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Giant African land snails (*Achatina achatina* and *Archachatina marginata*) as bioindicator of heavy metal pollution

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It is important to always monitor the bioaccumulation potential for heavy metals by organisms especially the edible ones, to assess their potential risk to human health. This study evaluated the bioaccumulation of heavy metals in the shell and soft tissues of snails. Forty snails each were purchased from Ikire and Ore towns. The snails' shells, feet, digestive tracts and glands were analysed for bioaccumulation of heavy metals using an Atomic Absorption Spectrophotometer. The results showed that the concentration of heavy metals varied with the location and species of the snail. *Archachatina marginata* from Ore accumulated higher concentrations of heavy metals than *A. marginata* from Ikire. The concentration of Pb in *Achatina achatina* and *A. marginata* from Ikire, and Cd in *A. marginata* from Ore are slightly above the FAO/WHO permissible limits. Foot bioaccumulated more heavy metals in *A. achatina* while the digestive gland bioaccumulated more heavy metals in *A. marginata*. The study concluded that the shell and soft tissues of *A. achatina* at Ikire and *A. marginata* at Ikire and Ore bioaccumulated some levels of toxic heavy metals. *A. achatina* and *A. marginata* are capable of being used as a sentinel to study the physiological and biochemical imbalances in living organisms arising from the accumulation of heavy metals.

Key words: Bioaccumulation, heavy metal pollution, snails, A*chatina achatina, Archachatina marginata*.

INTRODUCTION

Giant African land snail is the common name for *Achatina achatina* (Linnaeus). It can grow up to 200 mm in length and a maximum diameter of 100 mm in the native range within the northern part of West Africa (Dar et al., 2017). *Archachatina marginata* (Swainson) is also one of the giant African snails with the common name banana rasp, it has the potential to grow up to 210 mm in length and 130 mm in diameter (Awodiran et al., 2012). *A. marginata* native range is within West Africa (Barker, 2001). These two species belong to the family Achatinidae. Achatinids are generally nocturnal forest dwellers but can fit into disturbed habitats. Hence, they are active more during the period of high humidity and feed on a wide range of living and dead plant materials. When reared in captivity, food materials often consumed by this species include banana, lettuce, papaya and the rind of watermelon (Ajayi and Babatunde, 2022). Achatinids attain sexual maturity at 9 to 10 months and can live up to 5 years (Cowie et al., 2009).

Appenroth (2010) and Oguh et al. (2019a) described

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heavy metals as those metals whose atomic mass exceeds that of Calcium; having relative densities greater than 5 g/cm^3. Heavy metals are toxic even at low concentrations, not biodegradable but can be assimilated and bioaccumulated in the tissues (Gupta and Singh, 2011). Heavy metals may include some trace elements such as Zinc (Zn), Iron (Fe), and Nickel (Ni) that are nutritionally required for enzymatic reactions and have functional roles in various metabolic processes. They become toxic when their concentrations exceed a certain limit (Gawad, 2018). The other category of heavy metals is nonessential and they are environmental pollutants. They are toxic even at a very low concentration. Examples include Arsenic (As), Cadmium (Cd), Thallium (Ti) and Tin (Sn).

The two major sources of heavy metals are natural and anthropogenic. Natural sources include atmospheric sources, geological weathering, the earth's crust and volcanic emissions while anthropogenic sources are a result of various human activities through effluent from automobiles, weathering, sewage sludge, fossil fuel burning, manufacturing industries, and fertilizer application (Mahmoud and Abu-Taleb, 2013). The probable health hazards posed by heavy metals remain a global concern especially, in developing countries, where treatment and elimination of effluents are inadequate or non-existent (Banaee and Taheri, 2019).

Snail meat is proteinous, rich in essential fatty acids and amino acids, supplies enough essential minerals, and contains less fat and cholesterol (Ademolu et al., 2004). Thus, snail meat holds the potential to bridge the gap of would-be nutritional deficiency owing to its nutritional profile, palatability and availability (Ajayi and Babatunde, 2022). These potentials are being harnessed because snails are easily accessible either by production, purchase or picking (hunting) in the wild (Anthony et al., 2010; Adeniyi et al., 2013).

Though snails are omnivores (Amobi and Ezewudo, 2019), wild snails which are commonly found in the bush, have free access to soil, vegetables, fruits, and plants which might have grown in heavy metals contaminated areas (Nica et al., 2012; Louzon et al., 2021). Domesticated snails fed with plant food materials that have been contaminated can accumulate such heavy metals. This could adversely affect their growth and reproductive capacity. Plants that grow near the roadside, domestic and industrial waste dumpsites tend to absorb and accumulate heavy metals (Singh et al., 2012; Salih et al., 2021). It is worthy to note that some of these elements are essential for the normal functions of the body but could cause acute and chronic poisoning when their concentrations exceed the tolerable limit.

Incessant consumption of fruits and vegetables grown in heavy metal highly contaminated soils and eating of animals that feed on the plants grown on such soil are the main route through which man gets infected (Khan et al., 2014). Heavy metals can bioaccumulate in the tissues of humans and non-humans and wreck great health havoc. Metal-induced pathologies remain a global public health concern (Hina et al., 2011; Izah et al., 2017). The toxic effects of heavy metals may be due to their interference with normal body biochemistry in the normal metabolic process (Okunola et al., 2011). Metals for instance Pb, Cd, and As may cause toxicity by preferentially interacting with thiol-containing groups of biomolecules, oxygen, or sulphur-containing compounds to induce oxidative stress, causing tissue damage (Lemire et al., 2013). Heavy metals are known disruptors of lipid homeostasis and the antioxidant system such as Pb and As in rats (Ademuyiwa et al., 2010), Cd in crabs (Yang et al., 2013), and Cd and Pb in snails and fish (Banaee and Taheri, 2019; Sarah et al., 2019). Exposure to Pb may cause mitochondrial apoptosis (Jin et al., 2017), disrupt the cellular redox state, inhibit haeme biosynthesis (Mani et al., 2018), and cause convulsion, encephalopathy and hypertension (Iweala et al., 2014). Cadmium has been reported to be hepatotoxic and nephrotoxic (Iweala et al., 2014). Cd may disrupt the metabolism of lipids by altering the levels of triacylglycerol, cholesterol, and lipoproteins via the inhibition of lipogenic enzymes (Yang et al., 2013). Keratosis, mitochondrial damage, disruption of glycolysis, dyslipidaemia, and carcinogenicity are hallmarks of arsenic (As) toxicity (Gupta and Singh, 2011; Afolabi et al., 2015). Furthermore, heavy metals toxicity may lower endogenous antioxidant molecules (such as metallothionein), impede secondary antioxidant enzymes (such as Arylesterase), reduce glutathione levels, increase lipid peroxidation, and induce oxidative stress (Gupta and Singh, 2011; Izah et al., 2017; Banaee and Taheri, 2019).

With these dangers posed by heavy metals in mind, it is appropriate to identify organisms that can be used as sentinel in the study of heavy metal pollution in our environment and the level of accumulation of such heavy metals in living organisms along with the physiological and biochemical imbalances arising from the bioaccumulation. This study seeks to evaluate the level of heavy metals (Copper, Zinc, Chromium, Lead, Nickel, Iron, Cobalt, Cadmium and Arsenic) (Figure 1) in selected tissues of *A. achatina* and *A. marginata* with the view to compare the extent of heavy metals bioaccumulation in the tissues of the snails from the two sampling locations and compare the levels of heavy metals with established regulatory standards.

MATERIALS AND METHODS

Area of study

Forty snails each were purchased from Ikire and Ore in June and July 2021. The month of June is an active farming season in southwest Nigeria when agrochemicals are used on farmlands for plant protection and weed control.

Ikire town is the administrative headquarter of Irewole local government of Osun State, Nigeria. It is the gateway town into

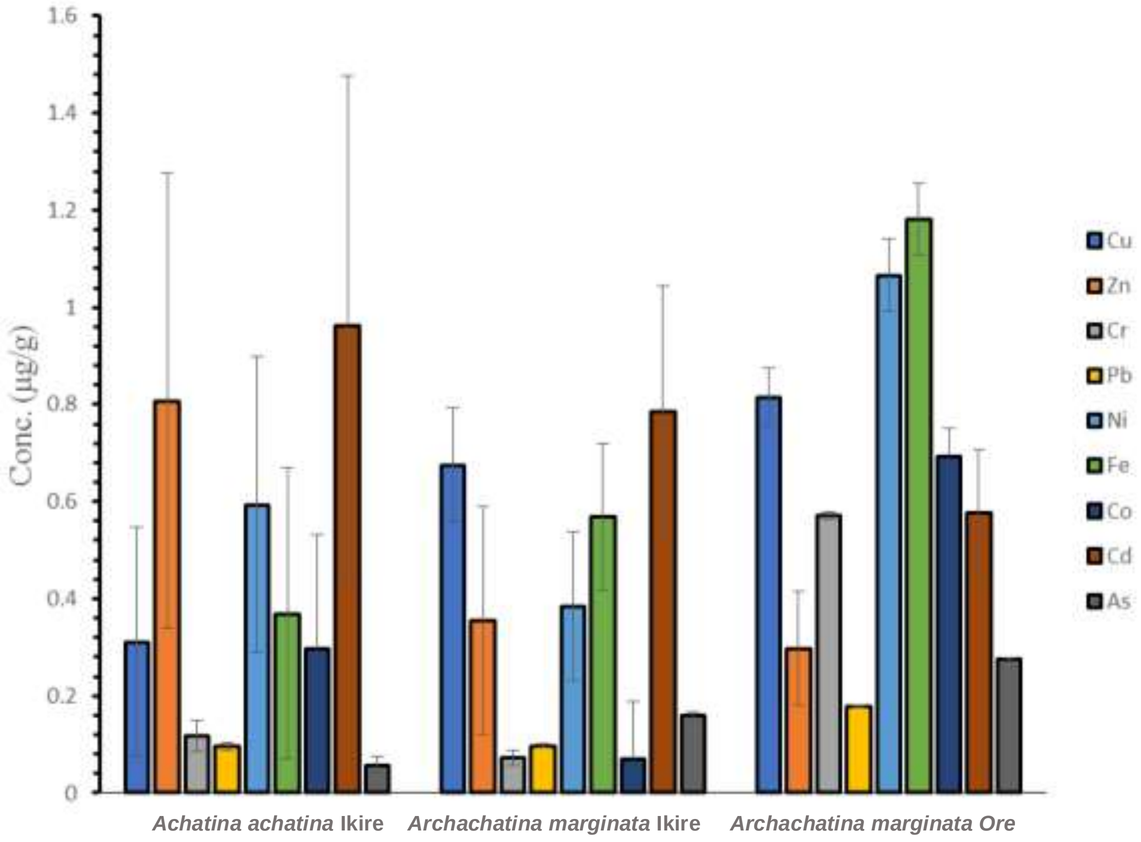

Figure 1. Level of heavy metal accumulation in *A. achatina* and *A. marginata*.
Source: Author

Osun from Oyo State. Ikire is within the basin of River Osun; it lies around latitude 07°21'29'' - 07°24'36'' North and longitude 004°10'11'' - 004°13'43'' East. Ore town is the administrative headquarter of Odigbo local government area in Ondo State, Nigeria. It is the major town separating southwestern Nigeria from the southeast; its geographical coordinates are between 06°42'18'' - 06°46'30'' North and 004°51'18'' - 004°54'55'' East.

Land use

The primary activity in Ikire is farming. The proximity to Ibadan, a major commercial and industrial centre in southwest Nigeria, facilitates the easy movement of goods and services. Ore is a commercial town with agriculture being the mainstay of the economy, cultivating different food crops and cash crops like cassava, plantain, cocoa etc. It is reputable for the large bitumen deposit in Ondo state.

Sample collections

Giant African land snails were purchased from farmers who sourced the snails in the wild. Procured snails were immediately taken into the Physiology laboratory at the Department of Zoology, Obafemi Awolowo University, Ile-Ife for identification. Fifteen *A. achatina* and twenty-five *A. marginata* were bought at Ikire; all the forty snail samples from Ore were *A. marginata*. Only fully grown snails were purchased because this is the preferred size consumed by the local population.

Dissection of snail specimens

Snails were dissected according to the method described by Low et al. (2016). The snails were thoroughly washed with distilled water. The snails were dissected to remove the foot, the digestive gland and the digestive tract. These parts were stored in small plastic jars and preserved in the deep freezer ready to be analysed. Snail shells were also kept in polythene bags and later analysed.

Determination of heavy metals

Each body part was defrosted for 2 h, weighed into a pre-weighed crucible and dried at 80°C in Gallenkamp hot box oven. The sample weights were taken and recorded at 4 h intervals until a constant weight was obtained. The samples were ground separately to fine particles using clean, dried mortar and pestle and then sifted using a sieve of particle size 0.02 mm. Each powdered sample (0.5 g) was measured into a 100 ml beaker; 5 ml of aqua regia HCL and HNO_3 (3:1) was added to digest the sample. The samples were evenly distributed in the acid using a glass stirring rod. The digested samples were filtrated (using Whatman filter paper No. 1) into a cylinder. The filtrate was made up to 25 ml of distilled water. The concentration of heavy metals: viz. Arsenic, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Nickel and Zinc in the

Table 1. Heavy metal concentration in *Achatina achatina* collected from Ikire.

Heavy metals (µg/g)	Tissues			
	Shell	Foot	Digestive tract	Digestive gland
Cu	0.052 ± 0.0000^{a}	1.018 ± 0.0028^{c}	0.088 ± 0.0028^{b}	0.086 ± 0.0000^{b}
Zn	2.003 ± 0.0014^{d}	0.031 ± 0.0035^{a}	0.087 ± 0.0021^{b}	1.111 ± 0.0014^{c}
Cr	0.200 ± 0.0014^{d}	0.051 ± 0.0014^{a}	0.099 ± 0.0092^{b}	0.119 ± 0.0014^{c}
Pb	0.092 ± 0.0014^{ab}	0.103 ± 0.0028^{bc}	0.116 ± 0.007^{c}	0.078 ± 0.0035^{a}
Ni	0.083 ± 0.0028^{b}	1.121 ± 0.0028^{c}	1.123 ± 0.0064^{c}	0.047 ± 0.0042^{a}
Fe	1.265 ± 0.0007^{c}	0.050 ± 0.0021^{a}	0.106 ± 0.0050^{b}	0.057 ± 0.0042^{a}
Co	0.078 ± 0.0028^{b}	1.001 ± 0.0007^{c}	0.055 ± 0.0042^{a}	0.055 ± 0.0042^{a}
Cd	0.059 ± 0.0000^{a}	2.306 ± 0.1060^{d}	0.258 ± 0.0042^{b}	1.227 ± 0.0063^{c}
As	0.061 ± 0.0000^{ab}	0.037 ± 0.0021^{a}	0.029 ± 0.0021^{a}	0.104 ± 0.0240^{b}

Mean ± standard deviation with the same alphabet along the rows are not significantly different at $p < 0.05$ by Tukey HSD.
Source: Author

Table 2. Heavy metals concentration in *Archachatina marginata* collected from Ikire.

Heavy metals (µg/g)	Tissues			
	Shell	Foot	Digestive tract	Digestive gland
Cu	1.030 ± 0.0007^{a}	0.549 ± 0.6378^{a}	1.030 ± 0.0424^{a}	0.095 ± 0.0778^{b}
Zn	0.072 ± 0.0021^{a}	0.058 ± 0.0028^{a}	0.087 ± 0.1768^{a}	1.200 ± 0.0184^{b}
Cr	0.090 ± 0.0028^{b}	0.102 ± 0.0028^{b}	0.039 ± 0.0014^{a}	0.055 ± 0.0092^{a}
Pb	0.042 ± 0.0000^{a}	0.190 ± 0.0007^{d}	0.055 ± 0.0050^{b}	0.101 ± 0.0028^{c}
Ni	0.255 ± 0.0000^{c}	0.023 ± 0.0050^{a}	1.199 ± 0.000^{d}	0.060 ± 0.0042^{b}
Fe	0.331 ± 0.0028^{b}	0.114 ± 0.0000^{a}	0.775 ± 0.0163^{a}	1.055 ± 0.6647^{c}
Co	0.029 ± 0.0000^{a}	0.080 ± 0.0021^{b}	0.087 ± 0.0014^{c}	0.087 ± 0.0014^{c}
Cd	0.086 ± 0.0014^{a}	1.107 ± 0.0014^{b}	0.087 ± 0.015^{c}	1.867 ± 0.2080^{c}
As	0.085 ± 0.0021^{a}	0.440 ± 0.0000^{b}	0.063 ± 0.0021^{a}	0.048 ± 0.0000^{c}

Mean ± standard deviation with the same alphabet along the rows are not significantly different at $p < 0.05$ by Tukey HSD.
Source: Author

samples was examined using PG 990 model Atomic Absorption Spectrophotometer (AAS).

Statistical analysis

Data were analysed using one-way ANOVA and Independent-sample T-test in IBM SPSS version 25. Tukey's HSD Post Hoc test was used to resolve differences among means. $P < 0.05$ indicates significant differences among groups.

RESULTS

Concentration (µg/g) of heavy metals in *A. achatina* procured from Ikire

The mean concentration of heavy metals in *A. achatina* collected from Ikire is shown in Table 1. Zn, Cr and Fe were accumulated in the shell more than in other organs. The foot accumulated more Cu, Co and Cd than other organs. The digestive tract had the highest concentration of Pb and Ni. The digestive gland accumulated the highest concentration of As and the lowest concentration of Pb and Ni. There was a significant difference ($p < 0.005$) in the concentration of heavy metals across the organs.

Concentration (µg/g) of heavy metals in *A. marginata* collected from Ikire

The results summarized in Table 2 showed that in *A. marginata* collected from Ikire, the shell had the lowest concentration of Pb, Co and Cd while the foot had the highest level of Cr, Pb and As. The digestive tract had the lowest level of Cr. However, Ni in the digestive tract was higher than in the other organs. The digestive gland had the highest concentration of Zn, Fe and Cd and the lowest concentration of Cu and As. The concentration of Cu and Zn in the digestive gland was significantly different ($p < 0.05$) from the concentration in the shell, foot and digestive tract. Moreover, there was a statistically significant ($p < 0.05$) difference in the level of Pb bioaccumulated across the organs.

Concentration (µg/g) of heavy metals in *A. marginata* collected from Ore

As shown in Table 3, the mean concentrations of Zn, Ni and As were more in the shell than in other tissues whereas the mean concentrations of Cu, Cr and Cd in the shell were lower than in other tissues. The concentration of Fe and Cd in the foot was higher than in other tissues. The concentration of Co in the foot was the least among the tissues. The highest concentration of Cr was recorded in the digestive tract while Pb, Fe and As in the digestive tract were lower than in other tissues. The digestive gland accumulated more Cu and Pb than other tissues while the level of Zn and Ni accumulated in the digestive gland were lower than in other tissues. There was a significant difference in the level of accumulated heavy metals across the tissues ($p < 0.005$) except Pb.

Relationship between the levels of heavy metals in the shell, foot, digestive tract and digestive gland of *A. achatina* and *A. marginata* collected from Ikire and Ore

Independent-sample t-test was used to compare the levels of heavy metals in the shell, foot, digestive tract and gland of *A. achatina* and *A. marginata* collected from Ikire and Ore. The result revealed that there was a significant difference ($p < 0.05$) in the level of heavy metals within the shell and foot (except Cu) of *A. achatina* and *A. marginata* in Ikire and Ore. Similarly, there was a statistical difference ($p < 0.05$) in the heavy metal concentrations except for Zn, Pb, Fe, Cd in the digestive tract of *A. marginata* collected from Ikire and Ore*;* and Zn and Fe in the digestive tract of *A. achatina* and *A. marginata* from Ikire.

Pb, Fe and As in the digestive glands of *A. marginata* from Ikire and Ore; Cu, Ni and As in the digestive glands of *A. achatina* and *A. marginata* from Ikire showed no significant difference ($p > 0.05$). The level of heavy metals in the shell, foot, digestive tract and digestive gland of *A. achatina* and *A. marginata* gathered from Ikire; and *A. marginata* from Ikire and Ore were not significantly different ($p > 0.05$).

Overall, the concentration of heavy metals in snail tissues varied with the location and species of the snail. Cd (0.963 µg/g) followed by Zn (0.808 µg/g) were the most accumulated heavy metals and As (0.058 µg/g) had the minimum accumulation in *A. achatina* from Ikire. The trend of heavy metal in *A. achatina* from Ikire showed that Cd > Zn > Ni > Fe > Cu > Co > Cr > Pb > As. In *A. marginata* from Ikire, Cd (0.787 µg/g) and Cu (0.676 µg/g) were the most accumulated heavy metals while Co (0.070 µg/g) was the least accumulated metal. The concentration of metals was detected in the following order Cd > Cu > Fe >Ni > Zn > As > Pb > Cr > Co. However, the trend of heavy metals in *A. marginata* from Ore revealed that Fe (1.182 µg/g) and Ni (1.066 µg/g) were the most accumulated heavy metals and Pb (0.178 µg/g) had the minimum accumulation following the trend: Fe > Ni > Cu > Co > Cd >Cr > Zn > As > Pb (Fig. 1). Moreover, the trend of heavy metals accumulation in *A. achatina* from Ikire showed that Foot (0.635 µg/g) > Shell (0.433 µg/g) > Digestive gland (0.320 µg/g) > Digestive tract (0.218 µg/g). The trend of heavy metals in *A. marginata* from Ikire was Digestive gland (0.508 µg/g) > Digestive tract (0.380 µg/g) > Foot (0.296 µg/g) > Shell (0.224 µg/g) while Digestive gland (0.713 µg/g) > Shell (0.655 µg/g) > Foot (0.615 µg/g) > Digestive tract (0.531 µg/g) was observed in *A. marginata* from Ore (Figure 2).

Comparison of inherent heavy metals with regulatory standards

The level of heavy metals in the tissues of *A. achatina* and *A. marginata* collected from Ikire and Ore were compared with the established regulatory safety standards for human consumption concerning the edible parts (Table 4). The concentrations of heavy metals recorded in the edible parts of *A. achatina* and *A. marginata* are lower than the FAO/WHO (2016) regulatory limits except for Pb (0.105 µg/g), Ni (1.123 µg/g), Co (1.002 µg/g) and Cd (2.314 µg/g) in *A. achatina*; Pb (0.190 µg/g) in *A. marginata* from Ikire*,* and Cd (2.100 µg/g) in *A. marginata* from Ore which is slightly above the permissible level*.*

DISCUSSION

Bioaccumulation of heavy metals in tissues varies significantly amongst the taxa and conspecifics (Iwegbue et al., 2009). The concentration of heavy metal in the tissues depends on the form in which the metal is bound (Mariam et al., 2004). Other factors that influence the accumulation of heavy metals are metal concentration in the soil, soil pH, and the physiological characteristics of the species which include assimilation and excretion capacity (Purchart and Kula, 2007). The giant African land snails are omnivores that feed on the debris from the soil surface which may have been contaminated with heavy metals and organic pollutants; therefore, they may accumulate the pollutants to harmful levels.

In *A. marginata* from Ikire, Cu was highest in the shell (1.030 ± 0.0071 µg/g), Ni was predominant in the digestive tract (1.199 ± 0.000 µg/g), the foot (1.107 ± 0.0014 µg/g) and the digestive gland (1.867 ± 0.208 µg/g) accumulated highest level of Cd. The results recorded in this study were within the tolerable limit of FAO/WHO

Table 3. Heavy metals concentration in *Archachatina marginata* collected from Ore.

Heavy metals (µg/g)	**Tissues**			
	Shell	**Foot**	**Digestive tract**	**Digestive gland**
Cu	0.071 ± 0.0021^{a}	1.106 ± 0.0042^{b}	0.075 ± 0.0042^{a}	2.010 ± 0.0014^{c}
Zn	1.025 ± 0.0350^{b}	0.082 ± 0.0035^{a}	0.046 ± 0.0000^{a}	0.036 ± 0.0021^{a}
Cr	0.051 ± 0.0000^{a}	0.065 ± 0.0028^{a}	1.105 ± 0.0063^{c}	1.070 ± 0.0120^{b}
Pb	0.070 ± 0.0028^{a}	0.051 ± 0.0000^{a}	0.037 ± 0.0050^{a}	0.553 ± 0.6480^{a}
Ni	2.161 ± 0.0000^{d}	0.089 ± 0.0014^{b}	2.000 ± 0.00071^{c}	0.016 ± 0.0007^{a}
Fe	1.433 ± 0.0014^{c}	2.008 ± 0.0028^{d}	0.045 ± 0.0020^{a}	1.241 ± 0.0370^{b}
Co	0.054 ± 0.0021^{a}	0.024 ± 0.0000^{a}	1.346 ± 0.0760^{b}	1.346 ± 0.0760^{b}
Cd	0.030 ± 0.0021^{a}	2.096 ± 0.0056^{d}	0.112 ± 0.0021^{c}	0.075 ± 0.0160^{b}
As	1.000 ± 0.0021^{c}	0.017 ± 0.0021^{a}	0.011 ± 0.0000^{a}	0.074 ± 0.0150^{b}

Means ± standard deviation with the same alphabet along the rows are not significantly different at $P < 0.05$ by Tukey HSD.
Source: Author

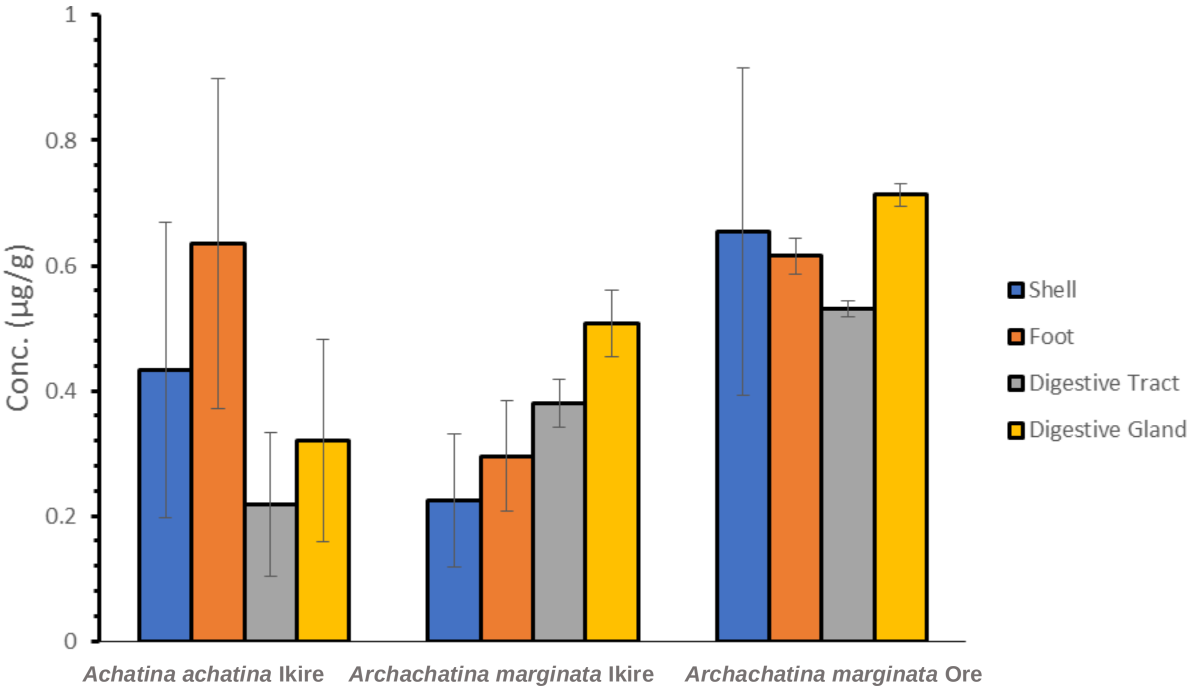

Figure 2. Level of heavy metal accumulation in the tissue of *Achatina achatina* and *Archachatina marginata*.
Source: Author

(expect Ni in the digestive tract). Ogidi et al. (2020) reported (0.14 ± 0.001 µg/g), (0.032 ± 0.002 µg/g) and (0.96 ± 0.007 µg/g) for Cd, Ni and Cu, respectively in the tissue of *A. marginata* from Ekowe community and observed that *A. marginata* bioaccumulate high levels of Zinc when compared with other metals such as Cu, Cd, Ni, Cr. Iwegbue et al. (2009) recorded higher levels of Pb (6.53 ± 1.03 µg/g), Fe (7.86 ± 0.36 µg/g), Ni (0.18 ± 0.16 µg/g) and Cd (1.47 ± 0.55 µg/g) in the tissues of *A. marginata* in industrial sites of Warri.

The main sources of heavy metal contamination are vehicle exhaust and untreated industrial wastes that find their way through irrigation channels, therefore polluting the soil layers (Mariam et al., 2004). An increased Pb content may be found in crops and animals at distances of 50 m radius from highways, depending on weather conditions and traffic volume (Eltier and Sivacioglu, 2021). The level of heavy metals in the tissues of *A. marginata* from Ore is relatively higher than in *A. marginata* from Ikire (except Zn and Cd). Cadmium is

Table 4. Permissible maximum limit (µg/g) of heavy metals in regulatory standards.

Heavy metals (µg/g)	*Archachatina marginata* Ikire	*Archachatina marginata* Ore	*Achatina achatina* Ikire	Acceptable Maximum Limits (µg/g)
Cu	1.000	1.109	1.020	NL
Zn	0.060	0.085	0.033	3.000
Cr	0.104	0.067	0.053	0.300
Pb	**0.190**	0.051	**0.105**	0.100
Ni	0.026	0.090	**1.123**	0.500
Fe	0.114	2.010	0.051	NL
Co	0.081	0.024	**1.002**	1.000
Cd	1.108	**2.100**	**2.314**	2.000
As	0.044	0.018	0.038	0.500
References	This study	This study	This study	FAO/WHO (2016)

NL: No limit given by FAO/WHO. The bold values represent the concentration of metals above the permissible limit by FAO/WHO (2016).
Source: Author

closely related to Zinc and is found wherever Zinc is found in nature. Cd may occur as a contaminant in phosphate fertilizers and municipal sludges and so enter the food supply. Shell (2.161 ± 0.0000 µg/g) and digestive tract (2.000 ± 0.0007 µg/g) in *A. marginata* from Ore have a higher accumulation of Nickel. The foot accumulated Cd (2.096 ± 0.0056 µg/g) than other tissues while the digestive gland has a rich deposit of Cu (2.010 ± 0.0014 µg/g). Although, Cr and Co (in the digestive tract and gland), Ni (in the shell and digestive gland), Pb (in the digestive gland) and As (in the shell) outstripped the FAO/WHO permissible limit yet this finding is comparatively low to studies recorded by other authors. Moreover, heavy metal concentration in the muscular foot (the main constituent of snail meat) did not exceed the FAO/WHO regulated limit. Therefore, *A. marginata* from Ore may be tenable for human consumption. Awharitoma et al. (2016) reported higher values for Fe, Pb, Cd and Co in the range between (38.61 - 70.49 µg/g), (0.39 - 0.71 µg/g), (0.19 - 0.35 µg/g) and (0.04 - 0.007 µg/g), respectively in infected *A. marginata* from three communities in Edo State while Oguh et al. (2019b) reported that the concentration of heavy metals (As, Cd, Cr, Cu and Pb) in snails treated with dumpsite soil were 3.05, 3.89, 3.60, 2.89 and 2.55 mg/kg, and snails treated with mining site soil recorded 2.73, 2.74, 3.91, 4.96 and 4.82 mg/kg, respectively.

Lead (Pb) has no beneficial biological function and is known to accumulate in the body (Assi et al., 2016). Ingestion of Pb through the consumption of contaminated foods may cause mental retardation among children, inhibit haemoglobin synthesis; distort the cardiovascular system and hypertension in humans (Bello et al., 2015; Nkpaa et al., 2016). Cadmium is a toxic element because it can be absorbed through the alimentary tract and damage membrane and DNA (Maobe et al., 2012). In comparison with levels of heavy metals recorded in *A. achatina* by previous authors, the mean concentration of heavy metals in *A. achatina* collected from Ikire is low. Zn was predominant in the shell (2.003 ± 0.0014 µg/g), Cd recorded (2.306 ± 0.106 µg/g) in the foot, Ni (1.123 ± 0.0064 µg/g) was more accumulated in the digestive tract while Cd (1.227 ± 0.0063 µg/g) and Zn (1.111 ± 0.0014 µg/g) had higher accumulation in the digestive gland. Ugbaja et al. (2020) reported 1.80 µg/g of Cd in the foot of *A. achatina* collected from the Papalanto cement factory area. Eneji et al. (2016) recorded (0.42 - 2.80 mg/kg) of Cd in *A. achatina* from Abak, Akwa Ibom, Nigeria. However, Adedeji et al. (2011) had earlier recorded a low concentration (0.01 mg/kg) of Cd in snails from Alaro River in Oluyole Industrial Area Ibadan, Oyo State.

The levels of heavy metals across the tissues in *A. achatina* and *A. marginata* from Ikire and Ore were relatively within the FAO/WHO (2016) benchmarks limits except for Pb, Ni, Co and Cd in *A. achatina*; Pb in *A. marginata* from Ikire, and Cd in *A. marginata* from Ore which are slightly above the permissible level. This shows that the environment is gradually being polluted with toxic waste. It is important to always determine the bioaccumulation capacity for heavy metals by organisms especially the edible ones, to assess the potential risk to human health and other animals that feed on the organisms. Though, the level of heavy metals in *A. marginata* from Ore was comparatively higher which could probably be due to overdose of agrochemical application, higher traffic emission and higher concentration of toxic wastes from the activities of industrial presence in the Ore axis. Heavy metals often find their way into the soil and vegetation through an overdose of agrochemical application, pollution from traffic emissions and sewage from industrial estates (Adedeji et al., 2011; Eltier and Sivacioglu, 2021; Salih et al., 2021). The ability of snails to bioaccumulate essential heavy metals enables them to acquire other non-essential heavy metals from the soil and vegetation.

Conclusion

This study has shown that giant African land snails *A. achatina* and *A. marginata* can accumulate high levels of heavy metals in the shell and soft tissues. Thus, *A. achatina* and *A. marginata* serve as good bioindicators of heavy metal pollution in the terrestrial ecosystem. The results of this study provided baseline data on the levels of heavy metals in *A. achatina* in Ikire and *A. marginata* in Ikire and Ore. Very close monitoring of heavy metal levels in Ore and Ikire towns is recommended. Snails need to be thoroughly screened to make sure that unnecessarily high levels of toxic heavy metals are not being transferred through them to the human population that depends on the snail meat for their protein requirements. Therefore, proper monitoring of agrochemical application is recommended to reduce the level of heavy metals built-up which will contribute to further environmental pollution in the not-too-distant future.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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