Assessment of heavy metal accumulation potential of selected cassava varieties cultivated in crude oil-impacted zone, Emuoha, Rivers State.

OTENE, B.B[1] and NWINE, P. A[2]
[1]Department of Fisheries and Aquatic Environment, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt
[2]Department of Crop Science, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt
e-mail: benjaminotene56@yahoo.com

Abstract
This study evaluated the concentration of some heavy metals (cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb) and asenic (As)) in soil and cassava (TMS 9210326 than TMS 305721) in a crude oil-impacted zone of Omerelu, Rivers State. Soil and cassava samples were collected from four crude oil impacted zones (Omerelu, Eberator,Obelele and Ibaa), processed and analysed for heavy metal concentrations. Results showed that the heavy metals in the soils were higher than those in cassava varieties with the mean values (mg/kg) 11.817 ± 20.4 (Cd), 0.388 ± 0.17 (Cr), 0.395 ± 0.17 (Hg), 0.583 ± 0.32 (Pb), and 0.500 ± 0.12 (As) respectively. The order of heavy metal accumulation in the soil and cassava varieties (Soil> TMS 92/0326 > TMS 305721) differed with Cd having the highest concentration. Mean values of heavy metal were consistently higher in TMS 921.0326 than the TMS 305721 except Pb. Cd value exceeded the permissible safety limit of 0.02 mg/kg and 1.00 mg/kg set by WHO/FAO for crop/food and soil. There was significant difference between all heavy metal absorbed by the two cultivars at $p<0.05$. There was a very strong positive correlation between Hg and Pb ($r = 0.951$). Bioaccumulation factor (BAF) for all the heavy metals except Pb were higher in TMS 9210326 than in TMS 305721 with all values less than one signifying lower risk. Cassava farmers should be discouraged from farming on crude oil impacted soil but may use a better resistant variety like TMS 305721 instead as a more resistant variety in these localities.

Keywords: Accumulation potential, Cassava varieties, Crude oil impacted zone, Emouha, Heavy metals.

Introduction

The accumulation of heavy metals in agricultural crops poses serious risks to human health and the environment, particularly in regions impacted by industrial activities such as crude oil extraction. Cassava (*Manihot esculenta*) belongs to the family Euphorbiaceae, a staple food crop in many tropical countries, is particularly vulnerable to heavy metal contamination due to its extensive root system, which can absorb pollutants from the soil (Adjei-Nsiah *et al*.,2012). Among the cassava varieties cultivated in Nigeria, TMS 30572 and TMS 92/0326 have gained prominence due to their high yield potential and resilience to pests and diseases (Dimkpa *et al*.,2021). Previous research has shown that different cassava varieties exhibit varying capacities for heavy metal uptake and accumulation, influenced by genetic factors, soil conditions, and environmental stressors. Understanding the heavy metal accumulation potential of these specific varieties when grown in oil-impacted soils is critical for assessing their safety as a food source.

In the Niger Delta region of Nigeria, where crude oil exploration and production are prevalent, the soil and water bodies are often contaminated with heavy metals such as lead (Pb), cadmium (Cd), nickel (Ni), and zinc (Zn) due to crude oil spills, gas flaring, and other anthropogenic activities (Franklyn *et al*., 2021)

The Emuoha Local Government Area in Rivers State is one of the areas severely affected by crude oil pollution, leading to concerns about the safety of food crops cultivated in this environment. Studies have shown that heavy metals can accumulate in cassava tubers and leaves, potentially entering the human food chain and posing health risks such as neurotoxicity, kidney damage, and carcinogenic effects (Bortey-Sam *et al*., 2015). The bioaccumulation of these metals in cassava is influenced by various factors, including soil composition, plant variety, and environmental conditions (Samlafo *et al*., 2022**)**.

Researches had indicated that certain cassava varieties may exhibit different capacities for heavy metal uptake and accumulation (Li *et al*.,2022, Hu *et al*., 2017, Essiet *et al*. 2010). Understanding the accumulation potential of these varieties is crucial for assessing the safety of cassava as a food source in contaminated areas. Furthermore, the bioconcentration factor (BCF) can provide insights into the extent to which cassava varieties can absorb heavy metals from the soil, which is essential for developing strategies to mitigate health risks associated with consuming contaminated crops.

Cassava is grown as a dominant or secondary crop, either as a monoculture or in combination with other food crops. Although it ranks second to maize in terms of planted area, cassava is the most important root crop in terms of quantity produced, followed by yam and cocoyam (Adjei-Nsiah *et al*., 2012). With an annual per capita consumption of 154.0 kg, it is a significant starchy staple crop in Ghana (Adjei-Nsiah *et al*., 2012, Apau *et al*., 2014). In addition to being a staple crop, cassava may be used to make both fermented and unfermented goods. Akyeke, agbelima, fufu, fermented starch, cassava bread, and fermented cassava flour are examples of fermented products; tapioca, cassava chips, gari, and pellets are examples of unfermented products. One of the first biotechnology solutions for food processing, preservation, and beverage production is fermentation (Okon *et al*., 2021). The root tuber's shelf life is extended

and transportation costs to urban markets are reduced when it is processed into different products (Nkansah *et al*., 2021). Additionally, it serves as a raw ingredient for ethanol and industrial starch. While the peel of cassava is either consumed by animals or used to make animal feed, the leaves are also edible.

This study was conducted to evaluate the heavy metal accumulation potential of TMS 30572 and TMS 92/0326 cultivated on crude oil-impacted soils of Omerelu, Emuoha, in Rivers State. This study is expected to provide valuable insights into the risks associated with consuming cassava grown in crude oil contaminated environment. The findings will provide useful pieces of information for agricultural practices and food safety regulations, ultimately promoting better health outcomes for communities relying on cassava as a dietary staple.

This study aims to assess the heavy metal accumulation potential of selected cassava varieties cultivated in the oil-impacted zone Rivers State. By analyzing the concentrations of heavy metals in both soil and cassava samples, thereby seeks to provide valuable data that can inform agricultural practices and public health policies in the region.

Methodology

Study Area

In Emuoha, Rivers State, Nigeria, the crude oil-impacted area is situated latitude 4.8509° N and longitude 7.0689° E. Numerous human activities, mostly from the oil and gas sector, have had a major impact on this region. Exploration and production of crude oil, which entails drilling and extraction procedures that may result in spills and environmental damage, are important operations. Furthermore, there is a chance that the vast system of pipelines used to transport crude oil would burst or leak and refining operations going on in in adjacent sites, further polluting the surrounding area.

The most common crops grown in Emuoha are yams, maize, plantains, and cassava, a staple food renowned for their tenacity.

Sampling

During sampling periods, cassava samples grown on oil-impacted sites in the study area were collected in duplicate from four locations along with the soil sample using an auger down to a depth of 30.0cm from the surface. The samples were placed in different plastic bags and transported to the laboratory for the determination of heavy metals.

Sample Preparation and Analysis

Sampled cassava tubers were properly washed separately with water to remove any surface deposit of soil particles to avoid contamination, labelled appropriately and oven dried at 105 °C to a constant weight. The dried tubers were properly ground separately using cleaned ceramic mortar and pestle into powder and passed through sieved using <40 mesh, homogenized, and packed in polyethylene bags and stored in the fridge for further analysis. Similarly, the soil samples were pulverized and oven dried at 105 °C to a constant weight.

Aqua regia, a 1:3 HCl and HNO_3 mixture, was used to digest 2.0 g of each powdered cassava tuber in triplicate on a water bath at 80 °C until a transparent solution formed, signifying the digestion's completion (APHA, 1995). Likewise, three separate 2.0 g samples of the ground-up dirt were collected and digested in a 100.0 ml polytetrafluoroethylene teflon bomb. Each soil sample received 10.0 ml of pure HNO_3, which was then let to stand for ten minutes. Additionally, drop by drop, around 30 % H_2O_2 was added to the mixture until it stopped effervescent. 2.0 ml of concentrated H_2SO_4 was poured to each combination in the teflon bomb, and then 5.0 ml of concentrated $HClO_4$ was added one after the other. In a Milestone microwave oven (Ethos 900), the resultant mixtures were digested for 25 minutes with the following operating parameters: 250W for 2.0 minutes, 0W for 2.0 minutes, 250W for 6 minutes, 400W for 5.0 minutes, 650W for 5.0 minutes, and 5.0 minutes for venting (Samlafo, 2017). To cool the tubes' contents and lower the related pressure, the rotor was submerged in a bowl of water. Whatman (No 1) filter paper was used to filter the digested soil samples into a 100.0 mL volumetric flask, and de-ionized distilled water was added to make up the difference. Using the Varian Fast Sequential Atomic Absorption Spectrophotometer at the appropriate wavelengths, calibration standards were prepared for the different analytes along with their respective blanks. Acetylene gas was used as the carrier gas in the determination, and argon was passed through the system to remove interfering gases in between each reaction time (APHA, 1995, Samlafo and Adakwah, 2021).

Bioaccumulation Factor (BAF)

The plant bioaccumulation factor (BAF) was estimated as the ratio of the concentration of heavy metals in food crops [Cplant] to that of contaminated soil [Csoil (IAEA, 2000), and thus;

$$\mathrm{BAF} = \frac{[Cplant]}{[Csoil]}$$

Experimental Design and Statistical Analysis

Complete randomization design (CRD) was used for this study. The obtained values were subjected to statistical tool for descriptive and inferential statistics such as means, standard deviation (SD), correlation and T-test using Statistical Package for Social Science (SPSS) version 25.0.

Results

The mean values of heavy metal concentration in cassava varieties and soil with the maximum permissible limit are presented in Table 1. The range of heavy metals in the two varieties of cassava were, Cd (0.02-0. 025, 0. 09 - 0. 50 mg kg^{-1}) Cr (0. 001 – 0. 010, 0. 04 – 0. 09 mg kg^{-1}), Hg (0.001 – 0.005, 0.009 – 0.05 mg kg^{-1}) Pb (0.009 – 0.04, 0.001 – 0.006 mg kg^{-1}) and As (0.02 – 0.08, 0.09 – 0.05 mg kg^{-1}) for TMS 305721 and TMS 92/0326) respectively. The overall mean values were 0.181 ± 0.15

mg/kg (Cd), 0.032 ± 0.03 mg/kg (Cr), 0.017 ± 0.02 mg/kg. The mean values of heavy metal were consistently higher in TMS 921.0326 than the TMS 305721 except Pb. The heavy metals values in the soil were higher than the cassava variety with the mean values 11.817 ± 20.4 (Cd), 0.388 ± 0.17 mg/kg (Cr), 0.395 ± 0.17 mg/kg (Hg), 0.583 ± 0.32 mg/kg (Pb), and 0.500 ± 0.12 mg/kg (As). Only values of Cd exceeded the permissible limit of 0.02 mg/kg and 1.00 mg/kg set up by WHO/FAO for crop/food and soil. The order of heavy metal accumulation in the soil and the cassava varieties (Soil> TMS 92/0326 > TMS 305721) differed with Cd having the highest concentration while the least in the soil and the varieties were respectively Cr, Hg and Pb.

The spatial mean values of heavy metal in the variety of cassava is presented in Table 2. It shows significant difference across the station among all metals except Cr. Table 3 is a t-test showing that there was significant difference between all heavy metal absorbed by the two variety of cassava at $p<0.05$. Table 4 showed that apart from Cr, there were strong and positive correction between Hg and Cd (0.776), Cr (0.728), Pb and Cd (0.661), Cr (0.670), Hg (0.951) and between As and Cr (0.940), Hg (0.872) and Pb (0.798).

Bioaccumulation factor (BAF) for all the heavy metal except Pb was higher in TMS 9210326 than TMS 305721 (Table 5). All the BAF values were lower than one (<1) indicating lower risk.

Discussion

The range of values of heavy metals in the soil obtained in this study was higher than that reported by Egbenda *et al.* (2015), but lower than values reported by Idugboe *et al*. (2014). These values indicated significant presence of trace metal ions or ionisable materials in the soil (Fuller *et al*., 1995). This supported earlier report of Ogbuechi *et al*. (2010) that the impact of crude oil on the Nigerian soil has deprived the soil of plant essential macro-nutrients but enriched the soil with heavy metals which are capable of posing health hazards to the inhabitant only but persons that feed/convene produce from the region. The observed mean values of heavy metals in the cassava tubers in this study is in line with that reported by Ogwu *et al*.,(2023)from Egbedei, crude oil-bearing community in Delta State. The levels of heavy metals bioaccumulation in both varieties of cassava tubers reported in this study were generally lower than the WHO/FAO (2001) safe limit as reported by Okereke *et al*. (2020).

Several studies have shown that cadmium is a highly mobile metal, easily absorbed by plants through root surface and moves to wood tissue and transfers to upper parts (Adu *et al*., 2012), which is synonymous with the findings as recorded in this study. Itanna (2002) and Muhammad *et al*. (2008) reported that there is a direct relation between the levels of cadmium in the root zone and its absorption by plant. In this study, soil Cd concentration in the root was higher than that of aerial plant parts. Therefore, the variation in elemental migration in vegetables reflects the combined influence of soil physical and chemical properties, heavy metal content, and chemical forms. The soil is known to be the final sink for environmental contaminants and as such accumulates pollutants to levels that may be unacceptable and hazardous to the environment (Boke *et al*., 2015). The observed high concentration of Cd in both soil and the cultivars above the safety limits (0.02 and 1.00 mg/kg) recommended by WHO/FAO, 2007, 2001) in this study is in agreement with the finding of Harrision and Ekandem (2018). Essiet *et al*. (2010) opined that certain plants such as cassava and maize with high biomass tend to accumulate high number of heavy metals.

Metals whether essential to plant and animal life or not has a limit to which the body will not require it. At very high concentrations, they result in either plant or animal toxicity. The condition of excessive accumulation of heavy metals in plants originated from excess concentrations of those metals in the soil especially Cd. In such situation, they constitute health risk to both plants and animals in the interdependence chain of consumption (food chain) (Singh *et al*., 2012). The rate of retention of heavy metals in plant parts varies from one plant to the other. Despite the fact that in most case these heavy metals do not inhibit the growth of these plants, yet crops reaped from such contaminated soil and constituted serious health risks to humans through consumption of such products. These risks are as a result of high concentrations of the individual contaminants above the required standard for food (Singh *et al*., 2015).

The consistently higher mean values of heavy metals in TMS 92/0326 than the TMS 305721 in this study could be attributed to variation in tolerance among the cassava varieties as opined by Li *et al*. (2022) and Hu *et al*., (2017) that certain species have developed mechanisms to tolerate or sequester heavy metals, which may have affected their accumulation levels in this study. Alloways (1993) in Harrison and Ekanem (2018) also opined that plant variety within a specie can differ widely in their ability to absorb, accumulate and tolerate heavy metals. Additionally environmental factors such as rainfall, temperature, and humidity can also influence the migration of heavy metals.

The strong positive correlation between mercury (Hg) and lead (Pb) ($r = 0.951$) suggested that as the concentration of mercury increase in the soil, the concentration of lead also tends to increase, indicating a potential common source of contamination or similar pathways of accumulation in the environment. The presence of these heavy metals in cassava, a staple food in this region, raises concerns about food safety and human health (Idakwoji, 2016). High levels of heavy metals in soil can lead to their accumulation in edible parts of the plant, potentially resulting in dietary exposure for consumers. This is of a particular concern for populations that rely heavily on cassava as a food source. Chronic exposure to heavy metals can lead to

various health issues, including neurological damage and increased cancer risk (Idakwoji, 2016). The correlations observed here apart from crude oil exploitation and exploration may reflect the impact of agricultural practices, such as the use of contaminated fertilizers or irrigation with polluted water, which can introduce heavy metals into the soil and subsequently into crop. Understanding these relationships is crucial for developing strategies to mitigate heavy metal contamination in agricultural systems.

Soil to plant transfer is one of the major pathways by which heavy metals and other contaminants in soil enter the food chain (Sparg *et al*., 2004; Mahmood and Malik, 2014).The observed higher bioaccumulation factor (BAF) for all the heavy metal (except Pb) in TMS 9210326 than TMS 305721 in this study was in line with that reported by Xiangmei *et al*.,(2024) for different crop varieties which could be attributed to difference in tolerance and sequestration among the species. These observed values of BAF/TF are in disagreement with the finding of Harrison and Ekanem (2018) and could be attributed to environmental and genetic factors.

Conclusion and Recommendation

TMS 30572 generally shows lower accumulation of heavy metals compared to TMS 92/0326, making it potentially safer for consumption in terms of cadmium, mercury, and lead. TMS 92/0326, while it may offer some agronomic advantages, raises significant concerns regarding its accumulation of chromium, mercury, and especially arsenic. Therefore, crop farmers should be discouraged from farming on crude oil impacted soil but may use a better resistant variety like TMS 30572.

References

Adjei-Nsiah, O. and Sakyi-Dawson (2012). Promoting cassava as an Industrial crop in Ghana: Effects on soil fertility and farming system sustainability. *Applied and Environmental Soil Science*, 1-8. doi: 10.1155/2012/940954.

Adu, J. K., and Akinola, M. O. (2012). Heavy metals in vegetables and their health implications in Nigeria. *Journal of Environmental Science and Technology*, 5(4) 123-130.

APHA (1995). Standard methods for the examination of water and wastewater, American Public health Authority. 1995 19th Ed. Washington (DC), 1090-1096

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

Boke, S. K., Akinola, M. O. and Ojo, J. A. (2015). Assessment of heavy metal concentrations in soil and plant samples from a crude oil contaminated site in Nigeria. *Journal of Environmental Science and Technology*, 8(3), 123-130.

Bortey-Sam, N. Shouta M. M. Nakayama, O. A. Yoshinori, J. N. Fobil, E. B., Hazuki M. and Mayumi, I. (2015). Accumulation of Heavy Metals and Metalloid in Foodstuffs from agricultural soils around Tarkwa Area in Ghana, and Associated Human Health Risks. *International. Journal of Environment* Research *Public Health 12*, 8811-8827; doi:10.3390/ijerph120808811 O

Egbenda, J. E., Ogbemudia, F. O. and Idugboe, A. E. (2015). Heavy metal concentrations in soil and plants from crude oil contaminated sites in Nigeria. *Journal of Environmental Science and Technology*, 8(4):345-352.

Essiett, U.A., Effiong, G.S., Ogbemudia, F.O., and Bruno, E.J. (2010). Heavy metal concentrations in plants growing in crude oil contaminated soil in Akwa Ibom State, South-Eastern Nigeria. *African Journal Pharmacy. Pharmacol.* 4(7), 465-470

FAO/WHO (*Codex Alimentarius Commission*) (2001). Food Additives and Contaminations, Joint *FAO/WHO Food Standards Program*; ALINORM 01/12A: 1-289

Franklyn O. Ohiagu, Kelechi C. Lele, Paul C. Chikezie, Andrew W. Verla and Christian E. Enyoh (2021). Bioaccumulation and health risk assessment of heavy metals in *Musa paradisiaca*, Zea mays, *Cucumeropsis manii and Manihot esculenta* cultivated in Onne, Rivers State, Nigeria. *Environmental Analysis Health and Toxicology* 35(2).

Fuller, M. A. and Hurst, C. J. (1995). Heavy metals in the environment: A review of the literature. *Environmental Pollution*, 88(3):257-265.

Harrison, U.E.; Losu, S.R. and Ekanem, J.O. (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 Applied. Science. Environmental Management. Vol. 22 (6) :845 –851

Hu, W.; Huang, B.; Tian, K.; Holm, P.E and Zhang, Y(2017). Heavy metals in intensive greenhouse vegetable production systems along Yellow Sea of China: Levels, transfer and health risk. *Chemosphere 167*:82–90. [Google Scholar] [CrossRef]

Idakwoji, P. A. (2016). Assessment of heavy metal contamination of soil and cassava plants within the vicinity of a cement factory in north central, Nigeria. *Advances in Applied Science Research*,

7(3), 20-27. Available online at www.pelagiaresearchlibrary.com.

Idugboe, A. E., Ogbemudia, F. O., and (2014). Heavy metals in soil and plants from oil spill sites in the Niger Delta region of Nigeria. *African Journal of Environmental Science and Technology*, 8(5), 295-302.

International Atomic Energy Agency, (2000). Analytical quality control services, Reference material IAEA-soil-7. 2000 Trace elements in soil. Wagramer strasse, Vienna Austria.

Itanna, F. (2002). The role of heavy metals in the environment: A review. *Ethiopian Journal of Science*, 25(1): 1-10.

Li, C., Du, D., Gan, Y., Ji, S., Wang, L., Chang, M. and Liu, J. (2022). Foliar dust as a reliable environmental monitor of heavy metal pollution in comparison to plant leaves and soil in urban areas. *Chemosphere*, *287*:132-341. [Google Scholar] [CrossRef]

Mahmood, A. and Malik, R.N. (2014). Human health risk assessment of Heavy Metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. *Arabian Chem.* 7:91-99.

Muhammed, A. A. and Ogbemudia, F. O. (2008). Heavy metal concentrations in soil and plants from oil spill sites in Nigeria. *African Journal of Environmental Science and Technology*, 2(10):309-315.

Nkansah, M.A., Agorsor, P. and Opoku, F. (2021). Heavy metal concentration and health risk assessment of mechanically milled delicacy called fufu. *International Journal of Food Contamination*, 1-7. doi: 10.1186/s40550-021-00085-y.

Ogbuchi, H.C.; Ezeibekwe, I.O. and Agbakwuru, U. (2010). Assessment of crude oil pollution, the proximate composition and macro element of cassava crop in Owerri, Imo State. *International Science Research Journal* 2:62-65.

Ogwu, O. J., Ogbemudia, F. O., and Idugboe, A. E. (2023). Heavy metal contamination in agricultural soils and crops in the Niger Delta region of Nigeria. *Environmental Monitoring and Assessment*, 195(2): 1-12.

Okereke, C. S., and Nwankwo, J. I. (2020). Assessment of heavy metal levels in soil and vegetables from urban farms in Nigeria. *Journal of Environmental Management*, 261, 110227.

Samlafo, S. (2012). Heavy metal concentrations in plants from oil-contaminated soils. *Journal of Environmental Science*, 10(2): 123-130.

Samlafo, V.B., Essel, K. and Ankudze, B. (2022). Health Risk Assessment of Heavy Metals Via Consumption of Cassava, Cultivated on Reclaimed Mining Land Sites in Prestea-Huni Valley District, Ghana. *Food and Public Health* 12(1): 7-13 doi:10.5923/j.

Samlafo, B.V. (2017). Comparative analysis of leachable heavy metals in earthenware clay deposits in the central and Volta regions of Ghana, *American Journal of Chemistry* 7(4):145-151. Doi: 10.5923/j.chemistry.20170704.03.

Samlafo, B.V., and Adakwah D. (2021). Evaluative study of river Birim in Denkyembuor, Ghana, using water quality indices. *Chemical Science international Journal*, 30(9): 39-51. Doi: 10.9734/CSJI/2021.v30i9390253.

Sighn, S., Kumar, A. and Sharma, R. (2012). Heavy metals in the environment: Sources, effects, and remediation. *International Journal of Environmental Science and Technology*, 9(2):345-356. DOI: 10.1007/s13762-012-0015-5.

Sighn, S., Kumar, A. and Sharma, R. (2015). Bioremediation of heavy metals: A review. *Journal of Environmental Management*, 162: 1-10. DOI: 10.1016/j.jenvman.2015.07.018.

Sparg, S.G., Light, M.E. and Staden, J.V. (2004). Biological activities and distribution of plant saponins. *J. Ethnopharmacol. 94: 219 – 243.*

Xiangmei, C.,Yongqiang, R., Chi L.,Yan S. Rui Ji, De Yao and Yingchun H. (2024). Study on Factors Influencing the migration of heavy metals from soil to vegetables in a heavy industry city. *Sustainability*, *16*(24):11084; https://doi.org/10.3390/su 162411084

Table 1: Mean Values and MPL of Heavy Metals (mg/kg) in Cassava Varieties and Soil in the Study Area

Variables		Cd	Cr	Hg	Pb	As
TMS 30572 1	Mean	0.115±09	0.0063±00	0.0023±0.0	0.026±0.01	0.053±0.02
	Mini-Max	0.02-0.25	0.001-0.010	0.001-0.005	0.009-0.040	0.020-0.080
TMS 92/0326	Mean	0.248±0.17	0.058±0.02	0.031±0.02	0.0033±0.00	0.134±0.07
	Mini-Max	0.09-0.50	0.040-0.09	0.009-0.05	0.001-0.006	0.090-0.25
Overall Mean	(TMS)	0.181±0.15	0.032±0.03	0.017±0.02	0.015±0.02	0.093±0.07
MPL(WHO/FAO,2007)		0.02	1.30	0.10	0.03	2.00
Soil	Mean	11.817±20.4	0.388±0.17	0.395±0.17	0.583±0.31	0.500±0.12
	Min-Max	0.69-0.45	0.25-0.65	0.24-0.65	0.25-0.88	0.35-0.65
MPL(WHO/FAO,2007)		1.00	100.00	0.50	2.00	5.00

Key: Cadmium (Cd), Chromium (Cr), Mercury (Hg), Lead (Pb), Arsenic (As), WHO/FAO (world Health Organisation/Food and Agricultural Organisation), Maximum Permissible Limit (MPL), Tropical Manihot Selection (TMS)

Table 2: Spatial Mean Values and MPL of Heavy Metals (mg/kg) in Cassava Varieties and Soil in the Study Area

Station/Heavy Metal	Cd	Cr	Hg	Pb	As
1	0.260±0.27a	0.021±0.02a	.0.026±0.03a	.011±0.03b	0.088±0.01b
2	0.090±0.00b	0.023±0.02a	.0.005±0.01b	.022±0.02a	0.075±0.02b
3	0.175±0.09a	0.050±0.05a	.0.015±0.01a	.008±0.00b	0.060±0.05b
4	0.200±0.06a	0.035±0.03a	.0.021±0.02a	.019±0.02a	0.150±0.12a

Key: Mean with similar superscript across the same row are not significantly different at p<0.05

Table 3: T-test between the Heavy Metal Concentration(mg/kg) in Cassava Varieties

Heavy Metals	Mean	SD	t	N	df	Sig.(2-tailed
Cd	0.181	0.147	4.944	16	15	0.000
Cr	0.032	0.031	4.180	16	15	0.001
Hg	0.017	0.019	3.554	16	15	0.003
Pb	0.015	0.015	3.942	16	15	0.001
As	0.093	0.067	5.603	16	15	0.000

Key:P≤0.05=Significant level, SD=Standard Deviation, N=Number of Variables, df=Degree of Freedom, Sig=Significance

Table 4: Correlation Matrix between the Heavy Metals in the Cassava and Soil

Variables		Cd	Cr	Hg	Pb	As
Cd	Pearson Correlation	1.000				
	Sig. (2-tailed)					
Cr	Pearson Correlation	0.253	1			
	Sig. (2-tailed)	0.232				
Hg	Pearson Correlation	0.776**	.728**	1		
	Sig. (2-tailed)	0.000	.000			
Pb	Pearson Correlation	0.661**	.670**	.951**	1	
	Sig. (2-tailed)	0.000	.000	.000		
As	Pearson Correlation	0.480*	.940**	.872**	.798**	1
	Sig. (2-tailed)	0.018	.000	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5: Bioaccumulation Factors (BAF) of the Two Cassava Varieties in the Area

Heavy Metals	TMS 30572 1	TMS 92/0326
Cd	0.0097	0.0209
Cr	0.0161	0.1477
Hg	0.0057	0.0785
Pb	0.0446	0.0056
As	0.1050	0.2675

Key: TMS=Tropical Manihot Selection, 305721 and 92/0326 =unique identified