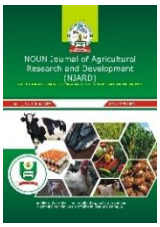
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Evaluation of Heavy Metal Concentrations and Associated Human Health Risks in Wild Oyster Mushroom (*Pleurotusostreatus*) from Southeastern Nigeria

Iroegbulam C [1], Nwoko C.O [1], Okeke P.N [1], Njoku-Tony R. F [1], Irokwe I.F [2].

[1] *Department of Environmental Management, Federal University of Technology, Owerri.*
[2] *Department of Soil Science and Technology, Federal University of Technology, Owerri.*
Corresponding author: chrisiroegbulam@gmail.com

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Abstract

The detrimental effects of heavy metals on food substances are concerning because they pose a threat to human health and food security in general. This study evaluated heavy metal concentrations and assessed the associated human health risks in wild oyster mushroom (Pleurotusostreatus) from southeastern Nigeria. Using stratified random sampling method, representative mushroom samples were collected from the five states of southeastern Nigeria (Abia, Anambra, Ebonyi, Enugu and Imo). Heavy metals were measured with a Varian Spectra AA 200 Atomic Absorption Spectrophotometer. Duncan's Multiple Range Test (DMRT) was used to differentiate significant means at a 5% probability level after the data was analyzed using analysis of variance (ANOVA). HMs (Pb, Ni, Cr, Fe, Cd, As, Zn, Cu, and Hg) in the mushrooms varied significantly across the locations with their distribution decreasing in the order of Zn > Cu > Fe > Pb > Ni > Cr > Hg > Cd > As. Greater concentrations of most of the heavy metals including Cd(0.03±0.01-1.41±0.02 mgkg-1), As (0.02±0.07-0.43±0.001 mgkg-1), Cu(9.63±0.07-23.07±0.18 mgkg-1) and Hg(0.04±0.06-1.95±0.07 mgkg-1) were obtained in Ebonyi, Anambra had more concentrations of Fe(1.82±0.07-3.86±0.06 mgkg-1) and Zn(18.56±0.5-50.64±0.04 mgkg-1), Enugu state had more concentrations of Pb(1.01±0.02-3.30±0.06) and Ni(0.29±0.05-1.49±0.013 mgkg-1) whereas Cr(0.34±0.001-1.73±0.03 mgkg-1) was greater in Abia state. Additionally, most of the heavy metals' carcinogenic health risk had values below 10-4, which generally suggested an acceptable carcinogenic risk for both adults and children. Although most risk assessment findings showed uncontaminated to low contamination, indicating that the sampled mushrooms are safe, it is nevertheless vital to maintain a careful eye on the heavy metal profiles because heavy metals can bioaccumulate in living tissue over time.

Keywords: accumulation, edible, mushrooms, heavy metal, oyster, Southeastern.

1.0 Introduction

Mushrooms are heterotrophic eukaryotes that belong to the kingdom fungi (Rashid *et al*., 2018). The reproductive structure that bears spores is referred to as the fruiting body of the fungus and is known as the mushroom (Rashid *et al*., 2018). From the more than 70,000 different species of mushrooms found so far, only about 2000 species are regarded as edible mushrooms, including the following: Oyster mushrooms (*Pleurotus ostreatus*), *Agaricus bisporus*, portobello mushrooms, straw mushrooms, enokitake and shiitakes (Chaurasia *et al*., 2019). In many countries, people prefer to consume wild mushrooms rather than cultivated ones, and even in the developed nations, this preference is believed to

be spreading (Agrahar-Murugkar & Subbulakshmi, 2005).

Southeastern Nigeria is a high rainfall area and is one of the world's wettest regions. During the rainy season (April–September), the region's high humidity levels produce ideal atmospheric conditions for the growth of a variety of fungi, including edible Macromycetes (Falandysz, 2016). This are the period during which the residents of this area would pick and eat mushrooms (weighing more than 15 kg per year). Nowadays, nutrition has become the most critical issue for humans. Nutrition becomes especially vital when we take into consideration the intake of minerals, vitamins, and quality proteins. In addition to serving as good foods, mushrooms could even be used medicinally (Çağlarirmak, 2011). Driven by rising interest in natural, tropical, and ethnic foods, as well as hunger (high food and feeding costs) (Oguntoye *et al*., 2022), the market for wild edible mushrooms in southeast Nigeria is booming, providing consumers with more mushroom species. They stand out for their particular flavour, aroma, nutritional value, and therapeutic characteristics.

Although edible mushrooms are rich in essential nutrients, they can also absorb potentially toxic HMs, leading to accumulation of these toxins not only in the mushrooms themselves but also in the bodies of third-level consumers like man (Nowakowski *et al*., 2020; Igbiri *et al*., 2018; Alsafran *et al*., 2021; Onifade *et al*., 2016). In addition, in certain instances, heavy elements accumulated in the mushrooms can be at hazardous levels depending on their environmental concentrations (Chungu *et al*. 2019; Kokkoris *et al*. 2019; Sun *et al*. 2017) and concentration of macromolecules in the cell walls of each specific species (Ostos *et al*., 2015). Accumulation of HMs in humans takes place mainly through the consumption of contaminated foods (Achparaki *et al*. 2012). Toxic metals endanger human health by destroying cell membranes and DNA, as well as affecting protein function and enzyme activity (Witkowski *et al*., 2019). Due to their environmental persistence, heavy metals (HMs) can build up in living organisms after ingestion, resulting in bioaccumulation through repeated consumption (Masindi *et al*., 2021). For wild edible mushrooms in particular, ongoing monitoring of potentially hazardous trace elements in food is necessary (Fu *et al*., 2020).

Taking into consideration their hierarchical position in the food chain, it is assumed that the presence of elevated metal concentrations in mushrooms is highly significant due to the possible toxicological risk associated with their consumption (Zhu *et al*., 2011). So far, there have been many research works conducted with regards to the analysis of elemental concentration in fruiting bodies collected from various locations (Swisłowski *et al*., 2020), for example, Slovakia (Svoboda *et al*., 2000), the Czech Republic (Svoboda *et al*., 2002), Poland (Nowakowski *et al*., 2021), and Spain (García *et al*., 2009; Alonso *et al*., 2003), Portugal (Carvalho *et al*., 2005), Turkey (Mendil *et al*., 2005; Yamaç *et al*., 2007), China (Fu, *et al*., 2020; Zhu *et al*., 2011), Greece (Kokkoris *et al*., 2019). However, published results frequently differ greatly and typically involve a limited range of elements and/or locales (Dastan, 2017; Dastan, 2015; Panahi *et al*., 2016) while few have reported the determination of many elements in wild edible mushrooms in Nigeria (Orisakwe and Nduka, 2010; Nnorom *et al*., 2012; Nnorom *et al*., 2013; Ndimele *et al*., 2017; Ihugba *et al*., 2018; Ilechukwu and Okoye, 2020; Nwokeke and Enyoh, 2021; Usman *et al*., 2022; Ukaogo *et al*., 2024), Very few research have been conducted on the levels of several metals in mushrooms and the potential health concerns associated with metal intakes from mushroom consumption in various states of southeastern Nigeria (Nnorom *et al*., 2020). In southeastern Nigeria, wild oyster mushrooms have been gathered and eaten for generations, and they continue to play a significant role in regional diets and culinary customs. Despite this long-standing custom, there is still a dearth of information regarding their safety in terms of heavy metal contamination. Therefore, this study aimed to determine heavy metal concentrations and evaluate the associated non-carcinogenic and carcinogenic health risks of consuming wild oyster mushrooms collected from Southeastern Nigeria.

2.0 Materials and methods

2.1 Study Location

The research region, which is lying between 6°0'0" and 7°0'0" N and 7°0'0" and 8°0'0" E, is located in the five states of southeast Nigeria (Abia, Anambra, Ebonyi, Enugu, and Imo) (Fig. 1).

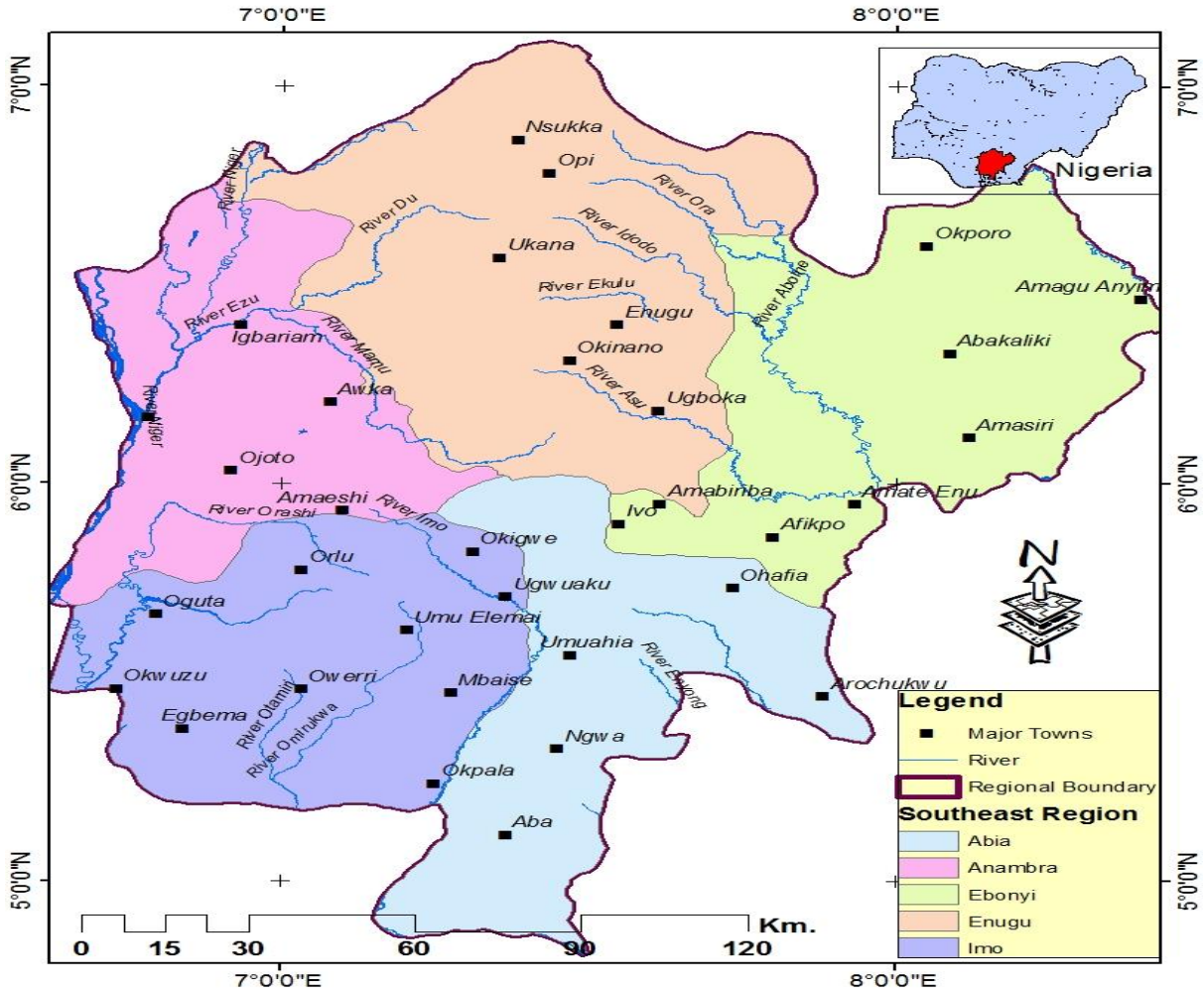


Figure 1: Map of the Study Areas - Southeast Nigeria

2.2 Soils and climatic conditions and vegetation of the study area

Egede (2013) stated that the soils of southeastern Nigeria are heterogeneous in nature, consisting of loose red earth soils mixed with sands, sandstone, clayey loam soil, either containing ferric or not, with shale rock formation underneath. Ezemonye & Emeribe (2012) also highlighted that the soils are formed from shale and sandstone rocks which are deep, porous, and acidic, and have low organic matter due to heavy leaching through rainfall activities. Ogbonna *et al*. (2011) stated that there are at least ten types of soil found in southeastern Nigeria, including Eutric Fluvisols, Hystic Fluvisols, Dystric Fluvisols, Rhodic Ferrosols, Lithosols, Dystric Gleysols, Eutric Gleysols, Eutric Nitosols, Dystric Cambisols, and Gleyic Cambisols. Southeastern soils have poor levels of organic matter, base status, and water storage capacity, and they are very vulnerable to rapid erosion and land degradation (Ufot *et al*., 2016). The area has a tropical climate with consistently high temperatures and a seasonal distribution of bimodal rainfall, with humidity and rainfall declining from the coast inland (Anyadike, 2002). According to Chukwu (2007), the average minimum and maximum temperatures were between 21 and 30°C along the coast and between 29 and 33°C in the interior or inlands. Igwe (2012) and Ezemonye and Emeribe (2012) state that southern Nigeria typically has considerable rainfall, ranging from approximately 2500 mm in the southernmost region towards the Atlantic to roughly 1500 mm yearly along the River Benue in the northern borders. The area is located in a lowland rainforest natural vegetation belt with evergreen trees in the south, which gradually gives way northward to rainfall-savanna forest with trees scattered with grass (Chukwu *et al*., 2009). The vegetation extends from the mangrove swamp along the coast to the derived savanna in the interior.

2.3 Field studies

Reconnaissance visit was carried out to identify the sampling sites between July to August 2025. Thereafter In Abia, Anambra and Ebonyi state 3 senatorial zones including Central, South and North

senatorial zones were selected whereas in Enugu and Imo 3 senatorial zones including North. Efforts were made to identify the edible mushroom specie (oyster *(Pleurotus Tuberregium)*) in eight sampling sites in Abia, Anambra and Enugu State and seven sampling sites in Ebonyi and Imo State as shown in Table 1. Triplicate samples were collected in each of the sampled sites given a total of 114 mushroom representative samples used for the study.

Table 1: Locations and coordinates of the sites studied

S/NO	Location	GPS Coordinates Latitude / Longitude		Town	LGA	Senatorial Zones
1	ABIA_1	5°27'31.2"N	7°29'35.7"E	Umuahia	Umuahia South	Abia Central
2	ABIA_2	5°27'52.7"N	7°26'34.0"E	Ubakala	Umuahia South	Abia Central
3	ABIA_3	4°54'47.1"N	7°24'54.4"E	Akwete	Ukwa East	Abia South
4	ABIA_4	5°15'58.7"N	7°32'47.3"E	Umuopara	Ukwa East	Abia South
5	ABIA_5	5°57'13.4"N	7°24'58.4"E	Isuochi	Umunneochi	Abia North
6	ABIA_6	5°56'25.5"N	7°29'25.4"E	Umuchieze	Umunneochi	Abia North
7	ABIA7	5°28'18.8"N	7°29'33.7"E	Olokoro	Umuahia South	Abia Central
8	ABIA_8	5° 48' 25.1028" N	7° 28' 53.0976" E	Imenyi	Isuikwuato	Abia North
1	ANA_1	6°06'05.0"N	6°48'48.2"E	Obosi	Idemili North	Anambra Central
2	ANA_2	5°49'14.8"N	6°49'14.5"E		Ihiala	Anambra South
3	ANA_3	5°58'26.3"N	7°07'49.7"E	Umuchu	Aguata	Anambra South
4	ANA_4	6°10'37.5"N	7°07'03.4"E	Isiagu	Awka South	Anambra Central
5	ANA_5	5°57'39.7"N	7°15'01.4"E	Umunze	Orumba South	Anambra South
6	ANA_6	6°32'39.9"N	6°56'27.8"E	Igbakwu	Ayamelum	Anambra North
7	ANA_7	6°17'48.7"N	6°51'56.9"E	Umuleri	Anambra East	Anambra North
8	ANA_8	6°34'11.0"N	6°54'03.6"E	Enugu otu	Anambra West	Anambra North
1	EBNY_1	5°53'33.4"N	7°53'42.4"E	Amasiri1	Afikpo North	Ebonyi North
2	EBNY_2	5°52' 39.9"N	7°52' 55.1"E	Amasiri2	Afikpo North	Ebonyi North
3	EBNY_3	5°53'28.4"N	7°55'59.6"E	Amachara	Afikpo North	Ebonyi North
4	EBNY_4	6°23'23.4"N	7°48'56.4"E	Ishiagu	Ishielu	Ebonyi Central
5	EBNY_5	6°14'32.3"N	8°06'30.1"E	Uwule	Ishielu	Ebonyi Central
		6°02'54.6"N	7°48'07.2"E	Okposi	Ohaozara	
6	EBNY_6			Okwu		Ebonyi South
7	EBNY_7	6°01'20.4"N	7°51'37.0"E	Umuka	Ohaozara	Ebonyi South
1	ENU_1	6°46'49.8"N	7°30'49.3"E	-	Nsukka	Enugu North
2	ENU_2	6°54'01.9"N	7°30'07.4"E	-	Udenu	Enugu North
3	ENU_3	6°15'12.5"N	7°16'22.5"E	-	Oji river	Enugu West
4	ENU_4	6°32'10.8"N	7°26'08.6"E	-	Nkanu East	Enugu East
5	ENU_5	6°19'55.6"N	7°30'10.9"E	-	Nkanu West	Enugu East
6	ENU_6	6°04'40.8"N	7°28'44.5"E	-	Awgu	Enugu West
7	ENU_7	6°23'05.6"N	7°30'50.4"E	-	Enugu South	Enugu East
8	ENU_8	6°23'04.4"N	7°17'35.6"E	-	Ezeagu	Enugu West
1	IMO_1	5°43'00.2"N	6°48'56.8"E	Oguta	Oguta	Imo West
2	IMO_2	5°44'24.2"N	7°06'46.6"E	Ama-Igbo	Oguta	Imo West
		5°31'28.1"N	7°15'47.9"E	Umuokeawa	Ahiazu Mbaise	
3	IMO_3			Ogbe		Imo East
4	IMO_4	5°29'02.4"N	7°16'07.3"E	Eziala	Aboh Mbaise	Imo East
5	IMO_5	5°33'14.9"N	7°23'04.9"E	Otoko	Obowo	Imo North
6	IMO_6	5°40'52.9"N	7°14'50.7"E	Umuduru	Onuimo	Imo North
7	IMO_7	5°27' 19.4"N	7°01'26.5"E	Nekede	Owerri West	Imo East

ANA=Anambra, EBNY=Ebonyi, ENU=Enugu,

2.4 Sample Preparation

The collected mushroom samples were cleaned of dust using distilled water, dried in the open for five days, then crushed into smaller pieces using a blender and kept in polyethylene bags until acid digestion for further HM analysis.

2.5 Acid digestion and metal analysis of mushroom samples

Ten milliliters of a nitric/perchloric acid combination (2:1 ratio) were added to digestion containers containing two grams of each pulverized sample. After an hour of digestion at 80°C, a clear, transparent solution was produced. The digests were

cooled before being filtered through Whatman No. 42 filter paper into 100 mL volumetric flasks and filled with distilled water. A Varian Spectra AA 200 Atomic Absorption Spectrophotometer was then used to examine the resultant solutions for heavy metals, including Pb, Ni, Cr, Fe, Cd, As, Zn, Cu, and Hg.

2.6 Health Risk Assessment

2.6.1 Non-Carcinogenic Risk Assessment

Hazard Quotient (HQ) is a word used to describe non-carcinogenic hazards . The likelihood that a person will have an adverse effect is represented by the unitless number HQ. Equation 1 (USEPA, 2004) defines it as the chronic reference dose (RfD) in mg/kg-day of a particular heavy metal, which is calculated by dividing the acceptable daily intake (ADI) or dose by the toxicity threshold value.

$HQ = \frac{\text{ADI}}{R\,f\,D}$ ……*equ. 1*

The total of all the HQs caused by individual heavy metals is the non-carcinogenic effect on the population for a given number of heavy metals. According to USEPA (2004), this is another word known as the Hazard Index (HI). This parameter's mathematical representation is shown in equation (2).

$\text{HI} = \sum_{k=0}^{n} \text{HQ k}$……...*equ. 2*

where HQk is the heavy metal k's value. The exposure population is unlikely to suffer adverse health impacts if the HI value is less than one; if it is greater than one, there may be cause for concern regarding possible non-carcinogenic effects (USEPA, 2004).

2.6.2 Carcinogenic Risk Assessment

When it comes to carcinogens, the risks are calculated as the increased likelihood that a person will get cancer over their lifetime due to exposure to the potential carcinogen. The excess lifetime cancer risk was determined using equation 3, which is:

$\text{Risk}\ pathway = \sum_{k=0}^{n} (\text{ADI})k\ .\ (\text{CSF})\ k$……*equ. 3*

where risk is the unit-less likelihood that a person will get cancer over their lifetime. For n heavy metals, the average daily intake for the kth heavy metal is ADIk (mg/kg/day) and the cancer slope factor is CSFk $(\text{mg/kg/day})^{-1}$. The slope factor directly relates an individual's increased risk of developing cancer to the estimated daily intake of the heavy metal averaged over a lifetime of exposure (USEPA, 2004).

2.7 Statistical Analysis

Data generated were subjected to Analysis of Variance (ANOVA) and means separated using least significant difference (LSD) at 5 % probability level. This test was used to distinguish locations on the bases of intrinsic HM and identify the state(s) exposed to high risk as a result of Oyster mushroom consumption. All analysis was conducted using Genstat Statistical Package Version 18.

3.0 Results and Discussion

3.1 Heavy metal concentrations of Oyster mushrooms studied (mg/kg)

The results showed that Pb concentrations in Oyster mushroom (*Pleurotus ostreatus*) varied significantly across the study locations. Within the sample points of Abia, highest value (1.33±0.06) was obtained in ABIA_7 while the lowest value (0.75±0.05) occurred in ABIA_2. However, values recorded in ABIA_7, 5 and 3 were not significantly different. Concentration of Pb in Anambra (ANA) was in a range of 2.17±0.02 - 0.24±0.02. Significantly greater value occurred in ANA_8 whereas the least value occurred in ANA_4. In Ebonyi State (EBNY), Pb differed significantly with EBNY_2 (Amasiri 2, Ebonyi North) showing greater value of 4.0±0.06 whereas the least value of 1.94±0.02 was recorded in EBNY_7. However, values obtained in EBNY_5 and EBNY_6 were not significantly different. In Enugu State (ENU), variation of Pb was significant with a range of 1.460±0.0 - 0.43±0.010. It was also observed that values obtained in ENU_4 and ENU_5 were not significantly different. Equally, in Imo (IMO), Pb concentrations obviously differed amongst the sampling points with highest value of 3.52±0.015 obtained in IMO_1 compared to the least value of 2.69±0.06 in IMO_3. In general, based on the mean values of Pb concentrations of the Oyster mushroom at the different location, it was observed that Enugu recorded significantly highest (3.30±0.06) followed by Imo (3.15±0.02), Abia (1.14±0.01), Anambra (1.10±0.05) and Ebonyi (1.01±0.02). It was observed that Pb concentrations of Abia, Anambra and Ebonyi did not vary significantly. This geographic variation in Pb concentrations clearly implies that one of the main factors influencing metal uptake is the local substrate composition, which may be impacted by different degrees of anthropogenic activity like mining or agricultural activities (Nnorom *et al*., 2020). However, all the mushroom samples examined in this investigation had Pb concentrations below the WHO-recommended threshold of 5.0 mg/kg (FAO/WHO,

2010). Lower Pb concentrations of less than 6 mg kg−1 were found in earlier studies on a variety of mushroom species collected from unpolluted areas (Kalač, 2013; Falandysz and Borovińska, 2013; Sun *et al*., 2017; Falandysz, 2018), including measurements on C. comatus, V. gloiocephalus, and A. bisporus (Isildak *et al*., 2007; Zhu *et al*., 2011; Sarikurkcu *et al*., 2012). Exceptions were reported from urban areas with concentrations between 10 and 15 mg kg^{-1} (García *et al*., 2009; Schlecht and Säumel, 2015) and highly contaminated mining sites with values up to 270 mg kg^{-1} (Kojta *et al*., 2012; Borovińska *et al*., 2019). According to environmental scientists, lead toxicity is harmful to plants, animals, and humans (Kumhomkul and Panich-pat, 2013).

Nickel has also been linked with lung cancer, and the tolerated upper intake level for this harmful metal is stated as 1 mg/day (Abdullah *et al*., 2017). Variation in Ni concentration was significant across locations studied. Values of Ni in Oyster mushroom are between 0.18±0.01 to 0.48±0.006, 0.04±0.05 to 0.74±0.06, 1.0±0.01 to 1.8±0.0, 0.22±0.06 to 0.57±0.06, and 1.2±0.01 to 1.5±0.06 with mean values of 0.29±0.05, 0.43±0.57, 1.49±0.013, 1.39±0.01 and 1.36±0.05 in Abia, Anambra, Ebonyi, Enugu and Imo states respectively, indicating highest and least Ni concentration was in Abia and Enugu respectively. The mean Ni concentrations of this study are all higher than the recommended limit of 0.5 mg/kg (FAO/WHO, 2017) apart from Oyster mushrooms from Abia and Anambra. Previous investigations found greater Ni levels of 0.4-15.9 mg/kg, 2.73-19.4 mg/kg, and 0.4-2 mg/kg (Isildak *et al*., 2007; Işıloğlu *et al*., 2001).

Chromium (Cr) concentrations of the Oyster mushroom studied in Abia indicated significant variation with a wide range of 11.2±0.09 to 0.27±0.01 in ABIA_4 and ABIA_1 respectively. Moreover, ABIA_1, 2, 3, 5, 6, 7 and 8 did not vary significantly. Within the samples collected from Anambra, Cr concentration was significantly highest (0.74±0.01) in ANA_8, while the lowest value (0.23±0.06) was recorded in ANA_1. However, values obtained in ANA_2 and 5 were not significantly different. In Ebonyi Cr was in a significant range of 0.68±0.01 to 0.48±0.06 with EBNY_3 and EBNY_6, showing maximum and minimum values respectively. However, in Enugu, significantly greater value (0.45±0.01) of Cr occurred in ENU_6, whereas the least value (0.13±0.06) occurred in ENU_1. Besides, it was observed that difference in concentration of samples from ENU_2 and ENU_5 was not significant. In Imo State, Cr also differed significantly across the studied areas with sample from IMO_3 showing greater value of 0.5±0.06 whereas the least value of 0.2±0.03 was recorded in IMO_5. However, values obtained in IMO_5 and IMO_6 were not significantly different. Generally, mean values of Cr concentrations of the Oyster mushroom at the different locations showed decreasing trend of Abia (1.73±0.03)> Ebonyi (0.56±0.05)> Anambra (0.50±0.08)> Imo (0.38±0.07)> Enugu (0.34±0.001). It was observed that Cr concentrations of Anambra and Ebonyi did not vary significantly. Also, Enugu and Imo varied not significantly. The current study's concentration did not exceed the 5 mg kg^{-1} threshold (WHO, 2004) and were far lower compared to 27.330 and 26.550 mg/kg recorded by Udochukwu *et al*. (2014) and Daniel-Umeri *et al*. (2015), respectively in *Agaricus bisporus* from Benin-city and Ozoro, Nigeria. Although Cr is not poisonous, excessive concentrations are always dangerous. In addition to being mutagenic and carcinogenic in humans (Wu *et al*. 2016), Cr (VI) also causes birth defects and suppresses the antioxidant defense system (Asatiani *et al*. 2011).

In results of Table 2a and b it was also shown that Fe concentrations varied significantly across the study locations. Within the samples from Abia, highest value (2.01±0.06) was obtained in ABIA_1, while the lowest value (1.72±0.02) was in ABIA_5. However, values recorded in ABIA_3 and ABIA_7 did not differ significantly. Also, ABIA_4, 6 and 8 were not significantly different. Iron concentration in Anambra was in a range of 4.7±0.01 to 3.34±0.5. Significantly greater value occurred in ANA_1, whereas the least value occurred in ANA_4. However, as observed, variation in ANA_2, 3, 5, 6, 7 and 8 were not significantly different. In Ebonyi State, Fe varied significantly with EBNY_4 showing greater value of 4.5±0.0a followed by EBNY_1 (Amasiri1, Ebonyi North, 4.2±0.03), EBNY_3 (4.0±0.0), EBNY_5 (3.9±0.1), EBNY_2 (3.4±0.01), EBNY_6 (2.3±0.06) and EBNY_7 (1.2±0.01), suggesting higher concentration of Fe in EBNY_4 than others. In Enugu State, variation of Fe was not significant within the samples with exception of ENU_4. Nevertheless, Fe showed a range of 2.92±0.06 - 2.34±0.5, indicating slight difference amongst the mushrooms studied in Enugu. Similarly, in Imo, Fe concentrations did not differ significantly amongst the samples with

highest value of 2.7±0.06 obtained in IMO_1 compared to the least value of 1.4±0.06 in IMO_3. In general, however, based on the mean values of Fe concentrations of the Oyster mushroom at the different location, it was observed that Anambra recorded significantly highest (3.86±0.06) followed by Ebonyi (3.36±0.01), Enugu (2.74±0.05), Imo (1.93±0.01) and Abia (1.82±0.07). The concentration of Fe found in the investigated mushrooms was under the maximum allowable limits for human consumption of 48 mg kg-1 according to WHO/FAO (2007) and the Turkish Food Codex Anonymous Regulation's 15 mg/kg limit (2002). Although it has occasionally been found to be less than 50 mg kg^{-1} (Borovińska and Òanda, 2007), the iron concentration was typically greater than 100 mg kg^{-1} in previous works (Isildak *et al*., 2004; Rudawska and Leski, 2005; Zhu *et al*., 2011; Sarikurkcu *et al*., 2012; Sun *et al*., 2017). It is well known that iron is important for the survival of almost all forms of life due to its role in several biological functions such as oxygen transport, DNA synthesis, and electron transport (Sun *et al*., 2017). Therefore, consumption of these mushrooms would be a reliable source of iron supplementation, especially in southeastern Nigeria where iron deficiency is common.

Also, with average values of 0.05±0.09, 0.03±0.01, 1.41±0.02, 0.03±0.001, and 0.95±0.07 in Abia, Anambra, Ebonyi, Enugu, and Imo, respectively, the Cd concentrations in the mushrooms ranged from 0.031±0.01 to 0.080±0.03, 0.01±0.01 to 0.05±0.01, 1.08±0.02 to 1.82±0.06, 0.02±0.02 to 0.04±0.0 and 0.83±0.06 to 1.17±0.02, implying that Cd was highest in mushrooms from Ebonyi and equally least in Anambra and Enugu. In similar study of Jain, Gupta, and Kumar, (2013), relatively higher cadmium concentration obtained in the species of Oyster mushroom (Pleurotus sajor-caju), Button mushroom (Agaricus bisporus), Shiitake (Lentinula edodes), and Milky mushroom (Calocybe indica) varied between 0.72 and 15.7 mg/kg dw, 1.0 to 12.0 mg/kg dw, 0.41 to 14.3 mg/kg dw, and 0.38 to 8.20 mg/kg dw respectively. Nonetheless, the mean cadmium concentration in mushrooms from Ebonyi and Imo was above the WHO's (2004) recommended limit of 0.05 mg/kg in food. This widespread Cd pollution is a serious public health issue because it is consistent with the finding that some mushrooms can be powerful accumulators of this harmful element, especially in areas with high soil metal content (Nnorom *et al*., 2020). The findings highlight the necessity of close observation, particularly for species that are collected from the wild. When Cd concentrations are above the prescribed level, they may accumulate in the body, affecting the kidneys and liver (FAO/WHO, 2017).

Large amounts of arsenic can have detrimental effects on the heart, brain, and gastrointestinal tract due to its extreme toxicity (Ahmed *et al*., 2015). Arsenic concentrations in the current research ranged from 0.014±0.006 to 0.032±0.002, 0.01±0.06 to 0.036±0.06, 0.19±0.06 to 0.61±0.06, 0.01±0.06 to 0.05±0.06, and 0.19±0.06 to 0.48±0.06 in Oyster mushroom samples collected from Abia, Anambra, Ebonyi, Enugu, and Imo states respectively. Averaged over locations it was 0.02±0.07c in Abia and Anambra, 0.43±0.001, 0.03±0.05, and 0.34±0.005 in Ebonyi, Enugu, and Imo states respectively. Because arsenic (As) has been shown to be carcinogenic, its presence, especially in Ebonyi, is a serious issue (Tchounwou *et al*., 2012). This work suggest that in addition to being species-dependent, heavy metal concentrations in mushrooms are also significantly impacted by the anthropogenic and geochemical features of the collection location. Other studies have found greater As levels, such as 11.86 and 16.947 mg/kg dw for Tuber indicum in China (Liu *et al*., 2015) and Tricholoma matsutake in Korea. Borovicˇka (2004) discovered high arsenic concentrations in inedible Sarcosphaera coronaria, reaching 2130 and 7090 $mgkg^{-1}$ dry matter, respectively. According to FAO/WHO, the allowed As level in food and vegetables is 0.2 mg/kg, indicating that on average, mushrooms from all the locations were under the tolerated limit, with the exception of oyster mushrooms from Imo state.

Additionally, Zn concentrations were generally greater in Oyster than Agaricus mushrooms. It differed significantly from 30.2±0.06 - 42.2±0.1, 44.2±0.06 - 61.5±0.6, 28.4±0.06 - 34.6±0.06, 40.2±0.06 - 52.2±0.1 and 16.9±0.04 -21.2±0.02 in oyster mushrooms from Abia, Anambra, Ebonyi, Enugu, and Imo, respectively. The mean values were in descending order of Anambra (50.64±0.04) > Enugu (47.14±0.01) > Abia (36.73±0.05) > Ebonyi (30.84±0.07) >Imo (18.56±0.5). In previous study (Ihugba *et al*., 2018) in Imo state, Zinc concentration ranged from 0.03± 0.007 mg/kg to 3.25 ± 0.01mg/kg, indicating its higher concentration in the present study. However, values of Zn in most of the locations were within 40.3–64.4 mg/kg and 29.3–158 mg/kg reported by Mendil *et*

al. (2004) in Oyster mushroom cap from Kastamonu, Turkey, but below 75.99–94.61 lg/g stated by Sithole *et al*. (2022).

Copper is an essential element, which is important for the body to transport and use iron (World Health Organization, 2004), but only in low concentrations (Turkekul *et al*., 2004). The Cu concentrations in this study varied within and across the locations sampled. Accordingly, in Oyster mushrooms Cu levels varied from 9.86±0.03 to 13.3±0.12, 7.2±0.12 to 11.3±0.15, 19.5±0.5 to 31.17±0.2, 7.3±0.06 to 11.9±0.03, and 8.94±0.05 to 16.2±0.06 in Oyster mushrooms from Abia, Anambra, Ebonyi, Enugu and Imo states. The mean values in Abia, Anambra, Ebonyi, Enugu, and Imo were 11.62±0.04, 9.63±0.07, 23.07±0.18, 9.84±0.2, and 13.04±0.05, respectively, suggesting greater and least concentrations in Ebonyi and Anambra respectively. In previous study, Ihugba *et al*. (2018) reported Cu concentration range of 0.03mg/kg to 0.83mg/kg in Oyster mushroom from Imo state, indicating its higher concentration in the present study. The variations in the content of Cu might be due to the following reasons: composition of the substrate that was used by the mushrooms for acquiring their nutrients, the location of the site at which the samples were collected, age of the mycelia and fruiting bodies and the distance of the samples from the source of pollution (Radulescu *et al*., 2010).

In results of Table 2a and b, mercury (Hg) concentrations of the Oyster mushroom studied in Abia indicated significant variation with a range of 0.45±0.06 in ABIA_6 to 0.25±0.01 in ABIA_1. However, samples ABIA_6, ABIA_3 and ABIA_8 did not show significant variation as well as samples ABIA_2, ABIA_4, ABIA_5 and ABIA_7. Within the samples collected from Anambra, Hg concentration was significantly highest (0.05±0.0) in both ANA_5 and ANA_6, while the lowest value (0.02±0.0) was recorded in ANA_3. Moreover, values obtained in samples ANA_2, ANA_4 and ANA_7 did not differ significantly. Equally, samples ANA_1 and ANA_8 were not significantly different. In Ebonyi State, Hg was in a significant range of 2.8±0.06 to 1.21±0.06 with EBNY_1 having maximum value whereas both sample EBNY_6 and EBNY_7 had minimum value. However, statistically, it was also shown that variations between sample EBNY_3 and EBNY_4 were not significant. In Enugu State, Hg also differed significantly across the studied samples with sample ENU_5 showing greater value of 0.06±0.06 and sample ENU_3 showing least value of 0.02±0.06. However, values obtained in samples ENU_5, ENU_6, ENU_7, ENU_4 and ENU_2 were not significantly different. Equally, no significant variation was also recorded for samples ENU_1 and ENU_8. Mercury levels in Imo were significantly greater (1.7±0.012) in IMO_2 compared to 0.96±0.006, 0.83±0.006, 0.51±0.006d, 0.44±0.006, 0.39±0.05 and 0.31±0.006 obtained in IMO_4, IMO_3, IMO_6, IMO_5, IMO_1 and IMO_7 samples respectively, indicating higher concentration of Hg in IMO_2 than others. Generally, mean values of Hg concentrations of the Oyster mushroom at the different location showed decreasing trend of Ebonyi (1.95±0.07)> Imo (0.74±0.05)> Abia (0.37±0.01)> Anambra (0.04±0.06)> Enugu (0.04±0.01). Contrarily, Hg was below detectable limit in the study of Udochukwu *et al* (2014) and Daniel-Umeri *et al* (2015) in *Agaricus bisporus* from Benin-city and Ozoro, Nigeria, respectively. The level of Hg in the substrate is of great importance in mushroom production because the higher level of Hg in the substrate increases its accumulation into the cap and stipe (Rzymski *et al*., 2016). In general however, distribution of HMs were in decreasing order of Zn(37.42) > Cu(13.19) > Fe(2.75) > Pb(1.87) > Ni(0.76) > Cr(0.71) > Hg(0.59) > Cd(0.46) > As(0.16). According to a similar study by Kalac (2010), the amount of heavy metals in mg/kg of dry weight in mushrooms consumed in each European country was found to be in the following ranges: Arsenic in the range of 0.5-5, Cadmium 1-5, Chromium 0.5-5, Copper 20-100, Fe 50-300, Mercury <0.5-5, Nickel nd-15, Lead <5, and Zinc 25-200, indicating lower concentrations of most of the HMs in the mushrooms investigated.

Table 2a Heavy metal (mg/kg) Conc of Oyster mushroom studied

Sample	Pb	Ni	Cr	Fe	Cd	As	Zn	Cu	Hg
					Abia State				
ABIA1	0.98±0.05d	0.35±0.02c	0.27±0.01b	2.01±0.06a	0.05±0.006c	0.032±0.002a	34.3±0.1f	12.6±0.4b	0.25±0.01c
ABIA2	0.75±0.05e	0.23±0.006	0.32±0.01b	1.92±0.06b	0.06±0.005b	0.024±0.006b	35.2±0.06e	11.6±0.61c	0.36±0.05b
ABIA3	1.29±0.06a	0.48±0.006a	0.43±0.06b	1.82±0.06c	0.031±0.01e	0.025±0.002b	40.2±0.10c	10.8±0.52d	0.42±0.06a
ABIA4	1.14±0.16bc	0.40±0.06b	11.2±0.09a	1.76±0.03d	0.040±0.06d	0.014±0.006c	36.3±0.12d	10.2±0.06de	0.35±0.06b
ABIA5	1.28±0.11a	0.22±0.06d	0.33±0.06b	1.72±0.02e	0.080±0.03a	0.021±0.001b	30.2±0.06g	12.3±0.06b	0.33±0.1b
ABIA6	1.23±0.01ab	0.24±0.006d	0.42±0.01b	1.76±0.01d	0.044±0.02d	0.014±0.006c	33.9±0.6f	9.86±0.03e	0.45±0.06a
ABIA7	1.33±0.06a	0.18±0.01e	0.43±0.02b	1.83±0.01c	0.052±0.01c	0.025±0.006b	41.5±0.6b	12.3±0.06b	0.35±0.06b
ABIA8	1.08±0.02cd	0.22±0.01d	0.44±0.012b	1.77±0.02d	0.042±0.06d	0.023±0.006b	42.2±0.1a	13.3±0.12a	0.43±0.06a
					Anambra State				
ANA1	1.21±0.01d	0.06±0.0f	0.23±0.06g	4.7±0.01a	0.03±0.0e	0.02±0.0c	44.2±0.06h	8.27±0.06cd	0.03±0.0c
ANA2	0.74±0.01e	0.04±0.05g	0.43±0.01e	3.76±0.03b	0.02±0.06f	0.01±0.06d	50.3±0.1d	9.2±0.06c	0.04±0.0b
ANA3	0.53±0.01g	0.57±0.05c	0.33±0.06f	3.81±0.06b	0.01±0.01g	0.02±0.0c	53.2±0.1c	10.5±0.06b	0.02±0.0d
ANA4	0.24±0.02h	0.66±0.01b	0.57±0.01d	3.34±0.5c	0.03±0.06e	0.04±0.0a	47.3±0.17f	11.3±0.15a	0.04±0.0b
ANA5	0.65±0.06f	0.5±0.06d	0.42±0.06e	3.9±0.06b	0.04±0.01c	0.036±0.06a	48.2±0.06e	10.1±0.8b	0.05±0.0a
ANA6	1.53±0.01c	0.74±0.06a	0.65±0.01b	3.76±0.06b	0.05±0.01a	0.02±0.006c	46.2±0.0g	11.2±0.03a	0.05±0.0a
ANA7	1.76±0.0b	0.37±0.01e	0.63±0.0c	3.83±0.01b	0.04±0.01b	0.03±0.0b	61.5±0.6a	9.3±0.06c	0.04±0.0b
ANA8	2.17±0.02a	0.52±0.01d	0.74±0.01a	3.77±0.01b	0.03±0.05d	0.02±0.0c	54.2±0.1b	7.2±0.12d	0.03±0.06c
					Ebonyi State				
EBNY1	3.8±0.06c	1.7±0.4d	0.49±0.06f	4.2±0.03b	1.82±0.06a	0.53±0.06d	32.1±0.01c	22.3±0.06c	2.8±0.06a
EBNY2	4.0±0.06a	1.7±0.0c	0.59±0.01c	3.4±0.01e	1.66±0.06b	0.61±0.06a	28.4±0.06g	21.4±0.01d	2.10±0.06c
EBNY3	3.9±0.05b	1.8±0.0a	0.68±0.01a	4.0±0.0c	1.49±0.06d	0.59±0.02c	29.4±0.06e	31.17±0.2a	1.98±0.02d
EBNY4	3.5±0.03d	1.8±0.01b	0.62±0.06b	4.5±0.0a	1.55±0.06c	0.6±0.003a	28.9±0.06f	23.7±0.06b	2.41±0.06b
EBNY5	3.0±0.02e	1.2±0.06f	0.56±0.06d	3.9±0.1d	1.07±0.03f	0.23±0.06e	34.6±0.06a	21.3±0.12d	1.96±0.06d
EBNY6	2.98±0.01e	1.0±0.01g	0.48±0.06g	2.3±0.06f	1.21±0.06e	0.24±0.06e	32.4±0.06b	22.1±0.05c	1.21±0.06e
EBNY7	1.94±0.02f	1.2±0.03d	0.52±0.06e	1.2±0.01g	1.08±0.02f	0.19±0.06f	30.1±0.00d	19.5±0.5e	1.210± 0.0e

Means that do not share a letter are significantly different at 5% probability level.

Table 2b Heavy metal (mg/kg) Conc of Oyster mushroom studied

Sample	Pb	Ni	Cr	Fe	Cd	As	Zn	Cu	Hg
					Enugu State				
ENU1	1.20±0.05c	0.22±0.06e	0.13±0.06f	2.7±0.01a	0.02±0.0c	0.02±0.0de	40.2±0.06d	7.3±0.06d	0.03±0.06b
ENU2	0.60±0.06e	0.44±0.06b	0.33±0.01d	2.76±0.03a	0.03±0.0b	0.01±0.06ef	46.3±0.12c	8.2±0.06c	0.05±0.06a
ENU3	0.43±0.010f	0.57±0.06a	0.23±0.01e	2.82±0.0a	0.01±0.0d	0.02±0.0de	50.2±0.1ab	9.8±0.5b	0.02±0.06b
ENU4	0.9±0.02d	0.45±0.01b	0.37±0.01c	2.34±0.5b	0.02±0.02c	0.03±0.06cd	44.3±0.2c	10.0±0.7b	0.05±0.01a
ENU5	0.95±0.07d	0.33±0.06c	0.32±0.01d	2.92±0.06a	0.04±0.0a	0.04±0.06b	45.2±0.05c	9.9±0.6b	0.06±0.06a
ENU6	1.33±0.01b	0.44±0.06b	0.45±0.01a	2.76±0.06a	0.03±0.0b	0.01±0.06f	47.2±6.0bc	11.9±0.03a	0.05±0.06a
ENU7	1.460± 0.0a	0.27±0.01d	0.43±0.0b	2.83±0.01a	0.03±0.0b	0.05±0.06a	51.5±0.6a	10.3±0.06b	0.05±0.06a
ENU8	1.17±0.01c	0.32±0.01c	0.44±0.01ab	2.77±0.01a	0.02±0.0c	0.03±0.06cd	52.2±0.1a	11.3±0.1a	0.03±0.06b
					Imo State				
IMO1	3.52±0.015a	1.4±0.06c	0.45±0.6c	2.0±7.5a	1.17±0.02a	0.40±0.06b	16.9±0.01de	13.1±0.06e	0.39±0.05f
IMO2	3.2±0.06c	1.3±0.06d	0.4±0.06b	1.4±0.06a	0.91±0.06c	0.48±0.06a	17.7±0.03c	14.2±0.02c	1.7±0.012a
IMO3	2.69±0.06g	1.5±0.06a	0.5±0.06a	2.7±0.06a	0.84±0.06d	0.39±0.06c	20.2±0.2b	16.2±0.06a	0.83±0.006c
IMO4	3.33±0.06b	1.3±0.06e	0.4±0.06e	2.0±0.01a	0.93±0.06c	0.26±0.06f	21.2±0.02a	15.4±0.06b	0.96±0.006b
IMO5	3.1±0.06e	1.4±0.06c	0.2±0.03g	1.8±0.06a	0.83±0.06d	0.29±0.06e	20.1±0.06b	8.94±0.05g	0.44±0.006e
IMO6	2.89±0.01f	1.2±0.01f	0.3±0.5f	2.1±0.01a	1.01±0.06b	0.34±0.06d	16.9±0.04e	14.1±0.05d	0.51±0.006d
IMO7	3.19±0.01d	1.49±0.01b	0.4±0.01d	1.5±0.06a	0.98±0.06b	0.19±0.06g	17.1±0.08d	9.2±0.02f	0.31±0.006g

Means that do not share a letter are significantly different at 5% probability level.

3.2a Non-Carcinogenic Health Risk of Oyster Mushroom in the Study Area

From the results of non-carcinogenic health risk (NCHR) of heavy metals in Oyster mushroom studied (Table 3a), NCHR varied in both child and adult. Values of NCHR for child were as follows; Pb (1.6×10^{-3}-5.2×10^{-3}), Ni (5.4×10^{-5}-8.0×10^{-3}), Cr (3.9×10^{-5}-3.5×10^{-3}), Fe (4.1×10^{-5}-6.0×10^{-3}) and Cd (4.7×10^{-6}-3.9×10^{-3}). Also, NCHR of As, Zn, Cu and Hg in Oyster mushroom was as follows; As (1.2×10^{-3}-2.2×10^{-2}), Zn (9.6×10^{-4}-2.6×10^{-3}), Cu (3.7×10^{-4}-3.8×10^{-3}) and Hg (1.2×10^{-2}-0.608). As shown, NCHR of Pb, As and Hg were higher in mushroom collected from Ebonyi, Cr, Fe, Cd and Cu was higher in Enugu, NCHR of Ni and Zn was higher in Anambra State. However, the least NCHR of Ni, Fe and As was obtained in Abia, Cd, Cu and Hg was least in Anambra while Cr and Zn was least in Imo. In addition, NCHR of Pb was highest in child consuming Oyster mushroom.

Values of NCHR for adult Oyster mushroom was as follows; Pb (9.6×10^{-5}-8.4×10^{-3}), Ni (2.5×10^{-6}-3.2×10^{-3}), Cr (1.8×10^{-6}-1.6×10^{-3}), Fe (1.9×10^{-6}-2.8×10^{-3}) and Cd (2.2×10^{-7}-1.8×10^{-3}). Also, NCHR of As, Zn, Cu and Hg in Oyster mushroom was as follows; As (5.3×10^{-5}-6.3×10^{-3}), Zn (4.4×10^{-5}-1.1×10^{-3}), Cu (1.7×10^{-5}-1.8×10^{-3}) and Hg (5.4×10^{-4}-4.9×10^{-2}). As recorded, apart from NCHR of Hg that was higher in Imo, NCHR of all the heavy metals were found to be higher among adult consuming Oyster mushroom in Enugu. However, least NCHR of Pb, Ni, Fe and As was obtained in Abia, Cd, Cu and Hg was least in Anambra while Cr and Zn was least in Imo. This indicates that higher level of non-carcinogenic health risk of most metals in Oyster mushroom was in Enugu especially for adult. In contrast to earlier research by Pedrero *et al*. (2010) and Guerra *et al*. (2012), which revealed greatest concentrations of copper followed by iron and comparatively lower concentrations of lead, the hazard quotient in oyster mushrooms in our study, where mercury was highest, was not in line with these findings. Moreover, previous study found that the target health quotient (THQ) of zinc was highest and ranged from 0.59-1.56, 0.65-1.72, and 1.49-3.90 for adults, adolescents, and children, respectively (Igbiri *et al*., 2018). However, the current study's findings were consistent with those of Zhiqiu *et al*. (2020), who indicated that Hg (6.87) had a higher non-carcinogenic risk than other HMs investigated. The need for a source study is further highlighted by the fact that the Hg values in Ebonyi are among the highest recorded in recent literature for Pleurotus species from Nigeria (Nnorom *et al*., 2020).

Table 3a Non-carcinogenic health risk of Oyster mushroom in the study area

Location	Pb	Ni	Cr	Fe	Cd	As	Zn	Cu	Hg
					Abia				
Child	1.8×10^{-3}	5.4×10^{-5}	1.8×10^{-4}	4.1×10^{-5}	7.8×10^{-6}	1.2×10^{-3}	1.9×10^{-3}	4.5×10^{-4}	0.114
Adult	9.6×10^{-5}	2.5×10^{-6}	8.2×10^{-5}	1.9×10^{-6}	4.0×10^{-5}	5.3×10^{-5}	8.7×10^{-5}	2.1×10^{-5}	5.3×10^{-3}
					Anambra				
Child	1.7×10^{-3}	8.0×10^{-3}	5.2×10^{-5}	8.6×10^{-5}	4.7×10^{-6}	1.3×10^{-3}	2.6×10^{-3}	3.7×10^{-4}	1.2×10^{-2}
Adult	9.2×10^{-4}	3.7×10^{-6}	2.4×10^{-6}	3.9×10^{-6}	2.2×10^{-7}	5.8×10^{-5}	1.2×10^{-4}	1.7×10^{-5}	5.4×10^{-4}
					Ebonyi				
Child	5.2×10^{-3}	2.8×10^{-4}	5.8×10^{-5}	7.5×10^{-5}	2.2×10^{-4}	2.2×10^{-2}	1.6×10^{-3}	9.0×10^{-4}	0.608
Adult	2.8×10^{-3}	1.3×10^{-5}	2.7×10^{-6}	3.4×10^{-6}	1.0×10^{-5}	1.0×10^{-3}	7.3×10^{-5}	4.1×10^{-5}	2.8×10^{-2}
					Enugu				
Child	1.6×10^{-3}	7.0×10^{-3}	3.5×10^{-3}	6.0×10^{-3}	3.9×10^{-3}	1.4×10^{-3}	2.4×10^{-3}	3.8×10^{-3}	1.3×10^{-2}
Adult	8.4×10^{-3}	3.2×10^{-3}	1.6×10^{-3}	2.8×10^{-3}	1.8×10^{-3}	6.3×10^{-3}	1.1×10^{-3}	1.8×10^{-3}	6.1×10^{-3}
					Imo				
Child	4.9×10^{-3}	2.5×10^{-4}	3.9×10^{-5}	4.3×10^{-5}	1.5×10^{-4}	1.7×10^{-4}	9.6×10^{-4}	5.1×10^{-4}	0.228
Adult	2.6×10^{-3}	1.2×10^{-5}	1.8×10^{-6}	2.0×10^{-6}	6.8×10^{-6}	8.0×10^{-4}	4.4×10^{-5}	2.3×10^{-5}	4.9×10^{-2}

3.2b Carcinogenic Health Risk of Oyster Mushroom in the Study Area

Table 3b summarized the results of carcinogenic health risk (CHR) of heavy metals in Oyster mushroom studied. From the results, CHR differed in both child and adult. Values of CHR for child was as follows; Pb (1.1×10^{-7}-3.7×10^{-7}), Ni (3.8×10^{-5}-1.9×10^{-4}), Cr (7.9×10^{-5}-4.0×10^{-4}), Fe (2.0×10^{-3}-4.2×10^{-3}) and Cd (3.9×10^{-6}-2.2×10^{-4}). Also, CHR of As, Zn, Cu and Hg in Oyster mushroom was as follows; As (1.0×10^{-8}-2.0×10^{-7}), Zn (8.7×10^{-3}-

6.6×10^{-2}), Cu (2.8×10^{-3}-6.6×10^{-2}) and Hg (1.0×10^{-9}-1.5×10^{-7}). As demonstrated, CHR of all the heavy metals were found to be higher in Ebonyi with the exception NCHR of Cr and Fe that was least in Abia and Anambra respectively.

Variation of CHR for adult consuming Oyster mushroom ranged as follows; Pb (6.0×10^{-8}-2.0×10^{-7}), Ni (1.7×10^{-6}-8.9×10^{-6}), Cr (3.6×10^{-6}-1.9×10^{-5}), Fe (9.1×10^{-5}-1.9×10^{-4}) and Cd (1.8×10^{-7}-1.0×10^{-5}). Also, CHR of As, Zn, Cu and Hg in Oyster mushroom was as follows; As (5.0×10^{-10}-1.0×10^{-8}), Zn (4.0×10^{-4}-1.4×10^{-3}), Cu (2.8×10^{-4}-6.6×10^{-4}) and Hg (1.0×10^{-10}-7.0×10^{-9}). As displayed in Table 3b, NCHR of all the heavy metals were found to be higher in Ebonyi with the exception CHR of Fe and Zn that was least in Anambra and NCHR of Cr that was least in Abia. This implied that incremental carcinogenic risk effects of most of these HMs would occur if there is high consumer intake of this mushroom (Zhiqiu *et al*., 2020) especially in Ebonyi. Given that children are more susceptible to heavy metal poisoning due to their higher food intake in relation to body weight and developing organ systems (Hauptman and Woolf, 2017), it is evident that samples from Ebonyi pose a possible health risk. Furthermore, the values of carcinogenic health risk observed in our current investigation agreed with the results provided by Chukwuka *et al.* (2023), whereby the carcinogenic risks associated with heavy metals in adults and children were stated as Pb ($2.30 – 3.04 \times 10^{-5}$ and $6.72 – 8.85 \times 10^{-5}$), Cd ($2.92–4.37 \times 10^{-3}$ and $8.51 \times 10^{-3}–1.27 \times 10^{-2}$), Cr ($6.3 \times 10^{-4}–1.03 \times 10^{-3}$ and $1.83–3.01 \times 10^{-3}$), and Ni ($6.05 \times 10^{-4}–2.08 \times 10^{-3}$ and $1.76–6.07 \times 10^{-3}$).

Table 3b Carcinogenic health risk of Oyster mushroom in the study area

Location	Pb	Ni	Cr	Fe	Cd	As	Zn	Cu	Hg
					Abia				
Child	1.3×10^{-7}	3.8×10^{-5}	4.0×10^{-4}	2.0×10^{-3}	7.8×10^{-6}	1.0×10^{-7}	1.7×10^{-2}	7.2×10^{-3}	2.9×10^{-8}
Adult	7.0×10^{-8}	1.7×10^{-6}	1.9×10^{-5}	9.1×10^{-5}	3.6×10^{-7}	5.0×10^{-10}	7.9×10^{-4}	3.3×10^{-4}	1.0×10^{-9}
					Anambra				
Child	1.3×10^{-7}	5.7×10^{-5}	1.2×10^{-4}	4.2×10^{-3}	4.9×10^{-6}	5.0×10^{-8}	1.1×10^{-2}	2.8×10^{-3}	1.0×10^{-9}
Adult	7.0×10^{-8}	2.6×10^{-6}	5.4×10^{-6}	1.9×10^{-4}	2.2×10^{-7}	5.0×10^{-10}	1.4×10^{-3}	2.8×10^{-4}	1.0×10^{-10}
					Ebonyi				
Child	3.7×10^{-7}	1.9×10^{-4}	1.3×10^{-4}	3.7×10^{-3}	2.2×10^{-4}	2.0×10^{-7}	6.6×10^{-2}	6.6×10^{-2}	1.5×10^{-7}
Adult	2.0×10^{-7}	8.9×10^{-6}	6.0×10^{-6}	1.7×10^{-4}	1.0×10^{-5}	1.0×10^{-8}	6.6×10^{-4}	6.6×10^{-4}	7.0×10^{-9}
					Enugu				
Child	1.1×10^{-7}	5.0×10^{-5}	7.9×10^{-5}	3.0×10^{-3}	3.9×10^{-6}	1.0×10^{-8}	2.2×10^{-2}	6.1×10^{-3}	3.0×10^{-9}
Adult	6.0×10^{-8}	2.3×10^{-6}	3.6×10^{-6}	1.4×10^{-4}	1.8×10^{-7}	6.0×10^{-10}	1.0×10^{-3}	2.8×10^{-4}	2.0×10^{-10}
					Imo				
Child	3.6×10^{-7}	1.8×10^{-4}	8.8×10^{-5}	2.1×10^{-3}	1.5×10^{-4}	1.6×10^{-7}	8.7×10^{-3}	8.1×10^{-3}	5.7×10^{-8}
Adult	1.9×10^{-7}	8.2×10^{-6}	4.1×10^{-6}	9.6×10^{-5}	6.8×10^{-6}	1.0×10^{-8}	4.0×10^{-4}	3.7×10^{-4}	3.0×10^{-9}

4.0 Conclusions

The results of this study made it clear that the heavy metals (Pb, Ni, Cr, Fe, Cd, As, Zn, Cu, and Hg) in mushrooms differed greatly among the locations. The results indicated that samples from Ebonyi had higher concentrations of most of the HMs, including Cd, As, Cu, and Hg; Anambra had higher concentrations of Fe and Zn; Enugu state had higher concentrations of Pb and Ni; and Abia state had higher concentrations of Cr, even though the majority of the heavy metals were within acceptable limits. In addition, all the non-carcinogenic health risk of heavy metals showed values less than 1 which generally indicated acceptable non-carcinogenic risk for both child and adult. Besides, carcinogenic health risk of HMs in the mushrooms showed values less than 10^{-4} which generally indicated acceptable carcinogenic risk in both child and adult except Zn and Cu that was unacceptable for both child and adult in all locations, Fe for both child and adult in all locations apart from adult in Abia and Imo, Cr for child in Abia, Anambra and Ebonyi as well as Ni and Cd for child in Ebonyi and Imo state. Although eating oyster mushrooms from the states of Abia, Anambra, Enugu, and Imo seems to be harmless, the study provides compelling evidence that eating mushrooms from Ebonyi State poses a serious health risk, especially for children.

Our results clearly indicate that environmental contamination in Ebonyi State is a major public health concern that has to be addressed immediately by regulatory bodies. Also, in order to safeguard the health of communities that depend on wild mushrooms for food, this study provides an essential baseline for future research and policy development. Future research should concentrate on pinpointing the precise causes of pollution in Ebonyi State and investigating the possibility of mitigating techniques, like launching public awareness campaigns about the dangers of consuming heavy metals.

References

Abdullah, K. K., Fevzi, K., Hacer Sibel, & Yasin, U. (2017). Mineral contents of some wild edible mushrooms. J. Fungus, 8(2), 178–183.

Achparaki, M., Thessalonikeos, E., Tsoukali, H., Mastrogianni, O., Zaggelidou, E., Chatzinikolaou, F., & Raikos, N. (2012). Heavy metals toxicity. Aristotle University Medical Journal, 39(1), 29–34.

Agrahar-Murugkar, D., & Subbulakshmi, G. (2005). Nutritional value of edible wild mushrooms collected from the Khasi Hills of Meghalaya. Food Chemistry, 89, 599–603. https://doi.org/10.1016/j.foodchem.2004.03.042

Ahmed, M. K., Baki, M. A., Islam, M. S., Kundu, G. K., Habibullah-Al-Mamun, M., Sarkar, S. K., & Hossain, M. M. (2015). Human health risk assessment of heavy metals in tropical fish and shellfish collected from the river Buriganga, Bangladesh. Environmental Science and Pollution Research, 22, 15880–15890. https://doi.org/10.1007/s11356-015-4813-z

Alaimo, M. G., Dongarrà, G., La Rosa, A., Tamburo, E., Vasquez, G., & Varrica, D. (2018). Major and trace elements in Boletus aereus and Clitopilus prunulus growing on volcanic and sedimentary soils of Sicily (Italy). Ecotoxicology and Environmental Safety, 157, 182–190. https://doi.org/10.1016/j.ecoenv.2018.03.090

Alonso, J., García, M., Pérez-López, M., & Melgar, M. J. (2003). The concentrations and bioconcentration factors of copper and zinc in edible mushrooms. Archives of Environmental Contamination and Toxicology, 44, 180–188. https://doi.org/10.1007/s00244-002-2051-0

Alsafran, M., Usman, K., Rizwan, M., Ahmed, T., & Al Jabri, H. (2021). The carcinogenic and non-carcinogenic health risks of metal(oid)s bioaccumulation in leafy vegetables: A consumption advisory. Frontiers in Environmental Science, 9, 742269. https://doi.org/10.3389/fenvs.2021.742269

Anyadike, R. N. C. (2002). Climate and vegetation. In G. E. K. Ofomata (Ed.), A survey of the Igbo Nation (pp. 73). African First Publishers Limited.

Asatiani, N., Kartvelishvili, T., Abuladze, M., Asanishvili, L., & Sapojnikova, N. (2011). Chromium (VI) can activate and impair antioxidant defense system. Biological Trace Element Research, 142, 388–397. https://doi.org/10.1007/s12011-010-8806-y

Borovička, J., Braeuer, S., Sácký, J., Kameník, J., Goessler, W., Trubač, J., Strnad, L., Rohovec, J., Leonhardt, T., & Kotrba, P. (2019). Speciation analysis of elements accumulated in Cystoderma carcharias from clean and smelter-polluted sites. Science of the Total Environment, 648, 1570–1581. https://doi.org/10.1016/j.scitotenv.2018.08.307

Borovička, J., & Řanda, Z. (2007). Distribution of iron, cobalt, zinc and selenium in macrofungi. Mycological Progress, 6(4), 249–259. https://doi.org/10.1007/s11557-007-0543-y

Bruno, M., Ross, J., & Ge, Y. (2016). Proteomic responses of BEAS-2B cells to nontoxic and toxic chromium: Protein indicators of cytotoxicity conversion. Toxicology Letters, 264, 59–70. https://doi.org/10.1016/j.toxlet.2016.08.025

Çağlarirmak, N. (2011). Edible mushrooms: An alternative food item. In Proceedings of the 7th International Conference on Mushroom Biology and Mushroom Products (ICMBMP7) (pp. 548–554). World Society for Mushroom Biology and Mushroom Products.

Chaurasia, P. K., Bharati, S. L., & Mani, A. (2019). Significances of fungi in bioremediation of contaminated soil. In J. S. Singh & D. P. Singh (Eds.), New and future developments in microbial biotechnology and bioengineering (pp. 281–294). Elsevier. https://doi.org/10.1016/B978-0-444-64191-5.00020-1

Choi, H., Park, S. K., & Kim, M. (2012). Risk assessment of arsenic and mercury in mushrooms. Journal of Food Hygiene and Safety, 27 (4), 388–394. https://doi.org/10.13103/JFHS.2012.27.4.388

Chukwu, G. O. (2007). Land suitability classification of southeastern Nigeria wetlands for Azolla. Scientific Research and Essays, 2(12), 512–515.

Chukwu, G. O., Chude, L. A., & Ekpo, I. E. (2009). Wetland of southeastern Nigeria: Extent and characteristics. Nigerian Journal of Agriculture, Food and Environment, 5(2–4), 42–46.

Chukwuka, K. S., Adesida, S. O., & Alimba, C. G. (2023). Carcinogenic and non-carcinogenic risk assessment of consuming metal-laden wild mushrooms in Nigeria: Analyses from field based and systematic review studies. Environmental Analysis, Health and Toxicology, 38, e2023013. https://doi.org/10.5620/eaht.2023013

Chungu, D., Mwanza, A., Ng'andwe, P., Chungu, B. C., & Maseka, K. (2019). Variation of heavy metal contamination between mushroom species in the Copperbelt province, Zambia: Are the people at risk? Journal of the Science of Food and Agriculture, 99, 3410–3416. https://doi.org/10.1002/jsfa.9558

Daniel-Umeri, R. A., Emumejaye, K., & Ojebah, C. K. (2015). Assessment of heavy metals in some wild edible mushrooms collected from Ozoro and its environs, Delta State, Nigeria. International Journal of Scientific & Technology, 5(10), 1–17.

Dastan, D. (2015). Nanostructured anatase titania thin films prepared by sol-gel dip coating technique. Journal of Atomic, Molecular, Condensate and Nano Physics, 2(2), 109–114.

Dastan, D. (2017). Effect of preparation methods on the properties of titania nanoparticles: Solvothermal versus sol-gel. Applied Physics A, 123, 1–13. https://doi.org/10.1007/s00339-017-1321-y

Ezemonye, M. N., & Emeribe, C. N. (2012). Rainfall erosivity in southeastern Nigeria. Ethiopian Journal of Environmental Studies and Management, 5(2), 11–17. https://doi.org/10.4314/ejesm.v5i2.2

Falandysz, J. (2016). Mercury bio-extraction by fungus Coprinus comatus: A possible bioindicator and mycoremediator of polluted soils? Environmental Science and Pollution Research International, 23, 7444–7451. https://doi.org/10.1007/s11356-015-5624-

Falandysz, J., & Borovička, J. (2013). Macro and trace mineral constituents and radionuclides in mushrooms: Health benefits and risks. Applied Microbiology and Biotechnology, 97(2), 477–501. https://doi.org/10.1007/s00253-012-4552-8

Falandysz, J., Mędyk, M., & Treu, R. (2018). Bio-concentration potential and associations of heavy metals in Amanita muscaria (L.) Lam. from northern regions of Poland. Environmental Science and Pollution Research, 25, 25190–25206. https://doi.org/10.1007/s11356-018-2699-2

FAO/WHO Expert Committee on Food Additives. (2010). Summary and conclusions by the JECFA.

FAO/WHO. (2017). Joint Expert Committee on Food Additives, Fifty-ninth meeting. http://www.fao.org/es/ESN/Jecfa/59corr.pdf

Fu, Z., Liu, G., & Wang, L. (2020). Assessment of potential human health risk of trace element in wild edible mushroom species collected from Yunnan Province, China. Environmental Science and Pollution Research, 27(23), 29218–29227. https://doi.org/10.1007/s11356-020-09079-z

García, M. A., Alonso, J., & Melgar, M. J. (2009). Lead in edible mushrooms: Levels and bioaccumulation factors. Journal of Hazardous Materials, 167, 777–783. https://doi.org/10.1016/j.jhazmat.2009.01.058

Giannaccini, G., Betti, L., Palego, L., Mascia, G., Schmid, L., Lanza, M., Mela, A., Fabbrini, L., Biondi, L., & Lucacchini, A. (2012). The trace element content of top-soil and wild edible mushroom samples collected in Tuscany, Italy. Environmental Monitoring and Assessment, 184, 7579–7595. https://doi.org/10.1007/s10661-012-2520-0

González, A., Cruz, M., Losoya, C., Nobre, C., Loredo, A., Rodríguez, R., Contreras, J., & Belmares, R. (2020). Edible mushrooms as a novel protein source for functional foods. Food and Function, 11(9), 7400–7414. https://doi.org/10.1039/d0fo01746a

Hauptman M, & Woolf AD. (2017). Childhood Ingestions of Environmental Toxins: What Are the Risks? Pediatr Ann. 2017 Dec 1;46(12):e466-e471. doi: 10.3928/19382359-20171116-01. PMID: 29227523; PMCID: PMC6982419.

Igbiri, S., Udowelle, N. A., Ekhator, O. C., Asomugha, R. N., Igweze, Z. N., & Orisakwe, O. E. (2018). Edible mushrooms from Niger Delta, Nigeria with heavy metal levels of public health concern: A human health risk assessment. Recent Patents on Food, Nutrition & Agriculture, 9(1), 31–41.

https://doi.org/10.2174/2212798409666171129173802

Igwe, C. A. (2012). Gully erosion in southeastern Nigeria: Role of soil properties and environmental factors. In InTech Open Science (pp. 157–171). https://doi.org/10.5772/31283

Ihugba, A., Nwoko, U. O., Tony-Njoku, C., R. Ojiaku, F. A., & Izunobi, L. A. (2018). Heavy metal determination and health risk assessment of oyster mushroom Pleurotus tuberregium (Fr.) Singer, collected from selected markets in Imo State, Nigeria. American Journal of Environmental Protection, 6(1), 22–27. https://doi.org/10.12691/env-6-1-4

Ilechukwu, B. C., & Okoye, C. O. B. (2020). Bioaccumulation of toxic metals from trace metals polluted soils using five species of mushroom found in Anambra State, Nigeria. African Journal of Agriculture and Food Science, 3(4), 103–121.

Işıloğlu, M., Yılmaz, F., & Merdivan, M. (2001). Concentrations of trace elements in wild edible mushrooms. Food Chemistry, 73(2), 169–175. https://doi.org/10.1016/S0308-8146(00)00279-1

Işıldak, O., Turkekul, I., Elmastas, M., & Aboul-Enein, H. Y. (2007). Bioaccumulation of heavy metals in some wild-grown edible mushrooms. Analytical Letters, 40(6), 1099–1116. https://doi.org/10.1080/00032710701297042

Işıldak, O., Turkekul, I., Elmastas, M., & Tuzen, M. (2004). Analysis of heavy metals in some wild-grown edible mushrooms from the middle Black Sea region, Turkey. Food Chemistry, 86, 547–552. https://doi.org/10.1016/j.foodchem.2003.09.007

Kalač, P. (2013). A review of chemical composition and nutritional value of wild growing and cultivated mushrooms. Journal of the Science of Food and Agriculture, 93(2), 209–218. https://doi.org/10.1002/jsfa.5960

Kojta, A. K., Jarzyńska, G., & Falandysz, J. (2012). Mineral composition and heavy metals accumulation capacity of Bay Bolete's (Xerocomus badius) fruiting bodies collected near a former gold and copper mining area. Journal of Geochemical Exploration, 121, 76–82. https://doi.org/10.1016/j.gexplo.2012.07.003

Kokkoris, V., Massas, I., Polemis, E., Koutrotsios, G., & Zervakis, G. I. (2019). Accumulation of heavy metals by wild edible mushrooms with respect to soil substrates in the Athens metropolitan area (Greece). Science of the Total Environment, 685, 280–296. https://doi.org/10.1016/j.scitotenv.2019.05.447

Kumhomkul, T., & Panich-pat, T. (2013). Load accumulation in the straw mushroom, Volvariella volvacea, from lead contaminated rice straw and stubble. Bulletin of Environmental Contamination and Toxicology, 91, 231–234. https://doi.org/10.1007/s00128-013-1022-y

Liu, B., Huang, Q., Cai, H., Guo, X., Wang, T., & Gui, M. (2015). Study of heavy metal concentrations in wild edible mushrooms in Yunnan Province, China. Food Chemistry, 188, 294–300. https://doi.org/10.1016/j.foodchem.2015.05.010

Masindi, V., Mkhonza, P., & Tekere, M. (2021). Sources of heavy metals pollution. In Inamuddin, M. I. Ahamed, E. Lichtfouse, & T. Altalhi (Eds.), Remediation of heavy metals: Environmental chemistry for a sustainable world (Vol. 454, p. XII). Springer International Publishing. https://doi.org/10.1007/978-3-030-80335-1_1

Mendil, D., Uluözlü, Ö. D., Tüzen, M., Hasdemir, E., & Sarı, H. (2005). Trace metal levels in mushroom samples from Ordu, Turkey. Food Chemistry, 91, 463–467. https://doi.org/10.1016/j.foodchem.2004.04.031

Ndimele, C. C., Ndimele, P. E., & Chukwuka, K. S. (2017). Accumulation of heavy metals by wild mushrooms in Ibadan, Nigeria. Journal of Health and Pollution, 7, 26–30. https://doi.org/10.5696/2156-9614-7.16.26

Nnorom, I. C., Eze, S. O., & Ukaogo, P. O. (2020). Mineral contents of three wild-grown edible mushrooms collected from forests of southeastern Nigeria: An evaluation of bioaccumulation potentials and dietary intake risks. Scientific African, 7, e00163. https://doi.org/10.1016/j.sciaf.2019.e00163

Nnorom, I. C., Jarzyńska, G., Drewnowska, M., Dryżałowska, A., Kojta, A., Pankavec, S., & Falandysz, J. (2013). Major and trace elements in sclerotium of Pleurotus tuber-regium (Ós ū) mushroom - dietary intake and risk in southeastern Nigeria. Journal of Food Composition and Analysis, 29, 73–81. https://doi.org/10.1016/j.jfca.2012.12.002

Nnorom, I. C., Jarzynska, G., Falandysz, J., Drewnowska, M., Okoye, I., & Oji-Nnorom, C.

G. (2012). Occurrence and accumulation of mercury in two species of wild grown Pleurotus mushrooms from southeastern Nigeria. Ecotoxicology and Environmental Safety, 84, 78–83. https://doi.org/10.1016/j.ecoenv.2012.06.020

Nowakowski, P., Naliwajko, S. K., Markiewicz-Żukowska, R., Borawska, M., & Socha, K. (2020). The two faces of Coprinus comatus – Functional properties and potential hazards. Phytotherapy Research, 34(11), 2932–2944. https://doi.org/10.1002/ptr.6741

Nowakowski, P., Markiewicz-Żukowska, R., Soroczyńska, J., Puścion-Jakubik, A., Mielcarek, K., Borawska, M. H., & Socha, K. (2021). Evaluation of toxic element content and health risk assessment of edible wild mushrooms. Journal of Food Composition and Analysis, 96, 103698. https://doi.org/10.1016/j.jfca.2020.103698

Nwokeke, U. G., & Enyoh, C. E. (2021). Contamination and dietary intake risks assessment of heavy metals in some species of wild edible mushrooms grown in southern Nigeria. World News of Natural Sciences, 39, 1–10.

Ogbonna, J. U., Alozie, M., Nkemdirim, V., & Eze, M. U. (2011). GIS analysis for mapping gully erosion impacts on the geo-formation of old Imo State, Nigeria. ABSU Journal of Environment, Science and Technology, 1, 48–61.

Oguntoye, A. O., Eades, N. T., Ezenwa, M. O., Krieger, J., Jenerette, C., Adegbola, M., Jacob, E., Johnson-Mallard, V., Yao, Y., Gallo, A., & Wilkie, D. J. (2022). Factors associated with young adult engagement with a web-based sickle cell reproductive health intervention. PEC Innovation, 1, 100063. https://doi.org/10.1016/j.pecinn.2022.100063

Onifade, R. S., Alimba, C. G., Adenipekun, C. O., & Bakare, A. A. (2016). White rot fungus (Pleurotus pulmonarius) cultivated on lead contaminated rice straw induced haematotoxicity and lead accumulation in liver and kidney of Wistar rats. Journal of Drug Metabolism & Toxicology, 7(2), 1000210. https://doi.org/10.4172/2157-7609.1000210

Orisakwe, O. E., & Nduka, J. K. (2010). Assessment of environmental distribution of lead in some municipalities of south-eastern Nigeria. International Journal of Environmental Research and Public Health, 7(6), 2501–2513. https://doi.org/10.3390/ijerph7062501

Ostos, C., Pérez-Rodríguez, F., Arroyo, B. M., & Moreno-Rojas, R. (2015). Study of mercury content in wild edible mushrooms and its contribution to the Provisional Tolerable Weekly Intake in Spain. Journal of Food Composition and Analysis, 37, 136–142. https://doi.org/10.1016/j.jfca.2014.10.001

Panahi, S. L., Dastan, D., & Chaure, N. B. (2016). Characterization of zirconia nanoparticles grown by sol-gel method. Advanced Science Letters, 22(4), 941–944. https://doi.org/10.1166/asl.2016.7002

Radulescu, C., Stihi, C., Busuioc, G., Gheboianu, A. I., & Popescu, I. V. (2010). Studies concerning heavy metals bioaccumulation of wild edible mushrooms from industrial area by using spectrometric techniques. Bulletin of Environmental Contamination and Toxicology, 84, 641–646. https://doi.org/10.1007/s00128-010-9976-1

Rudawska, M., & Leski, T. (2005). Macro- and microelement contents in fruiting bodies of wild mushrooms from the Notecka Forest in west-central Poland. Food Chemistry, 92(3), 499–506. https://doi.org/10.1016/j.foodchem.2004.08.014

Sarikurkcu, C., Tepe, B., Solak, M. H., & Cetinkaya, S. (2012). Metal concentrations of wild edible mushrooms from Turkey. Ecology of Food and Nutrition, 51(4), 346–363. https://doi.org/10.1080/03670244.2012.674448

Schlecht, M. T., & Säumel, I. (2015). Wild growing mushrooms for the Edible City? Cadmium and lead content in edible mushrooms harvested within the urban agglomeration of Berlin, Germany. Environmental Pollution, 204, 298–305. https://doi.org/10.1016/j.envpol.2015.05.018

Sithole, S. C., Agboola, O. O., Mugivhisa, L. L., Amoo, S. O., & Olowoyo, J. O. (2022). Elemental concentration of heavy metals in oyster mushrooms grown on mine polluted soils in Pretoria, South Africa. Journal of King Saud University – Science, 34(2), 101763. https://doi.org/10.1016/j.jksus.2021.101763

Stefanović, V., Trifković, J., Djurdjić, S., Vukojević, V., Tešić, Ž., & Mutić, J. (2016). Study of silver, selenium and arsenic concentration in wild edible mushroom Macrolepiota procera health benefit and risk. Environmental Science and Pollution

Research, 23, 22084–22098. https://doi.org/10.1007/s11356-016-7432-4

Sun, L., Chang, W., Bao, C., & Zhuang, Y. (2017). Metal contents, bioaccumulation, and health risk assessment in wild edible Boletaceae mushrooms. Journal of Food Science, 82, 1500–1508. https://doi.org/10.1111/1750-3841.13698

Svoboda, L., Kalač, P., Špička, J., & Janoušková, D. (2002). Leaching of cadmium, lead and mercury from fresh and differently preserved edible mushroom Xerocomus badius during soaking and boiling. Food Chemistry, 79, 41–45. https://doi.org/10.1016/S0308-8146(02)00174-9

Świsłowski, P., Dołhańczuk-Śródka, A., & Rajfur, M. (2020). Bibliometric analysis of European publications between 2001 and 2016 on concentrations of selected elements in mushrooms. Environmental Science and Pollution Research, 27, 22235–22250. https://doi.org/10.1007/s11356-020-08553-y

Tchounwou, P.B.; Yedjou, C.G.; Patlolla, A.K.; Sutton, D.J. Heavy Metal Toxicity and the Environment. In Molecular, Clinical and Environmental Toxicology; Luch, A., Ed.; Springer: Basel, Switzerland, 2012; Volume 101, pp. 133–164.

Tsegay, M. B., Asgedom, A. G., & Belay, M. H. (2019). Content of major, minor and toxic elements of different edible mushrooms grown in Mekelle, Tigray, Northern Ethiopia. Cogent Food & Agriculture, 5(1). https://doi.org/10.1080/23311932.2019.1686681

Turkekul, I., Elmastas, M., & Tuzen, M. (2004). Determination of iron, copper, manganese, zinc, lead and cadmium in mushroom samples from Tokat, Turkey. Food Chemistry, 84, 389–392. https://doi.org/10.1016/S0308-8146(03)00252-X

Udochukwu, U., Nekpen, B. O., Udinyiwe, O. C., & Omeje, F. I. (2014). Bioaccumulation of heavy metals and pollutants by edible mushroom collected from Iselu market Benin-city. International Journal of Current Microbiology and Applied Sciences, 3(10), 52–57.

Ufot, U. O., Iren, O. B., & Chikere-Njoku, C. U. (2016). Effects of land use on soil physical and chemical properties in Akokwa area of Imo State, Nigeria. International Journal of Life, Science and Scientific Research, 2(3), 1–6.

Ukaogo, P. O., Loai, A., Ezeibe, C. N., Ibrahim, I., Jian, T., Atem, B. A., Precious, O. E., Oys, S., & Ukaogo, C. T. (2024). Evaluation and risk assessment of heavy metals in King tuber mushroom in the context of COVID-19 pandemic lockdown in Sokoto state, Nigeria. Kuwait Journal of Science, 51(2), 100193. https://doi.org/10.1016/j.kjs.2024.100193

Usman, M. O., Anyanwu, O. O., Nnorom, I. C., & Oghale, I. (2022). Proximate composition and heavy metal content of Pleurotus tuberregium mushroom grown on different substrates in (Aba) Nigeria. GSC Biological and Pharmaceutical Sciences, 20(03), 213–222. https://doi.org/10.30574/gscbps.2022.20.3.0345

WHO. (2004). Fruit and Vegetables for Health – Report of a Joint FAO/WHO Workshop. http://www.fao.org/3/a-y5861e.pdf

WHO/FAO. (2007). Evaluation of Certain Food Additives and Contaminants (Technical Report Series 837). World Health Organization and Food and Agriculture Organization of the United Nations.

Witkowska, D., Słowik, J., & Chilicka, K. (2019). Heavy metals and human health: Possible exposure pathways and the competition for protein binding sites. Molecules, 26, 6060. https://doi.org/10.3390/molecules26196060

Wu, L. E., Levina, A., Harris, H. H., Cai, Z., Lai, B., Vogt, S., James, D. E., & Lay, P. A. (2016). Carcinogenic chromium (VI) compounds formed by intracellular oxidation of chromium (III) dietary supplements by adipocytes. Angewandte Chemie International Edition. https://doi.org/10.1002/anie.201608793

Yamaç, M., Yıldız, D., Sarıkürkcü, C., Çelikkollu, M., & Solak, M. H. (2007). Heavy metals in some edible mushrooms from the Central Anatolia, Turkey. Food Chemistry, 103, 263–267. https://doi.org/10.1016/j.foodchem.2006.07.056

Zhiqiu, F., Liu, G., & Luxiang, W. (2020). Assessment of potential human health risk of trace element in wild edible mushroom species collected from Yunnan Province, China. Environmental Science and Pollution Research, 27(23), 29218–29227. https://doi.org/10.1007/s11356-020-09079-z

Zhu, F., Qu, L., Fan, W., Qiao, M., Hao, H., & Wang, X. (2011). Assessment of heavy metals in some wild edible mushrooms collected from Yunnan Province, China. Environmental Monitoring and Assessment, 179(1–4), 191–199. https://doi.org/10.1007/s10661-010-1727-1