)										
Hydrocarbon	Site A			Site B			Control			
	Tuber	Stem	Leaf	Tuber	Stem	Leaf	Tuber	Stem	Leaf	Standard*
Naphthalene	3.25±0.12[a]	2.25±0.14[a]	0.14±0.08[a]	12.53±0.00[b]	1.25±0.14a	0.47±0.17[a]	1.94±0.03[b]	1.02±0.0[b]	0.22±0.00[b]	
Acenaphthylene	8.63±0.02[a]	-	-	-	-	-	-	-	-	
Acenaphthene	15.85±0.02[a]	1.54±0.03[b]	0.04±0.02[b]	8.16±0.09[a]	-	0.93±0.02[b]	3.24±0.02[b]	0.54±0.01[b]	0.31±0.03[b]	
Fluorene	-	-	-	-	-	-	-	-	-	
Phenanthrene	4.42±0.23[a]	-	-	6.21±0.01[a]	1.50±0.28a	0.12±0.07[b]	2.51±0.03[b]	1.11±0.06[b]	0.14±0.01[b]	
Anthracene	-	-	-	3.94±0.03	-	-	-			
Fluoranthene	5.05±0.02[a]	5.88±0.04[a]	1.27±0.15[a]	-	-	-	-			
Pyrene	9.95±0.02[a]	-	-	-	-	-	-			
Benzo(g,h,i)perylene	-	-	-	-	-	-				
Benz(a)anthracene	-	--	-	-	-	-				0.1mg/l
Chrysene	-	-	-	-	-	-				0.2mg/l
Benzo(b)fluoranthene	-	-	-	-	-	-				0.2mg/l
Benzo(k)fluoranthene	-	--	-	-	-	-				0.2mg/l
Benzo(a)pyrene	-	-	-	-	-	-				0.2mg/l
Indeno(1,2,30cd)pyrene	-	--	-	-	-	-				0.4mg/l
Dibenz(a,h) anthracene	-	-	-	-	-	-				0.3mg/l
TOTAL	47.14	9.66	1.45	30.65	2.75	1.52	7.69	2.69	0.67	
Σ Carcinogenic PAHS	0	0	0	0	0	0	0	0	0	
% Carcinogenic	0	0	0	0	0	0	0	0	0	

Note: Values represent Mean ± S.E.M at n= 3 and $p \leq 0.05$. means in the same row with the same superscript alphabets are not significantly different, while means in the same row with different superscript alphabets are significantly different at $p \leq 0.05$

*USEPA Regulatory Standards for Polycyclic Aromatic Hydrocarbons (PAH) in water, fish and plants

Table 4. THC: Result of Cassava analysis for Site A and B

Total Hydrocarbon Content (THC) (mg/l)									
Parameter	Site A			Site B			Control		
	Tuber	Stem	Leave	Tuber	Stem	Leave	Tuber	Stem	Leave
C8	-	-	-	-	-	-	-	-	-
C9	-	-	1.68±0.06[a]	-	-	-	7.12±0.13[d]	-	-
C10	138.5±0.17[a]	9.49±0.28[b]	1.3±0.17[c]	37.74±0.13[d]	-	0.16±0.01[e]			
C11	-	-	-	-	2.83±0.01[a]	-		3.10±0.10[a]	
C12	-	-	-	-	-	-			
C13	-	-	-	-	-	-			
C14	-	-	0.68±0.12[a]	-	-	-			0.24±0.13[c]
C15	194.46±0.27[a]	7.140.02[b]	-	13.67±0.18[b]	-	0.1±0.00[c]			
C16	-	-	-	-	-	-			
PRISTON	-	-	-	-	-	-			
C17	-	-	-	-	-	-			
C18	113.14±0.08[a]	-	-	-	-	-			
Ph	226.91±0.01[a]	-	-	19.02±0.01[b]	3.29±0.12[c]	-			
C19	-	-	1.13±0.08[a]	-	-	-			
C20	57.19±0.11[a]	3.64±0.12[b]	-	42.79±0.12[a]	-	1.34±0.02[b]			
C21			-	-		-			
C22			-	-		-			
C23			-	-		-			
C24			-	-		-			
C25			-	-		-			
C26				-					
C27									
C28									
C29									
C30									
T0TAL	730.2	20.27	4.79	113.22	6.11	1.6	7.12	3.10	0.24