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Blood Plasma Concentration of Heavy Metals in Under Five Children in Niger Delta, Nigeria

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Abstract

Environmental stressors such as pollution are major sources of heavy metal toxicity in humans. Biomonitoring studies are necessary for quantifying the body burden of these metals (As, Cd, Cr, Pb, Hg) of toxicological concern and their health effects especially for communities consistently exposed to crude oil pollution. This study investigated the level of heavy metals in the blood plasma of under-five children living in crude oil-polluted and non-crude oil-polluted environments in the Niger Delta, Nigeria. This cross-sectional study was conducted in 3 crude oil polluted communities in Gokana, Rivers State (B. Derek, K. Dere, Bomu) and 3 non-crude oil exploration communities in Ideato North LGA of Imo State (Umukegwu, Umuezeaga, Owerre-Akokwa) assigned as control; both States are in Niger Delta region of Nigeria. Ethical approval was obtained from the University of Port Harcourt Ethical Committee. A total of 78 children were recruited from Gokana (male =17, female= 22) and Ideato (Male=15, female=24) using multi-clustered sampling method. Standard methods of heavy metal analysis using atomic absorption spectrophotometer were used to analyze the samples. From the results, the concentration of Cr and Cd in the blood plasma of Gokana male was 2.81mg/kg and 3.19mg/kg while Ideato male was 0.497mg/kg of Cr and Cd was not detected. Gokana female was 1.22mg/kg for Cr and 0.92mg/kg for Cd. It was concluded that under-5 children living in crude oil-polluted communities of the Niger Delta region of Nigeria have high positive levels of heavy metals (Cr, Cd and AS). Health effect of the exposures is advised considering the sensitivity of the study population.

Keywords: *Crude oil pollution, under-five children, Heavy metals, Niger Delta*

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Introduction

Pollution and unhealthy environment threaten children survival, health and wellbeing. Persistence abusive on the environment violates a child's right to health and well-being (UNICEF, 2021). According to Rzymski *et al.* (2015), more than one-third disease burden in under-five population is caused by modifiable environmental factors. Since 1956 when oil was first discovered in commercial quantity in the Niger delta, the survival of the terrestrial and aquatic habitants in the ecological system has been threatened with several episodes of oil pollution, (Chinedu and Chukwuemeka, 2018). Crude oil is a complex mixture of volatile liquid hydrocarbons containing series of metals such as Mo, Zn, Cd, U, Na, Ba, Ga, Si Al, Pb, Fe, Mg, Ti, Mn, Sn, As, Cu. , Cr, Co and Sb (Ruiz-Fernández *et al.*, 2019), and the mainstay of developing economies like Nigeria. Spillage of crude oil can result from some anthropogenic activities and inappropriate practices during crude oil exploration and production. According to Balise *et al.* (2016), the global insatiable need for the energy that is obtained from natural gas and crude oil is directly tied to the deterioration of the environment that is brought on by the use of fossil fuels. According to Zulqarnain *et al.* (2021), the need for energy derived from crude oil has led to a growth in the utilization of a variety of crude oil processing techniques, including conventional, unconventional, and even covert practices. In natural condition, heavy metals introduced to the environment through crude oil spillage, other anthropogenic and industrial related activities do not decompose, they bioaccumulate and bio-magnify posing great risk to the habitants. Heavy metals have usefulness in industrial operations for production of alloy, battery, smelting and other commercial products. By definition according to scientific literatures, heavy metals are classified as groups of elements having specific density more than 5g/cm^3 and atomic number >20 (Rzymski *et al*., 2015; Ali *et al*., 2019). Some of these metals have metabolic usefulness in the body at small quantity e.g. Zinc (Zn), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), Cu but are toxic to the body in higher concentration (Egbuna and Ifemeje, 2015; Rzymski *et al*., 2015). These essential metals are important constituents in enzymatic induced redox reactions, transport, biosynthesis and other intracellular processes in DNA binding domain (Akram *et al*., 2020; Haidar *et al*., 2015) whereas others obligatory toxic in the body at the smallest concentration e.g As, Cd, Hg, V pose deleterious effect in the body (Rzymski *et al*., 2015). These heavy metals are classified under group 1 carcinogens by International Agency Research on Cancer (IARC), disrupting tumour suppressing gene (Kim *et al*., 2015). As, Pb, Hg and Cd are endocrine disruptors, they interfere with glucose metabolism and other biochemical process (Haidar *et al*., 2015). As induces toxicity via oxidative stress, producing reactive oxygen species (ROS) and impair DNA repairs processes through methyl-transferase (Kim *et al*., 2015).

The accumulation of heavy metals that pose a risk to human health in soil can also transit, bio-magnifying and result in their bioaccumulation in crops. These can subsequently be transferred to other media through the food value chain. The documentation of the bio-concentration factor (BCF) of various heavy metals in the interface between crop and soil, with a particular focus on major global staple crops like wheat and maize, has been reported by Gupta *et al*. (2022). The presence of heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) poses a significant risk to human health and is a matter of considerable public health concern. Rzymski *et al.* (2015) reports that pb lead can induce spontaneous abortion due to its inherent teratogenic action. The studies also report that in developing organism of children, serum Pb (lead) in excess of (19.71mcg/l) causes impaired cognitive ability According to Gupta *et al*. (2022) & Taylor *et al*. (2015), the consumption of vegetables that are contaminated with heavy metals can result in severe health problems for humans, including gastrointestinal cancer, weakened immune systems, impaired mental development, and malnutrition. The consumption of metal-contaminated food crops is strongly associated with human health risks, as these metals can accumulate in the human body's bones or fatty tissues through dietary intake. This can result in the depletion of vital nutrients and a weakened immune system. It has been postulated that specific heavy metals such as Aluminium, Cadmium, Manganese, and Lead may contribute to the occurrence of intrauterine growth retardation, as suggested by Haidar *et al*. (2023).

The presence of lead has a negative impact on cognitive development, resulting in the manifestation of neurological and cardiovascular ailments in human beings, particularly in the case of minors (Zhou, 2016; Ramírez *et al*., 2021). Increased level of Pb was found in human serum of those living in industrial area, among smokers and alcohol abusers (Rzymski *et al*., 2015). The presence of heavy metals, specifically Pb and Cd, has been linked to various adverse health outcomes, including but not limited to carcinogenic effects, bone fractures and malformation, cardiovascular complications, kidney dysfunction, hypertension, and serious diseases affecting the liver, lung, nervous system, cognitive functioning, and immune system (Balali-Mood *et al*., 2021). According to Zhou *et al*. (2016), an overabundance of zinc can cause a disturbance in the concentration levels of high-density lipoproteins and can also disrupt the immune system. Additionally, Zou (2016) notes that excess zinc intake can lead to liver damage and gastric-related issues in both adults and young children who are still in the growing phase.

According to Rai *et al*. (2019), the ingestion of metals or metalloids through contaminated soil and food sources such as fruits, crops, and vegetables can result in the development of gastrointestinal cancer in children. The haematological system, hepatic system, renal system, gastrointestinal tract, pulmonary system, and peripheral and central nervous systems are the organ systems that are impacted by cadmium, lead, mercury, and arsenic, as reported by Tchounwou *et al.* (2012) and Balali-Mood *et al*. (2021). The consumption or inhalation of lead can lead to toxicity in various systems of children, including the brain, kidneys, and bone marrow (Rai *et al*., 2019). According to Ruben *et al*. (2017), there is a correlation between blood lead levels in infants and children and developmental issues. Even at levels as low as 5µg/dL, impaired cognitive function, behavioural disorders, impaired hearing, and stunted growth have been observed. Conversely, levels exceeding 75µg/dL have been linked to more severe consequences such as coma, convulsions, and mortality. The study conducted by Jaishankar and colleagues (2014) investigated the toxicity, mechanism, and health effects of certain heavy metals. The findings indicated that exposure to cadmium during pre- and postnatal stages may result in deficits in intelligence quotient, suggesting its potential neurotoxicity. Studies conducted on laboratory animals have demonstrated that developmental exposure has adverse effects on operant performance and conditioned avoidance. According to Jaishankar *et al*. (2014), there is evidence to suggest that cadmium has the ability to traverse the placental barrier and amass within the developing foetus, leading to the onset of neurodegenerative conditions.

The present study investigates the relationship between heavy metals and erythrocytes. Erythrocytes, also known as red blood cells (RBC), possess a highly deformable morphology that enables efficient gaseous exchange. In addition to their function in oxygen and carbon dioxide transportation, red blood cells also serve a regulatory role in the bioavailability of nitric oxide (NO) (Kuhn *et al.*, 2022). According to Anand & Gupta (2018), the production of erythrocytes and erythrocyte mass per kilogramme is restricted by iron deficiency. According to Sakamoto *et al.* (2021), red blood cells (RBCs) serve as the most reliable biomarker for measuring exposure to methylmercury (MeHg), given that approximately 90% of the total mercury (Hg) present in RBCs is in the form of MeHg. The clinical implications associated with exposure to mercury involve the potential for neurotoxic and nephrotoxic effects. Exposure to Hg has been found to elevate the risk of cardiovascular disease, owing to its close association with cardiovascular tissues. The endothelial cells have been identified as the primary target for the deleterious effects of heavy metals, as per the findings of Kuhn *et al*.

(2021). Methylmercury, which is the organic variant of mercury, exhibits a longer half-life and undergoes biomagnification within the aquatic food chain. Methylmercury is transported through the gastrointestinal tract (GIT) and across the blood-brain barrier (BBB) via active mechanisms (Takahashi *et al.*, 2017). The evaluation of human exposure to mercury can be accomplished through the assessment of total mercury (THg) concentration in serum (plasma) or urine as a biomarker. In populations exposed to high levels of MeHg through ingestion, particularly via fish consumption, and elemental mercury vapour exposure, plasma THg concentration may increase in response to demethylation (Sakamoto *et al*., 2021).

Statement of the Problem

The release of heavy metals into the environment is commonly attributed to both natural and industrial processes, as noted by Ogundele *et al.* (2017). Lead (Pb), cadmium (Cd), and mercury (Hg) are commonly released into the environment through various sources: exhaust gas, paints, and industrial wastes are some of the sources of lead (WHO, 2019). According to UNICEF, 2023, neonatal deaths account for 49.3% of all births that take place in Nigeria. There has been a shift toward placing a larger emphasis on activities that promote healthy living and well-being for all individuals, but particularly for the vulnerable segment (UNICEF, 2021). There is a continuous global call by international organizations to integrate environmental degradation and its sustainability programmes across global and national health frameworks. This also necessitate biomonitoring of heavy metal status of developing children who are five years old and who live in an environment that is contaminated with crude oil in Ogoniland and non-crude oil contaminated Ideato North Local Government Area as it requires a closer thorough investigation and more empirical evidences for health and environmental policies, which is the premise for this study.

Aim and Objectives

This study aims to ascertain the concentration of heavy metals in the blood plasma of under-five children living in crude oil polluted environment in Niger Delta of Nigeria.

However, the study was guided by the following specific objectives:

1. Ascertain the proportion of heavy metals in the blood plasma of under five children living in Niger delta region of Nigeria.
2. To determine the percentage of heavy metals in the blood plasma of under five children living in crude oil polluted environment in Niger Delta of Nigeria.

Research Questions

1. Are there heavy metals in the blood plasma of under five children living in crude oil polluted environment in Niger Delta of Nigeria.
2. What are the proportions of heavy metals in the blood plasma of under five children living in crude oil polluted environment in Niger Delta, Nigeria.

Methodology

This cross sectional study with comparative group was conducted in 3 communities in Gokana, Rivers State (B. Derek, K. Dere, Bomu) labelled the case study region and 3 non-crude oil exploration communities in Ideato North LGA, Imo state (Umukegwu, Umuezeaga, Owerre-Akokwa) assigned control, both states are in Niger Delta region of Nigeria. Gokana is one of the 4 Local governments in Ogoniland heavily polluted by crude oil located along : latitude 4° 40′ 5″ N and 4° 43′ 19.5″ N and longitude 7° 22′ 53.7″ E and 7° 27′ 9.8″ E (Nkpaa *et al*., 2017). Ideato North North is located along Latitude: 5.88528, Longitude: 7.13139 5° 53′ 7″ North, 7° 7′ 53″ East (Nwosu *et al*., 2020). The data collection period was in December 2022. Ethical approval was obtained from University of Port Harcourt Ethics Committee with the number UPH/CEREMAD/REC/MM80/004. A community based cross-sectional comparative study was carried out among under five children from households in the region. Parents and guardians of children signed consent forms provided before participating in the study. Seventy-eight (78) children were recruited for the study through a multi stage sampling method. Two milliliter (2ml) of the whole blood was collected in a well labelled ethylenediaminetetraacetic acid (K_3EDTA) bottle gently inverter to mix with the anticoagulant and store at 4^{o}C throughout before centrifuge. The samples were transferred into labelled tubes and loaded into the centrifuge adhering to all safety protocols and manufacturers guidelines.

Heavy Metals Extraction Procedure

Serum sample was weighed into a clean 250ml conical flask, to the flask was added 1ml 60% Perchloric Acid; 5ml concentrated Nitric acid and 0.5ml sulphuric acid (conc.). The mixture was then heated to digest the sample to a clear and colourless solution within 5-minutes. The digest was not allowed to dry-up in the flask completely; hence a close observation was employed to avert this. The digest was cooled to room temperature and was diluted to 25ml mark with distilled water. The digest was analyzed for Pb, Cr, As, Cd and Hg with the atomic absorption spectrophotometer (Analytik Jena contrAA Series (AA 300/600 Series)). The operational manual of the AAS used was observed.

Atomic Absorption Spectrometric Analysis

In each test, the pure standard of the ions under observation was used to calibrate the equipment. The AAS was allowed to stabilize for 15 minutes wherein engaged to a power source. The wavelength of the metal ion to be tested was selected through the salting knob. Air gas-pressure flow was adjusted to specification; slit width and other essential settings as was recommended were adjusted. Hallow cathode lamp was allowed to stabilized for specified minutes.

De-ionized distilled water was aspirated into the AAS to clear any trace of metal ion in the tubings.

Procedure: The wavelength at which the various metals ion absorbs was selected strictly as follows:

Ions(element)	**Symbol**	**wavelength**
Arsenic	As	193.7nm
Lead	Pb	283.3nm
Mercury	Hg	229nm
Cadmium	Cd	229mm
Chromium	Cr	357.9nm

The standard of the respective metals ion to be tested was aspirated into the AAS equipment to obtain readings for standard graph plot. The aspirator tubing was flushed clean with a stream of de-ionized water before the test sample was aspirated. The metal ion concentration of test was displayed on as the sample was aspirated. The concentration of the metal ion can be printed out or copied directly from the equipment as may be desired. The wavelength of the individual metal ions was selected for each test.

Statistical Analysis

Statistical analysis was done using ANOVA, paired t test statistic and proportion. Software: IBM SPSS Version 25.

Results

Table 1 shows the test result of five heavy metals between Gokana (sample) and Ideato north (control), where two out of the heavy metals are positive (+ve) in the male individual with a proportion of 18% and 12% for Cr (mg/kg) and Cd (mg/kg) respectively (i.e. with the mean±SD of 2.81±1.55 for Cr and 3.19±0.44 for Cd). However, three of the heavy metals are not detectable (Hg, As and Pb). Similarly, it was found that three out of the heavy metals are positive (+ve) in the female individuals with a proportion of 23%, 5% and 5% for Cr (mg/kg), As (mg/kg) and Cd (mg/kg) respectively (i.e. with the mean±SD of 1.22±0.78 for Cr, 0.25±0.18 for As and 0.92±0.65 for Cd). However, three of the heavy metals are not detectable (Hg, and Pb). Likewise (Table 1), three out of the heavy metals are positive (+ve) in the both male and female individual with a proportion of 21%, 3% and 8% for Cr (mg/kg), As (mg/kg) and Cd (mg/kg) respectively (i.e. with the mean±SD of 2.02±0.54 for Cr, 0.25±0.00 for As and 2.06±0.15 for Cd). However, three of the heavy metals are not detectable (Hg, and Pb). It is observed that the heavy metals are more present in Gokana (+ve) than Ideato (-ve).

Table 1: Test Results of Heavy Metals for Gokana (sample) and Ideato North (control) LGA

Gender	Parameter (mg/kg)	IDEATO Parameters	GOKANA Parameters	Sample size (Gokana)	Sample size (Ideato)
Male	Hg	ND	ND	17	15
Male	Cr	0.497±0.351	2.81±1.551	17	15
Male	As	ND	ND	17	15
Male	Pb	ND	ND	17	15
Male	Cd	ND	3.19±0.438	17	15
Female	Hg	-0.031±0.019	ND	22	24
Female	Cr	-0.128±0.065	1.22±0.784	22	24
Female	As	-0.032±0.026	0.25±0.177	22	24
Female	Pb	-0.237±0.198	ND	22	24
Female	Cd	-0.075±0.067	0.92±0.651	22	24
Both	Hg	-0.031	ND	39	39
Both	Cr	0.185±0.203	2.015±0.542	39	39
Both	As	-0.032	ND	39	39
Both	Pb	-0.237	ND	39	39
Both	Cd	-0.075	2.055±0.151	39	39

ND- Not detected; Values are presented as Mean ± SD of triplicate determination.

Discussion

The results of this study are discussed in this section to relate the current finding to the extant literature and provide the likely reasons for the findings of this study regarding the proportion of heavy metals in the blood plasma of under-five children living in crude oil polluted environment in the Niger Delta of Nigeria. The findings of this study indicate that under-5 children living in Gokana have high positive levels of heavy metals in their plasma compared with under-5 children in Ideato. The high proportions of the heavy metals observed in under-5 Gokana children may be attributed to living in an environment polluted with crude oil in the Niger Delta region of Nigeria. The current finding is supported by Chinedu and Chukwuemeka (2018) that reported that human exposure to heavy metals is significantly associated with oil spills from crude oil and its products in the Niger Delta region of Nigeria. The study also reported that crude oil is composed of different heavy metals that could be toxic to individuals living in an environment exposed to crude oil pollution, such as manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), cobalt (Co), cadmium (Cd) and chromium (Cr) (Chinedu and Chukwuemeka, 2018). According to Briffa *et al.* (2020), heavy metals results mainly from the anthropogenic activities of humans, such as mining and industrial products. These heavy metals are significant environmental pollutants that can accumulate in the human body (bioaccumulation) and are toxic to the human body (Briffa *et al*., 2020). Heavy metals find their way into the human body through edible vegetables, eating seafood, and inhaling them from the atmosphere, as a result of industrial and mining activities (Loh *et al*., 2016; Azubuike-Osu *et al*., 2021; Mitra *et al*., 2022). Hence, in the study region of Gokana, increasing mining of crude oil products may be attributed to the environmental pollution of crude oil, which is a source of several heavy metals, thus, resulting in the observed presence of some proportions of heavy metals in the blood plasma of under-5 children in Gokana than Ideato. Also, seafood and vegetables are among the primary food sources in Gokana, which may also result in the positive proportions of those heavy metals (Umeoguaju *et al*., 2023), such as Cr, As, and Cd among Gokana under-5 children compared to that of Ideato under-5 children.

Various percentages, 21%, 3%, and 8% for Cr (mg/kg), AS (mg/kg), and Cd (mg/kg), respectively were observed respectively in this study in the 'Both Male and Female group' (mean± SD of 2.02±0.54 for Cr, 0.25±0.00 for As and 2.06±0.15 for Cd). The higher levels of the proportions of Cr and Cd coincide with the findings of Chinedu and Chukwuemeka (2018), which identified Cr and Cd as the significant heavy metals present in crude oil. A review study by Umeoguaju *et al*. (2023) identified a similar trend related to the current finding in the proportions of heavy metals in seafood, which showed that Cr has about 2.26 mg/kg, Cd has 0.985 mg/kg, and AS has the lower proportion, which is 0.777 mg/kg. So, the under-5 children in Gokana may have been exposed to such foods, which may be contaminated by crude oil spillage. Also, the smaller proportion of AS identified in this study corresponds with Azubuike-Osu *et al*. (2021), which showed that AS finds its way into the body through edible vegetables and drinking water sources, eventually accumulating and resulting in oxidative stress and toxicity. Therefore, the findings of this study are adequately supported by existing studies.

Conclusion

This study provides strong empirical evidence that under-5 children living in Gokana in the Niger Delta region, a region known to be polluted by the crude oil, resulting from industrial activities, mining and oil spillage have proportions of heavy metals in their blood plasma. Cadmium (Cd) and Arsenic (As) are classified as members of group 1 carcinogens by International Agency Research on Cancer (IARC), which prolong exposure can bioaccumulate in vital organs causing kidney dysfunction, growth retardation, bone damage, disruption of major physiological processes. Stringent attention is necessary to curb exposure of these harmful heavy metals in the environment due to their high toxicity, wide spread and industrial applications.

Recommendations

The following are the recommendations for future research, practice and policymaking in this research area.

1. Future research may concentrate on investigating the impact of the heavy metals isolated in this study (Cr, Cd and AS) on the health of under-5 children in the Niger Delta region and determine their toxicity levels in the blood and other vital organs of the body, such as heart, liver, kidney and brain.
2. Future public health practice should concentrate on increasing awareness of the sources of heavy metals and proffer solutions to mitigate the pollution of edible vegetables, seafood and drinking water, which can be done using health promotional strategies focusing on the parents of under-5 children.
3. Policymakers can be informed from the findings of this research to develop relevant policies that will help reduce the pollution of the Niger Delta environment through oil spillage, mining and industrial activities, and effectively implement such policies, as well as sanctioning industries that violates such policies.

References

Akram, M., Munir, N., Daniyal, M., Egbuna, C., Găman, M.-A., Onyekere, P. F. and Olatunde, A. (2020). Vitamins and Minerals: Types, Sources and their Functions. In: Egbuna, C., Dable Tupas, G. (eds) Functional Foods and Nutraceuticals. Springer, Cham. https://doi.org/10.1007/978-3-030-42319-3_9

Anand, I. S., & Gupta, P. (2018). Anemia and Iron Deficiency in Heart Failure: Current Concepts and Emerging Therapies. *Circulation*, *138*(1), 80–98. https://doi.org/10.1161/CIRCULATIONAHA.118.030099.

Ali, H., Khan, E., Ilahi, I., (2019): Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation, J. Chem 2019 (2019) 6730305, https://doi.org/ 10.1155/2019/6730305.

Azubuike-Osu, S. O., Famurewa, A. C., David, J. C., Abi, I., Ogbu, P. N., Oparaji, C. K., Nwaeze, K. G., & Akunna, G. G. (2021). Virgin Coconut Oil Resists Arsenic-Induced Cerebral Neurotoxicity and Cholesterol Imbalance via Suppression of Oxidative Stress, Adenosine Deaminase, and Acetylcholinesterase Activities in Rats. Natural Product Communications. https://doi.org/10.1177_1934578X211016962

Balali-Mood M, Naseri K, Tahergorabi Z, Khazdair MR, Sadeghi M. (2021): Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. Front Pharmacol. 2021 Apr 13; 12:643972. doi: 10.3389/fphar.2021.643972. PMID: 33927623; PMCID: PMC8078867.

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and its toxicological effects on humans. Heliyon, 6(9), e04691. https://doi.org/10.1016/j.heliyon.2020.e04691

Chinedu, E., & Chukwuemeka, C. K. (2018). Oil Spillage and Heavy Metals Toxicity Risk in the Niger Delta, Nigeria. Journal of Health & Pollution, 8(19). https://doi.org/10.5696/2156-9614-8.19.180905.

Egbuna, C. and Ifemeje, J.C. (2017). Oxidative Stress and Nutrition. *Tropical Journal of Applied Natural Sciences*, 2(1): 110-116.

Ephraim-Emmanuel, B. C., & Ordinioha, B. (2021). Exposure and Public Health Effects of Polycyclic Aromatic Hydrocarbon Compounds in Sub-Saharan Africa: A Systematic Review. International Journal of Toxicology. https://doi.org/10.1177/10915818211002487.

Gupta, N., Kumar, V., Yadav, K., Cabral P., Marina, Prasad, S., Jeon, B., Kumar, S., & Abdellattif, M., (2022). Investigation of heavy metal accumulation in vegetables and health risk to humans from their consumption in Jhansi, India. Frontiers of Environmental Science & Engineering. 10. 10.3389/fenvs.2022.791052.

Howard, I. C., Okpara, K. E., & Techato, K. (2021). Toxicity and Risks Assessment of Polycyclic Aromatic Hydrocarbons in River Bed Sediments of an Artisanal Crude Oil Refining Area in the Niger Delta, Nigeria. Water, 13(22), 3295. https://doi.org/10.3390/w13223295

Haidar, Z., Fatema, K., Shoily, S. & Sajib, A. (2023): Disease-associated metabolic pathways affected by heavy metals and metalloid, Toxicology Reports, Volume 10, 2023, Pages 554-570,

Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol. 2014 Jun;7(2):60-72. doi: 10.2478/intox-2014-0009. Epub 2014 Nov 15. PMID: 26109881; PMCID: PMC4427717.

Loh, N., Loh, H., Wang, L. K. & Wang, M.-H.-S. (2016). Health effects and control of toxic lead in the environment. Natural Resources Control Process, 233–284.

Kim, H. S., Kim, Y. J., & Seo, Y. R. (2015). An Overview of Carcinogenic Heavy Metal: Molecular Toxicity Mechanism and Prevention. Journal of Cancer Prevention, 20(4), 232–240. doi:10.15430/jcp.2015.20.4.232

Kuhn V, Diederich L, Keller TCS 4th, Kramer CM, Lückstädt W, Panknin C, Suvorava T, Isakson BE, Kelm M, Cortese-Krott MM. (2017) Red Blood Cell Function and Dysfunction: Redox Regulation, Nitric Oxide Metabolism, Anemia. Antioxid Redox Signal. 2017 May 1;26(13):718-742. doi: 10.1089/ars.2016.6954. Epub 2017 Jan 18. PMID: 27889956; PMCID: PMC5421513.

Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. B., Nainu, F., Khusro, A., Idris, A. M., Khandaker, M. U., Osman, H., Alhumaydhi, F. A., & Simal-Gandara, J. (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. Journal of King Saud University - Science, 34(3), 101865. https://doi.org/10.1016/j.jksus.2022.101865

Ogundele, L. T., Owoade, O. K., Hopke, P. K., & Olise, F. S. (2017). Heavy metals in industrially emitted particulate matter in Ile-Ife, Nigeria. Environmental Research, 156, 320–325. doi:10.1016/j.envres.2017.03.051

Okoye, E. A., Bocca, B., Ruggieri, F., Ezejiofor, A. N., Nwaogazie, I. L., Domingo, J. L., Rovira, J., Frazzoli, C., & Orisakwe, O. E. (2021). Concentrations of polycyclic aromatic hydrocarbons in soil, feed, and food samples collected in the Niger Delta region, Nigeria: A probabilistic human health risk assessment. Environmental Research, 202, 111619. https://doi.org/10.1016/j.envres.2021.111619

Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F., & Kim, K.-H. (2019). Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environment International, 125, 365–385. doi:10.1016/j.envint.2019.01.067

Reuben A, Caspi A, Belsky DW, Broadbent J, Harrington H, Sugden K, Houts RM, Ramrakha S, Poulton R, Moffitt TE. (2017): Association of Childhood Blood Lead Levels with Cognitive Function and Socioeconomic Status at Age 38 Years and With IQ Change and Socioeconomic Mobility Between Childhood and Adulthood. JAMA. 2017 Mar 28;317(12):1244-1251. doi: 10.1001/jama.2017.1712. PMID: 28350927; PMCID: PMC5490376.

Ruiz-Fernández, A. C., Sanchez-Cabeza, J. A., Pérez-Bernal, L. H., & Gracia, A. (2019). Spatial and temporal distribution of heavy metal concentrations and enrichment in the southern Gulf of Mexico. Science of The Total Environment, 651, 3174–3186. doi:10.1016/j.scitotenv.2018.10.109

Sakamoto, M., Haraguchi, K., Tatsuta, N., Nakai, K., Nakamura, M., & Murata, K. (2021). Plasma and red blood cells distribution of total mercury, inorganic mercury, and selenium in maternal and cord blood from a group of Japanese women. Environmental Research, 196, 110896. doi:10.1016/j.envres.2021.110896.

Takahashi, T., Fujimura, M., Koyama, M., Kanazawa, M., Usuki, F., Nishizawa, M., & Shimohata, T. (2017). Methylmercury Causes Blood-Brain Barrier Damage in Rats via Upregulation of Vascular Endothelial Growth Factor Expression. PLOS ONE, 12(1), e0170623. doi:10.1371/journal.pone.0170623

Taylor, C., Golding, J., and Emond, A. (2015). Adverse Effects of Maternal lead Levels on Birth Outcomes in the ALSPAC Study: a Prospective Birth Cohort Study. Bjog: Int. J. Obstet. Gy 122, 322–328. doi:10.1111/1471-0528.12756.

Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ.(2012) Heavy metal toxicity and the environment. Exp Suppl. 2012; 101:133-64. doi: 10.1007/978-3-7643-8340-4_6. PMID: 22945569; PMCID: PMC4144270.

UNICEF (2021): Healthy Environment for Healthy Children Global Programme Framework: Published on 19 January 2021

UNICEF (2023): Child mortality estimates: UNICEF Global databases (data.unicef.org). Estimates generated by the UN inter-agency Group Mortality estimation (UN IGME), 10 January 2023.Downloaded from http://data.unicef.org

Umeoguaju, F. U., Akaninwor, J. O., Essien, E. B., Amadi, B. A., Igboekwe, C. O., Ononamadu, C. J. & Ikimi, C. G. (2023). Heavy metals contamination of seafood from the crude oil-impacted Niger Delta Region of Nigeria: A systematic review and meta-analysis. Toxicology Reports, 11, 58-82. doi 10.1016/j.toxrep.2023.06.011. PMID: 37416859; PMCID: PMC10320387.

Ramírez O. D., González E. D. F., Blanco A. T., Pineda, B., Gómez M. S., Marcial Q. J., Carrillo Mora, P., *et al.* (2021). Cognitive Impairment Induced by Lead Exposure during Lifespan: Mechanisms of Lead Neurotoxicity. Toxics, 9(2), 23. MDPI AG. Retrieved from http://dx.doi.org/10.3390/toxics9020023

Rzymski, P., Tomczyk, K., Rzymski, P., Poniedzialek, B., Opala, T., & Wilczak, M. (2015). Impact of heavy metals on the female reproductive system. Annals of agricultural and environmental medicine, 22(2).

Zulqarnain, Ayoub M, Yusoff MHM, Nazir MH, Zahid I, Ameen M, Sher F, Floresyona D, Budi Nursanto E. (2021): A Comprehensive Review on Oil Extraction and Biodiesel Production Technologies. Sustainability; 13(2):788. https://doi.org/10.3390/su13020788.