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Original Research Article

Heavy Metals Health-Risk Assessment of *Zingiber officinale* in Akwa Ibom and Enugu following High Consumption During the COVID-19 Era

Onyeukwu Nkechi Jovita[1], Urua Scholastica Patrick[1], Awala Victoria Ebisindor[2], Bunu Samuel Jacob[3], Onwuka Ngozi Amanda[4], Osom Unwana Akpan[5]

[1]Department of Pharmacology and Toxicology, Faculty of Pharmacy, University of Uyo, Akwa Ibom, Nigeria
[2]Department of Healthcare Informatics, University of the Potomac, USA
[3]Department of Pharmaceutical and Medicinal Chemistry, Faculty of Pharmacy, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
[4]Department of Pharmacology and Therapeutics, Faculty of Basic Clinical Sciences, Rivers State University, Port Harcourt, Rivers State, Nigeria
[5]Health Centre, University of Uyo, Uyo, Akwa Ibom State, Nigeria

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Abstract: ***Background:*** The World Health Organization's designation of Corona Virus Disease - 2019 (COVID-19) as a global pandemic in 2020 shocked the world. There is no known treatment for the virus, although the FDA has licensed several vaccines for its prevention; thus, desperation within society has resulted in a growing use of medicinal plant-based therapies, such as *Azadirachta indica, Zingiber officinale, Allium sativum, Nigella sativa, and, Vernonia amygdalina* among others, that have been claimed to alleviate COVID-19 symptoms. ***Aim:*** the study assessed the health risk of some heavy metals associated with the consumption of Z. officinale rhizome in some selected Local Government Areas of Akwa Ibom (Southern Nigeria) and Enugu (Eastern Nigeria) States, where consumption was increased significantly due to COVID-19 pandemic. ***Method:*** Atomic absorption spectroscopy was used to quantify the amount of heavy metals in *Zingiber officinale* following standard digestion procedures. Health Risk Assessment was conducted using Estimated Daily Intake, Target Hazard Quotient, Hazard Index, Carcinogenic Risk as well overall statistical analysis, to ascertain the long-term health potential risk of consuming *Zingiber officinale* herbal supplements. ***Result:*** The mean concentration of arsenic, cadmium, and lead in *Z. officinale* rhizome ranges from 0.001 to 0.942 mg/kg, 3.403 to 4.386 mg/kg, and 0.002 to 0.244 mg/kg, respectively, while that of mercury, and nickel all locations was 0.001 mg/kg, and 1.377 to 3.100 mg/kg, respectively. ***Conclusion:*** All heavy metals but arsenic and mercury were higher in concentration than the prescribed limit, hence possess are potential risks among these locations in the future. The hazard quotient (HQ) values of all heavy metals were <1 in all the samples, thus relatively safe to consume the plant but with caution to checkmate arsenic or mercury poisoning.

Keywords: *Zingiber officinale*, ginger, COVID-19, Nigeria, Akwa Ibom, Enugu.

INTRODUCTION

The World Health Organization declared Corona Virus Disease - 2019 (COVID-19) a global pandemic on March 11, 2020, which upended the world. To combat the virus's spread, a global lockdown was implemented, along with other precautions [1,2]. Currently, there is no known cure for the virus, however the Food and Drug Administration (FDA) has approved various vaccinations for its prevention, such as Pfizer's Moderna®, AstraZeneca's Novavax®, Johnson-Johnson COVID-19 vaccines, and so on [3-5]. The known strains of the virus include Alpha (B.1.1.7), Beta (B.1.351), Gamma (P.1), and Delta (B.1.617.2) strains with Mu (B.1.621) strain being the newest. The virus is still a major threat as there is the emergence of new strains [6-8]. Desperation within the society resulted in an increasing interest in exploring choices of medicinal plant-based therapy. Among these plants include *Zingiber officinale, Nigella sativa, Allium sativum, Vernonia amygdalina, Azadirachta indica, and Eurycoma longifolia*, among others [9-13]. There have been allegations that certain natural therapies can help with some COVID-19 symptoms [14-17], but no

***Corresponding Author:** ONYEUKWU Nkechi Jovita
Department of Pharmacology and Toxicology, Faculty of Pharmacy, University of Uyo, Akwa Ibom, Nigeria

scientific studies back this up. At times, chloroquine and similar combinations have been observed to alleviate symptoms associated with COVID-19 infection [18-20].

Zingiber officinale Roscoe (ginger) belongs to the Zingiberaceae family and is one of the most widely utilized plants in Asia, Australia, and many other nations [21, 22]. *Zingiber officinale* rhizome contains a high concentration of phytocomponents that preserve cells and prevent body harm [23, 24]. Ginger may treat chronic disorders such as high blood pressure, upper respiratory tract ailments, heart disease, and lung diseases, while also promoting healthy aging. Powdered ginger is a buff-colored ground spice derived from the dried root [25]. Preserved or'stem' ginger is created by peeling and slicing fresh young roots and then cooking them in a thick sugar syrup. *Z. officinale* rhizome has been used to treat digestive issues (indigestion, flatulence, constipation, nausea), headaches, rheumatism, colds, and coughs [26]. In recent decades, *Z. officinale* rhizome has been intensively explored for its therapeutic characteristics using advanced scientific procedures, and several bioactive chemicals have been extracted from different regions of the plant [27, 28]. The use of *Z. officinale* rhizome has been shown to have antibacterial, analgesic, anti-inflammatory, antioxidant, antidiabetic, anticancer, nephroprotective, and hepatoprotective properties [21, 22, 29–31].

The majority of herbs' secondary metabolites are commercially relevant and used in a variety of medicinal substances. Flavonoids and phenolics are the most important classes of secondary metabolites and bioactive chemicals in plants [29]. Shogaol and gingerol are the most frequent bioactive chemicals identified in ginger, and they provide a variety of pharmacological effects. *Z. officinale* is cultivated primarily in Nigeria's northern regions, with Kaduna State being the largest producer in the north and Abia State being the largest producer in the south [32].

Figure 1: Fresh *Zingiber officinale* (ginger) rhizome

Ginger cultivation has been increasingly popular in Nigeria due to its economic and medical importance. According to TRIDGE's 2020 research on ginger production and consumption in Nigeria, around 37,000 metric tons of fresh ginger are produced each year. Out of this total, 10% is consumed fresh locally (Figure 1), while the remaining 90% is consumed dry. Approximately 20% of the dried ginger is consumed locally for various purposes, with the remaining 80% exported. However, with the outbreak of COVID-19 in Nigeria in 2020, there was an increase in the rate of consumption of ginger, mainly to prevent the contraction of the deadly virus [33, 34]. Approximately 11.86% of respondents to an investigation of people's knowledge and perceptions of COVID-19 in Nigeria claimed that ingesting gins, garlic, ginger, herbal mixtures, and African foods/soups were means of COVID-19 prevention [35]. Given the sensitivity of heavy metals in edible spices and foods, the presence of heavy metals such as arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), and nickel (Ni) was determined in samples of fresh Zingiber officinale Roscoe (Ginger) rhizomes available for public consumption [35].

Nigeria is a major producer and exporter of ginger, ranking third globally behind China and India [36]. In 2013, Nigeria was the world's fifth-largest ginger grower [37]. Ginger's medicinal benefits are attributed to two primary components: non-volatile and volatile. The nonvolatile component is an oleoresin. The volatile component is primarily composed of sesquiterpene derivatives, which are responsible for the aroma. These mixes include (-)-zingiberene, (+)-curcumene, (-)-β-sesquiphelandrene, and β-bisabolene [38, 39]. Z. officinale rhizome contains 1–4% essential oil and oleoresin, but the main ingredient is sesquiterpene (53.57%) [40]. Approximately 28 components have been identified in the essential oil. The essential oil contains eudesmol (8.19%), γ-terpinene (7.88%), α-curcumene (7.28%), zingiberene (6.06%), alloaromadendrene (6.56%), α-pinene (5.76%), δ-cadinene (3.84%), elemol (3.39%), farnesal (3.45%), E-β-farnesene (3.57%), neril acetic acid derivative (2.8%), and β-myrcene (2.94%). [41]. Ginger contains several volatile sesquiterpenoids, including zingiberene, β-sesquiphellandrene, bisabolene, and farnesene, as well as trace monoterpenoids including cineol, citral, and β-sesquiphellandrene [42]. Gingerol is the primary nonvolatile component [43]. The bulb of Z. officinale is widely used because to gingerol, an active component. Similarly, it has amadaldehyde, paradols, gingerdiols, gingerdiacetates, gingerdiones, 6-gingersulfonic acid, and gingerenones [39].

A study in Ethiopia used flame atomic absorption spectroscopy (AAS) to determine the concentration of heavy metals in ginger samples and discovered that the concentration of zinc was relatively higher than the concentration of nickel in the samples; both were below the WHO/FAO permissible limits and could not pose a health risk. However, the quantities of cadmium and lead metals were less than the method's detection limit [44]. Another study examined the heavy metal content of *Zingiber officinale* and determined that the soil is the primary but not the only source of metal accumulation in ginger and other plants [45]. Several regulatory agencies have set exposure limits for certain heavy metals (Table 1). Nigerians use ginger in a variety of ways, including as a spice in stews and porridges, and as a beverage to cure colds, nausea, migraines, hypertension, and other ailments. Ginger is used to flavor a range of foods, including ginger cookies, gingerbread, soft drinks, liqueur, carbonated beverages, ginger cocktails, and bitters. Ginger is used by manufacturers to produce oleoresin, essences, tinctures, ginger oil, and other goods. Analysis of heavy metals in food and other consumables [52, 53], medications, and herbal items is required to protect end users' health and prevent potential adverse events [54]. Given the increased consumption of ginger and growing awareness of the health risks associated with heavy metals in ginger, it is necessary to assess the presence of these heavy metals (Pb, Cd, Ni, Hg, and As) in the species. As a result, this study evaluated the health risk of some heavy metals associated with Z. officinale rhizome consumption in some selected Local Government Areas of Akwa Ibom (Southern Nigeria) and Enugu (Eastern Nigeria), where consumption has increased significantly since the COVID-19 pandemic. It is critical to ensure that when we ingest Z. officinale rhizome to avoid illness or alleviate some of its symptoms, we are not doing ourselves more harm than good.

Table 1: Maximum permissible limit (MPL) of some heavy metals

Heavy Metal	MPL (NMW) ppm	MPL (IW) ppm**	MPL (PL) mg/kg[#]
Arsenic	0.010[a, b]	0.100	-
Cadmium	0.003[a], 0.005[b]	0.010	0.02
Lead	0.010[a], 0.050[b]	0.065	2.00
Mercury	0.001[a], 0.002[b]	0.500	-
Nickel	0.200**, 0.100[b]	1.400	10.00

***Legend**: **[46], **[47], **[48]; [a][49]; [b][50]; [#][51]; PL – plants; IW – irrigation water; NMW – natural mineral water*

METHODS

The Study Area

The study areas (Figure 2), which were chosen using a map to avoid proximity, were nine Local Government Areas (LGAs), three senatorial districts in Akwa Ibom State and two LGAs in Enugu State. The three LGAs chosen for the Eket senatorial district are Oron, Ibeno, and Ikot Abasi. The three LGAs chosen for the Uyo senatorial district are Uyo, Nsit Atai, and Ibiono Ibom. The three LGAs designated for the Ikot Ekpene senatorial district are Ikot Ekpene, Ukanafun, and Ika. Enugu State, on the other hand, included two LGAs: Enugu South and Nsukka. Akwa Ibom State was picked to symbolize an oil-producing state, whereas Enugu State, which does not produce oil, was chosen for comparison.

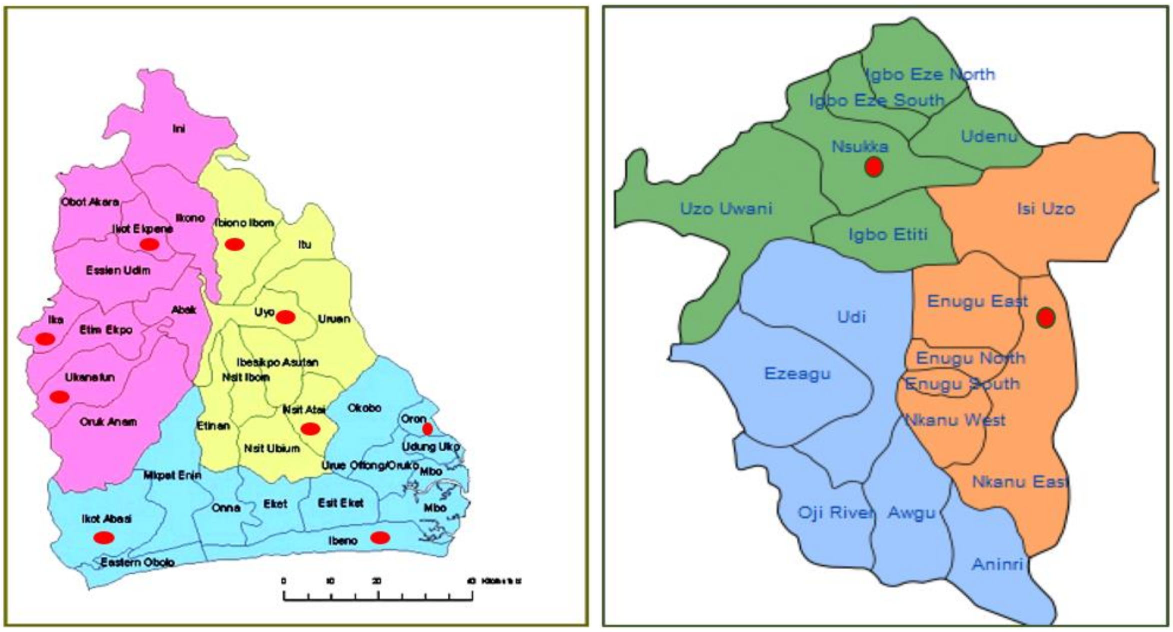

Figure 2: (A) Map of Akwa Ibom State showing LGAs where samples were collected (https://akwaibomstate.gov.ng/). (B) Map of Enugu State showing LGA where samples were collected (www.researchgate.net)

Plant collection and preparation

Fresh rhizomes of Zingiber officinale were acquired at random from five separate stores in each market across the eleven Local Government Areas and suitably labeled. Each sample was completely cleaned of dirt particles and air-dried for approximately an hour. The samples were then cut into smaller pieces and dried at 200oC in a Gallenkamp Hot Box Bench Top Laboratory Oven before being crushed into fine particles and passing through a 20mm/10 mesh sieve. A mass of 0.5 g sieved powder from the samples was combined with 1 mL of HNO_3 (95-97%) and 100 mL of distilled water. The preparation was heated in a fume cupboard with a water bath. The appearance of white vapors indicated the end of acid-wet digestion, at which point the sample had evaporated to 20 mL of its original volume. The digests were allowed to cool, then diluted with distilled water, filtered into a 100 mL volumetric flask, filled to the mark with distilled water, and mixed to ensure homogeneity. Samples were then placed in sample bottles. Calibration standards and blanks were made simultaneously with the samples [55, 56]. The filtrate from wet digestion was then tested for arsenic, cadmium, lead, mercury, and nickel using the SOLAAR 969 Atomic Absorption Spectrometer (AAS). The AAS was fueled by acetylene. Standard solutions of the respective metals were used for instrument calibration and all chemicals were of analytical grade [55, 56].

Health Risk Assessment

Due to a lack of agreed-upon thresholds for acceptable maximum carcinogenic and non-carcinogenic risk levels in Nigeria, this study used USEPA models and threshold values to analyze potential human health concerns posed by heavy metal contamination. The heavy metal contamination/pollution danger in urban residential areas was assessed using the USEPA's multi-phase and multi-component risk assessment methodology [57]. The health risk assessment was calculated using the estimated daily intake (EDI), target hazard quotient (THQ), health index (HI), and carcinogenic risk (CR) of exposure to *Zingiber officinale* rhizome.

Estimated Daily Intake (EDI):

Throughout the exposure evaluation stage, EDI (or CDI when exposure is chronic) is used to calculate the oral exposure dosage of chemicals for both carcinogenic and non-carcinogenic risk assessments [58]. The estimated daily intakes of Zingiber officinale rhizome were determined using the method used in prior risk assessment research [59–61]. This was calculated using Equation 3.1 [61].

$$EDI = \frac{C_{metal} \times D_{food\ intake}}{BW\ average} \quad \text{.................. Equation 1}$$

EDI = Estimated daily intake,
C_{metal} = concentration of metal,
$D_{food\ intake}$ = food ingestion/intake rate in kg/person/day,
BW = body weight average.
$D_{food\ intake}$ or ingestion rate (IR) of the *Zingiber officinale* rhizome used was 0.5 – 3.0 g [62].
The body weights used were: adults (70 kg); adolescents (54.5 kg); and geriatrics (62.5 kg) [63, 64].

Target Hazard Quotient (THQ)

This was utilized to estimate the non-carcinogenic risk associated with heavy metal ingestion in Zingiber officinale rhizome. It is determined by dividing the possible exposure to the dose of the substance (hence referred to as the toxicant) by the reference dose at which no adverse health consequences are expected. THQ > 1 increases the likelihood of negative health impacts, while THQ < 1 decreases them [59 - 61].

$$THQ = \frac{Efr \times ED \times FIR \times C \times 10^{-3}}{RfDo \times BWaverage \times ATn} \quad \text{……… Equation 2}$$

Or

$$THQ = \frac{EDI}{RfDo} \quad \text{……………….. Equation 3}$$

Efr = exposure frequency (365 days per year)
ED = exposure duration in 55.8 years equivalent to an average life expectancy for Nigeria
F_{IR} = food ingestion rate in mL/kg per person/day
C = concentration of metal in the *Zingiber officinale* rhizome in mg/kg
RfDo = reference dose in mg/kg/day
ATn = average exposure time for non-carcinogens in days
EDI = estimated daily intake [60].

The reference doses adopted for this study were: Cd = 0.0005 mg/kg, Pb = 0.0036 mg/kg, As = 0.0003 mg/kg, Hg = 0.0003 mg/kg, and Ni = 0.02 mg/kg [65 – 67].

Hazard Index

The hazard index calculates the danger associated with a metal mixture by adding the corresponding target quotients. When HI exceeds one, there is an unacceptable risk of noncarcinogenic consequences. However, HI < 1 indicates an acceptable and non-carcinogenic risk level [61].

$$HI = \sum_{k=1}^{n} THQ = HI = \sum_{k=1}^{n} CDIk/RFDk \quad \text{………… Equation 4}$$

HI = hazard index: summation of all metals THQ found in *Zingiber officinale* rhizome
CDI_k = metal daily intake
RFD_k = value for the metal chronic reference dose.

Carcinogenic Risk (CR)

The risk of cancer from exposure to a carcinogen or potential carcinogen is best assessed and measured using a slope factor. The cancer slope factor calculates an individual's lifetime probability of developing cancer as a result of oral pollutant exposure [68]. Furthermore, cancer slope factors are carcinogenic potency estimates that compare the projected daily intake of a chemical over a lifetime of exposure to the lifetime risk of tumor growth. The USEPA model [61] was used to estimate the cancer risk associated with the heavy metal content of the Zingiber officinale rhizomes.

Cancer Risk = CDI x CSF ……………… Equation 5

CDI = chronic daily intake of potent carcinogenic agents (mg/kg/day)
CSF = ingestion cancer slope factor of hazardous substances (mg/kg/day).

The cumulative or total cancer risk shows the probability of cancer due to lifetime exposure to two or more carcinogenic substances or due to multiple exposure routes to a potential carcinogen [61].

Total cancer risk (TCR) = $\sum_{k=1}^{n} CDIkCSFk$ ………………..Equation 6

CDI_k = chronic daily intake (mg/kg/day) of substance k, CSF_k = ingestion cancer slope factor for substance k (mg/kg/day).

From previous studies, 10^{-6} – 10^{-4} (i.e. 1 in 1,000,000 to 1 in 10,000) is the most acceptable safe range for cancer risk [60, 61, 69]. The ingestion cancer slope factors adopted in this study were 0.0085, 0.38, 0.91, and 1.50 mg/kg/day for Pb, Cd, Ni, and As, respectively [69–71].

Assumptions for Risk Assessment:

The assumptions for assessing human health risks were as follows: One kilogram was supposed to be 1,000 grams. Heavy metal exposure (Efr) is projected to occur 365 days per year. The heavy metal exposure duration (ED) was estimated to be 55.8 years, which is the same as Nigeria's average life expectancy. The average body weight (BW) for the researched categories was calculated to be 70 kg for adults, 54.5 kg for children 12 and older, and 62.5 kg for seniors [69]. The US Environmental Protection Agency (USEPA) and earlier risk assessment studies were used to determine oral reference values for heavy metals, as well as the oral cancer slope factor and conversion factor.

Statistical Analysis

Data entry and early summaries were completed using a Microsoft Office Excel spreadsheet. The generated data was statistically analyzed using SPSS version 17. The statistical significance between the groups was determined using a one-way analysis of variance (ANOVA) followed by the Duncan® post hoc test. Results were provided as mean ± standard deviation (SD) of the mean, with values less than ($p < 0.05$) indicating statistical significance.

RESULTS

The mean concentration of arsenic, cadmium and lead in *Zingiber officinale* rhizome consumed in Akwa Ibom and Enugu States ranges from 0.001 to 0.942 mg/kg, 3.403 to 4.386 mg/kg, and 0.002 to 0.244 mg/kg, respectively. While the mean concentration of mercury, and nickel in *Zingiber officinale* rhizome consumed in Akwa Ibom and Enugu States for all locations was 0.001 mg/kg, and 1.377 to 3.100 mg/kg, respectively.

Table 1: Estimated daily intake (EDI) and target hazard quotient (THQ) of arsenic in *Z. officinale* rhizome consumed in Akwa Ibom and Enugu States

Location	Concentration (mg/kg)	Children		Adult		Geriatrics	
		EDI (mg/kg)	THQ (mg/kg)	EDI (mg/kg)	THQ (mg/kg)	EDI (mg/kg)	THQ (mg/kg)
Nsit Atai	0.001	9.174×10^{-9}	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ikot Abasi	0.001	9.174×10^{-9}	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ibeno	0.001	9.174×10^{-9}	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Oron	0.001	9.174×10^{-9}	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ikot Ekpene	0.001	9.174×10^{-9}	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ukanafun	0.001	9.174×10^{-9}	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ika	0.942	8.642×10^{-6}	2.881×10^{-2}	4.037×10^{-5}	1.346×10^{-1}	4.522×10^{-5}	1.507×10^{-1}
Ibiono Ibom	0.005	4.587×10^{-8}	1.529×10^{-4}	2.143×10^{-7}	7.143×10^{-4}	2.400×10^{-7}	8.000×10^{-4}
Uyo	0.009	8.257×10^{-8}	2.752×10^{-2}	3.857×10^{-7}	1.929×10^{-5}	4.320×10^{-7}	1.440×10^{-3}
Nsukka	0.005	4.587×10^{-8}	1.529×10^{-4}	2.143×10^{-7}	7.143×10^{-4}	2.400×10^{-7}	8.000×10^{-4}
Enugu South	0.227	2.083×10^{-8}	6.942×10^{-2}	9.729×10^{-6}	4.864×10^{-4}	1.090×10^{-5}	3.632×10^{-2}

Table 2: Estimated daily intake (EDI) and target hazard quotient (THQ) of cadmium in *Z. officinale* rhizome consumed in Akwa Ibom and Enugu States

Location	Concentration (mg/kg)	Children		Adult		Geriatrics	
		EDI(mg/kg)	THQ	EDI (mg/kg)	THQ	EDI (mg/kg)	THQ
Nsit Atai	4.307	3.951×10^{-5}	0.079	1.846×10^{-4}	0.369	2.067×10^{-4}	0.413
Ikot Abasi	3.993	3.663×10^{-5}	0.073	1.711×10^{-4}	0.342	1.917×10^{-4}	0.383
Ibeno	3.729	3.421×10^{-5}	0.068	1.589×10^{-4}	0.320	1.790×10^{-4}	0.358
Oron	3.635	3.335×10^{-5}	0.067	1.558×10^{-4}	0.312	1.745×10^{-4}	0.349
Ikot Ekpene	4.386	4.024×10^{-5}	0.080	1.880×10^{-4}	0.376	2.105×10^{-4}	0.421
Ukanafun	3.805	3.491×10^{-5}	0.070	1.631×10^{-4}	0.326	1.826×10^{-4}	0.365
Ika	4.012	3.681×10^{-5}	0.074	1.719×10^{-4}	0.344	1.926×10^{-4}	0.385
Ibiono Ibom	4.095	3.757×10^{-5}	0.075	1.755×10^{-4}	0.351	1.966×10^{-4}	0.393
Uyo	3.612	3.314×10^{-5}	0.066	1.548×10^{-4}	0.310	1.734×10^{-4}	0.347
Nsukka	3.403	3.122×10^{-5}	0.062	1.458×10^{-4}	0.292	1.633×10^{-4}	0.327
Enugu South	3.966	3.639×10^{-5}	0.073	1.700×10^{-4}	0.340	1.904×10^{-4}	0.381

Table 3: Estimated daily intake (EDI) and target hazard quotient (THQ) of lead in *Z. officinale* rhizome consumed in Akwa Ibom and Enugu States

Location	Concentration (mg/kg)	Children		Adult		Geriatrics	
		EDI (mg/kg)	THQ	EDI (mg/kg)	THQ	EDI mg/kg)	THQ
Nsit Atai	0.008	7.339×10^{-8}	2.039×10^{-5}	3.429×10^{-7}	9.524×10^{-5}	3.840×10^{-7}	1.067×10^{-4}
Ikot Abasi	0.009	8.257×10^{-8}	2.294×10^{-5}	3.857×10^{-7}	1.071×10^{-4}	4.320×10^{-7}	1.200×10^{-4}
Ibeno	0.004	3.670×10^{-8}	1.020×10^{-5}	1.714×10^{-7}	4.762×10^{-5}	1.920×10^{-7}	5.333×10^{-5}
Oron	0.004	3.670×10^{-8}	1.020×10^{-5}	1.714×10^{-7}	4.762×10^{-5}	1.920×10^{-7}	5.333×10^{-5}
Ikot Ekpene	0.008	7.339×10^{-8}	2.039×10^{-5}	3.429×10^{-7}	9.524×10^{-5}	3.840×10^{-7}	1.067×10^{-4}
Ukanafun	0.002	1.835×10^{-8}	5.097×10^{-6}	8.571×10^{-8}	2.381×10^{-5}	9.600×10^{-8}	2.667×10^{-5}
Ika	0.244	2.239×10^{-6}	6.218×10^{-4}	1.046×10^{-5}	2.905×10^{-3}	1.171×10^{-5}	3.253×10^{-3}
Ibiono Ibom	0.187	1.716×10^{-6}	4.765×10^{-4}	8.014×10^{-6}	2.226×10^{-3}	8.976×10^{-6}	2.493×10^{-3}
Uyo	0.041	3.761×10^{-7}	1.045×10^{-4}	1.757×10^{-6}	4.881×10^{-4}	1.968×10^{-6}	5.467×10^{-4}
Nsukka	0.100	9.174×10^{-7}	2.548×10^{-4}	4.286×10^{-6}	1.190×10^{-3}	4.800×10^{-6}	1.333×10^{-3}
Enugu South	0.096	8.807×10^{-8}	2.446×10^{-4}	4.114×10^{-6}	1.143×10^{-3}	4.608×10^{-6}	1.280×10^{-3}

Table 4: Estimated daily intake (EDI) and target hazard quotient (THQ) of mercury in *Z. officinale* rhizome consumed in Akwa Ibom and Enugu States

Location	Concentration (mg/kg)	Children		Adult		Geriatrics	
		EDI (mg/kg)	THQ	EDI (mg/kg)	THQ	EDI (mg/kg)	THQ
Nsit Atai	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ikot Abasi	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ibeno	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Oron	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ikot Ekpene	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ukanafun	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ika	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Ibiono Ibom	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Uyo	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Nsukka	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}
Enugu South	0.001	$9. 174 \times 10^{-3}$	3.058×10^{-5}	4.286×10^{-8}	1.429×10^{-4}	4.800×10^{-8}	1.600×10^{-4}

Table 5: Estimated daily intake (EDI) and target hazard quotient (THQ) of nickel in *Z. officinale* rhizome consumed in Akwa Ibom and Enugu States

Location	Concentration (mg/kg)	Children		Adult		Geriatrics	
		EDI (mg/kg)	THQ	EDI (mg/kg)	THQ	EDI (mg/kg)	THQ
Nsit Atai	1.646	1.510×10^{-5}	7.550×10^{-4}	7.054×10^{-5}	3.527×10^{-3}	7.901×10^{-5}	3.950×10^{-3}
Ikot Abasi	1.59	1.459×10^{-5}	7.294×10^{-4}	6.814×10^{-5}	3.407×10^{-3}	7.632×10^{-5}	3.816×10^{-3}
Ibeno	1.377	1.263×10^{-5}	6.317×10^{-4}	5.901×10^{-5}	2.951×10^{-3}	6.610×10^{-5}	3.305×10^{-3}
Oron	1.384	1.270×10^{-5}	6.349×10^{-4}	5.931×10^{-5}	2.966×10^{-3}	6.643×10^{-5}	3.322×10^{-3}

Ikot Ekpene	1.519	1.394 x 10^{-5}	6.968 x 10^{-4}	6.510 x 10^{-5}	3.255 x 10^{-3}	7.291 x 10^{-5}	3.646 x 10^{-3}
Ukanafun	1.533	1.406 x 10^{-5}	7.032 x 10^{-4}	6.570 x 10^{-5}	3.285 x 10^{-3}	7.358 x 10^{-5}	3.679 x 10^{-3}
Ika	1.993	1.828 x 10^{-5}	9.142 x 10^{-4}	8.541 x 10^{-5}	4.271 x 10^{-3}	9.566 x 10^{-5}	4.783 x 10^{-3}
Ibiono Ibom	2.599	2.384 x 10^{-5}	1.192 x 10^{-3}	1.114 x 10^{-4}	5.569 x 10^{-3}	1.248 x 10^{-4}	6.238 x 10^{-3}
Uyo	2.827	2.594 x 10^{-5}	1.297 x 10^{-3}	1.212 x 10^{-4}	6.058 x 10^{-3}	1.357 x 10^{-4}	6.785 x 10^{-3}
Nsukka	3.010	2.762 x 10^{-5}	1.381 x 10^{-3}	1.290 x 10^{-4}	6.450 x 10^{-3}	1.445 x 10^{-4}	7.224 x 10^{-3}
Enugu South	3.100	2.844 x 10^{-5}	1.422 x 10^{-4}	1.329 x 10^{-4}	6.643 x 10^{-3}	1.488 x 10^{-4}	7.440 x 10^{-3}

Table 6: Hazard index of heavy metals in *Z. officinale* rhizome consumed in Akwa Ibom and Enugu States

Location	Hazard Index					
	$HI = \sum_{k=1}^{n} THQ$			$HI = \sum_{k=1}^{n} CDIk/RFDk$		
	Children	**Adult**	**Geriatrics**	**Heavy Metals**	**Children**	**Adult**
Nsit Atai	0.080	0.373	0.417	Arsenic	1.667	10.000
Ikot Abasi	0.074	0.346	0.387			
Ibeno	0.069	0.323	0.362	Cadmium	1.000	6.000
Oron	0.068	0.315	0.353			
Ikot Ekpene	0.081	0.379	0.425	Lead	0.139	0.833
Ukanafun	0.071	0.330	0.369			
Ika	0.104	0.486	0.544	Mercury	1.667	10.000
Ibiono Ibom	0.077	0.360	0.403			
Uyo	0.068	0.317	0.356	Nickel	0.025	0.150
Nsukka	0.064	0.301	0.337			
Enugu South	0.082	0.348	0.426			

Table 7: Carcinogenic risk of heavy metals in *Z. officinale* rhizome consumed in Akwa Ibom and Enugu States

Heavy Metals	Children	Adult
Arsenic	7.50 x $10^{\wedge -4}$	4.50 x $10^{\wedge -3}$
Cadmium	1.90 x $10^{\wedge -4}$	1.14 x $10^{\wedge -3}$
Lead	4.25 x $10^{\wedge -6}$	2.55 x $10^{\wedge -5}$
Mercury	-	-
Nickel	4.55 x $10^{\wedge -4}$	2.73 x $10^{\wedge -4}$

DISCUSSION

Exposure to inorganic arsenic is dangerous due to its cancer-causing properties. Inorganic arsenic is significantly more harmful than organic arsenic. The arsenic concentration was highest in the Ika LGA. Furthermore, samples from Enugu South L.G.A. had a rather high level of arsenic. This could be the result of excessive farming operations by people, incorrect chemical application (pesticides, herbicides, fertilizers), or indiscriminate waste dumping. In Nigeria as a whole, waste disposal is unregulated; these wastes can combine to produce hazardous compounds that leach into the soil, eventually penetrating plants and animals. A study found that arsenic levels in farmed ginger samples varied from 9.24 to 11.17 mg/kg, which was significantly higher than the maximum value in this study [45]. The ecological correlation between the arsenic content in well water in China (Taiwan Province) and deaths from various tumors that were malignant showed a great association with the arsenic content in well water (ranging from 0.35 to 1.14 mg/l, with a median of 0.78 mg/l) and liver cancer, nasal cavity cancer, lung cancer, skin cancer, bladder cancer, and kidney cancer in both men and women, as well as hyperpigmentation, hyperkeratosis, gangrene, and prostate cancer in men.

Cadmium was found to be dispersed equally throughout the soil. The lowest and highest cadmium concentrations found in this study came from Nsukka and Ikot Ekpene LGAs, respectively. The content of cadmium in this investigation exceeded the allowable limit of 0.02 mg/kg [73]. Concentrations of cadmium in samples studied in this study exceed other reports, that showed that cadmium levels were 0.92 to 2.27 mg/kg in India [74]. Another study conducted in the Odo-Ori market, Iwo, Nigeria recorded 0.30 mg/kg of cadmium [75]. Cadmium is a non-essential metal found in food and natural fluids that accumulates primarily in the kidneys and liver. It is primarily obtained from a variety of environmental pollution sources and occurs in massive amounts in the environment as a result of human activities such as the use of fossil fuels, the combustion of metallic minerals, and the combustion of trash. Cadmium compounds can be absorbed by plants when sewage sludge escapes into agricultural land, where they play an important role in the food chain and accumulate in many organs of the human body. Cigarette smoke is another potential source of exposure. Itai-itai ("it hurts-it hurts") appears to be a cadmium-related disease characterized by severe back and joint discomfort, bone fragility, and atrophy [76].

Lead was also discovered to be evenly spread throughout the soil. The minimum and maximum lead concentration readings obtained in this study were from the Ukanafun and Ika LGAs, respectively. The content of lead in this investigation was less than the allowed limit of 2.00 mg/kg [73]. Lead contents in the samples analyzed in this study were substantially lower than in previous reports, when lead concentrations in India ranged between 0.5 and 12.60 mg/kg [74]. Studies on heavy metals in spices collected from Polish markets revealed that lead concentrations ranged from 0.21 to 0.78 mg/kg [77]. Lead was previously measured at an average of 0.26 mg/kg [78]. Another study on ginger showed lead in substantially greater quantities, ranging from 3.44 mg/kg (Shimla, HP) to 8.83 mg/kg from Kolkata, India [79]. Lead is widely used in the acid battery industry around the world. Furthermore, it is widely used in the manufacture of munitions, pipes, cables, alloys, and paint. Lead contamination is primarily generated by untreated wastewater from industries such as battery production, coatings, automobiles, aviation, and steel, printing, pigments, fuels, photographic materials, and explosives production [80]. Lead is not an essential trace mineral in human or animal nutrition. It can be harmful to animals, including humans, even in low dosages due to bioaccumulation and bio-magnification in the food chain. Other sources of lead include gasoline. It is recommended that unleaded gasoline be used, however there is no monitoring in Nigeria to ensure that this policy is followed. Pollution from food, water, air, soil, and consumer products causes the body to absorb lead [81].

The concentration of mercury discovered in this investigation was negligible when compared to prior studies in which Solan samples (0.25 mg/kg) contained mercury levels that exceeded the safety limit of 0.2 mg/kg [45]. Previous research has found significant heterogeneity in mercury levels in Brazilian medicinal plants, ranging from 0.04 mg/kg in artichoke to 16.3 mg/kg in ginseng. [82]. Cosmetics, household bleach, acids, and corrosive chemicals are some of the most common sources of mercury in the environment. Excessive mercury exposure is associated with a number of unfavorable health outcomes, including damage to the central nervous system (neurotoxicity) and the kidney. Once released, mercury persists in the environment and cycles in many forms between air and water, as well as sediments in the soil and biota, before being remobilized. Mercury's effects are particularly worrying for pregnant or breastfeeding women and young children since it can cross the blood-brain barrier and affect brain development [52].

Nickel concentrations were higher in samples from Enugu South and Nsukka LGAs than in others. The larger amount in the two samples could be attributable to Z. officinale's metal affinity, which results in increased uptake from the soil, as nickel was found to be uniformly distributed throughout the soil. However, the levels remained below the permissible limit of 10.00 mg/kg [73]. The present study's nickel concentration is lower than that determined in Ethiopia in prior research (5.46-8.40 mg/kg) [83]. The current study also had a lower nickel concentration than that found in Ghana (43 g/kg) [84]. Nickel is involved in a variety of bodily functions, including enzyme activity. It may be advantageous to activate some enzyme systems in trace amounts, but its toxicity becomes more apparent at increasing concentrations. However, nickel poisoning in humans is a rare occurrence because its absorption by the body is quite low [85].

Estimating heavy metal exposure levels is critical in determining organismal health risk [86]. There are various ways of exposure to people, but the food chain is the most relevant. Tables 1-5 show that the five heavy metals studied are ingested below the WHO/FAO's recommended maximum tolerated daily intake (PMTDI) of 0.21 mg/person per day [48, 49]. Tables 1-5 demonstrate that all heavy metals have hazard quotient (HQ) values of less than one. When HQ surpasses one, it indicates that exposure may have health problems [87]. High HQ has significant carcinogenic health concerns to consumers. High Pb HQ levels have been found in vegetable samples from China and India [88, 89]. As a result, estimating the hazard index (HI), which takes into account chemical combinations, is critical in determining the various consequences of heavy metals. Tables 6 and 7 illustrate the heavy metal hazard index of *Z. officinale* rhizome ingested in Akwa Ibom and Enugu states, respectively. When the HI exceeds unity, it indicates that ingesting the meal can have health consequences [90, 91].

Metal contamination of medicinal plants varied depending on plant variety, collection site, and even climate within the same city [92]. The statistics indicate that soil is not the only source of heavy metals. Bioaccumulation can be influenced by a species' genetic tendency as well as other geoclimatic factors [93, 94]. Because ginger is used in small amounts, typically as a spice and flavoring, no long-term negative impacts are envisaged, as long as dangerous metal levels are far within the recognized authorized limits and provisional tolerated weekly consumption as specified by various regulatory agencies [93].

CONCLUSION

Given the global demand and popularity of Z. officinale rhizome, assessing its health risks was critical. The Z. officinale rhizome taken from several areas in Akwa Ibom and Enugu states contains heavy metals in varying amounts. All heavy metals except arsenic and mercury had concentrations higher than the allowed limit, posing future concerns in these places. The hazard quotient (HQ) values of all heavy metals were <1 in all samples, making the plant relatively safe to ingest. However, vigilance should be exercised to prevent arsenic or mercury poisoning. It demonstrates that the soil, while not the primary source of these elements, plays a major role in influencing the concentration of heavy metals in plants. As a result, regulatory and supervisory organizations should conduct safety assessments of raw materials used as food/ingredients and herbal preparations, as well as aid farmers in carefully selecting the type and location for planting.

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