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Heavy metals and metalloid accumulation in livers and kidneys of wild rats around gold-mining communities in Tarkwa, Ghana

Nesta Bortey-Sam[1], Shouta M. M. Nakayama[1], Yoshinori Ikenaka[1], Osei Akoto[2], Elvis Baidoo[2], Hazuki Mizukawa[1] and Mayumi Ishizuka[1]*

[1]Laboratory of Toxicology, Department of Environmental Veterinary Sciences, Graduate School of Veterinary Medicine, Hokkaido University, Japan.
[2]Department of Chemistry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

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Previous studies revealed high levels of metals in soils, drinking water, foodstuffs and food animals in several communities in Tarkwa, Ghana. Therefore wild rats were trapped from 16 communities in Tarkwa to estimate the environmental pollution state of metals; determine differences in sex in metal accumulation; and assess the potential risks involved. Concentrations of arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn) were measured in the livers and kidneys of wild rats; and livers accumulated higher levels of As than kidneys but the reverse was for Cd and Pb. In both organs, As, Cd and Zn levels were higher in female than the male rats. There was a strong positive correlation between body weight and Cd concentrations in livers and kidneys of wild rats which reflects a mechanism of protection against the development of osteopenia, although a biological effect remains a concern. Pb levels in the kidneys could cause intra nuclear inclusion bodies and karyocytomegaly in the proximal tubular cells in 29% of wild rats in Tarkwa and structural and functional kidney damage in 6%. Concentrations of As in kidneys of these wild rats could cause glomerular swelling in 9% of rats. Principal component analysis of the results showed that wild rats in Tarkwa were exposed to heavy metals and a metalloid through borehole drinking water and soils.

Key words: Wild rats, heavy metal, metalloid, liver, kidney, Ghana.

INTRODUCTION

Anthropogenic activities including artisanal and small-scale gold mining have caused elevated levels of heavy metal and metalloids in the environment (Naccari et al., 2009; Licata et al., 2010). This activity could lead to spillage and run-off into rivers, ponds, streams, wells, and borehole drinking water (Obiri, 2007), and further result in

*Corresponding author. E-mail: ishizum@vetmed.hokudai.ac.jp. Tel: +81–11–706–6949. Fax: +81–11–706–5105.

heavy metal and/or metalloid exposure to humans and animals through various pathways. Heavy metals and metalloids have a wide range of health effects including mutagenicity, carcinogenicity, teratogenicity, immunosuppression, poor body condition, and impaired reproduction in humans and animals (Scheuhammer, 1987; Florea and Busselberg, 2006). All of these make them a serious threat to living organisms (Battaglia et al., 2005; López-Alonso et al., 2007; Naccari et al., 2009).

Tarkwa (05°18′00″N; 01°59′00″W) is a town in the southwest of Ghana, with a population of 90,477 (Ghana Statistical Service, 2010). It is a noted centre for gold and manganese mining. Tarkwa mine, which is a large open-cast gold mine, is situated to the northwest of the town, and Nsuta manganese mine is situated to the east. Tarkwa has nearly a century of gold mining history and the largest concentration of mining companies in a single district in Ghana and the West African sub-region (Akabzaa and Darimani, 2001).

Studies conducted by Asante et al. (2007), Bortey-Sam et al. (2015a, b, c, d) and Hayford et al. (2008) on the impact of gold mining in soil, drinking water, foodstuffs and food animals (free-range chickens, goat and sheep) collected around mining communities in Tarkwa showed high levels of some toxic metals including arsenic (As) and mecury (Hg) than maximum levels by European Commission (EC) (2006), World Health Organization (WHO) (1996; 2011) and United States Environmental Protection Agency (USEPA) (2004; 2012). Bortey-Sam et al. (2015a) indicated that the concentrations of some heavy metals/metalloid in agricultural soils in some communities in Tarkwa exceeded the ecological-soil screening levels (USEPA, 2004) recommended for mammalian wildlife, which includes wild rats and mice. However, levels of metals (0.24 [Hg] to 72 mg/kg dw [Zn]) detected in soils collected from the University of Mines and Technology (uMaT) campus (reference site) were low compared to world range for unpolluted soils by Kabata-Pendias and Pendias (1992).

Although wildlife is rich and diverse, with a large number of mammals, reptiles and insects in the study area, rats were used as sentinels to measure the environmental pollution state because they are mammals that share many processes with humans and are appropriate for use to answer many research questions. They tend to pick food and water from the ground which could be contaminated with various pollutants including metals. In studies by Nakayama et al. (2011, 2013), wild rats in mining areas in Zambia were used as sentinels for heavy metal accumulation, and results showed that rats accumulated metals had likely originated from mining activities. Similarly, Guerrero-Castilla et al. (2014) used wild mice around coal mining areas in Columbia to study the exposure and health effects of heavy metals from the mining processes.

Despite the wide and numerous studies of heavy metals concentrations in various samples in Tarkwa, Ghana, there is limited or no data from literature on its accumulation in wild rats. The objectives of this study were to determine the accumulation of heavy metals and a metalloid in livers and kidneys of wild rats in Tarkwa; to determine sex differences in heavy metals and metalloid accumulation; to examine the relationship between body weight of rats and metal; to identify the possible exposure route of these metals to wild rats in Tarkwa; and to examine the potential risks heavy metals could pose to wild rats.

MATERIALS AND METHODS

Sampling

All procedures used in this experiment were according to the guidelines of the Hokkaido University Institutional Animal Care and Use Committee and the local veterinarian policy of the study area. In June, 2012, live wild rats (*Rattus norvegicus* or *R. rattus*) were captured using gauze cage traps with food as bait, in residential, commercial and farming areas (within 16 communities) in Tarkwa (n = 46). Rat species were morphologically identified. Some of the sampled communities were 2 (Samahu), 3.4 (Abekuase) and 5.2 (T-Tamso) km away from the mines, respectively (Figure 1). After anesthesia overdose, rats were euthanized, and body weight and sex were determined (25 females and 21 males). The livers and kidneys are target organs for monitoring metal contamination in animals because both organs function in removing toxic metals from the body (Abou-Arab, 2001; Husain et al., 1996). Studies of three animal species (free-range chickens, goat and sheep) in Tarkwa showed that the livers and kidneys contained the highest levels of metals (Bortey-Sam et al., 2015d). For these reasons, livers and kidneys were collected from each rat and stored at −20°C. Samples were kept in a freezer at the Chemistry Department of the Kwame Nkrumah University of Science and Technology, KNUST, Ghana and later transported to the Laboratory of Toxicology, Graduate School of Veterinary Medicine, Hokkaido University, Japan where they were stored in -30°C until analysis.

Sample preparation and metal analysis

Preparations and digestion of liver and kidney samples for heavy metals and metalloid analysis were done according to method described by Bortey-Sam et al. (2015d). Approximately 0.5 g of individual samples were dried in an oven at 40°C and placed in prewashed digestion vessels. Samples were digested (for 52 min) (Speed Wave MWS-2 microwave digestion, Berghof, Germany) using 5 ml of (65%) nitric acid, HNO_3 (Kanto Chemical Corp., Tokyo, Japan) and 1 ml of (30%) hydrogen peroxide, H_2O_2 (Kanto Chemical Corp., Tokyo, Japan). After digestion, cooled samples were transferred into corning tubes (Corning Incorporated, New York, USA) and diluted to a final volume of 10 ml with milli Q water. A reagent blank was prepared using the same procedure.

An inductively coupled plasma-mass spectrometer (ICP-MS; 7700 series, Agilent technologies, Tokyo, Japan) was used for quantification. The instrument was calibrated using standard solutions of the respective metals (to establish standard curves before metal analysis). All chemicals and standard stock solutions were of analytical reagent grade (Wako Pure Chemicals, Osaka, Japan). The detection limits (ng/g) of chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn),

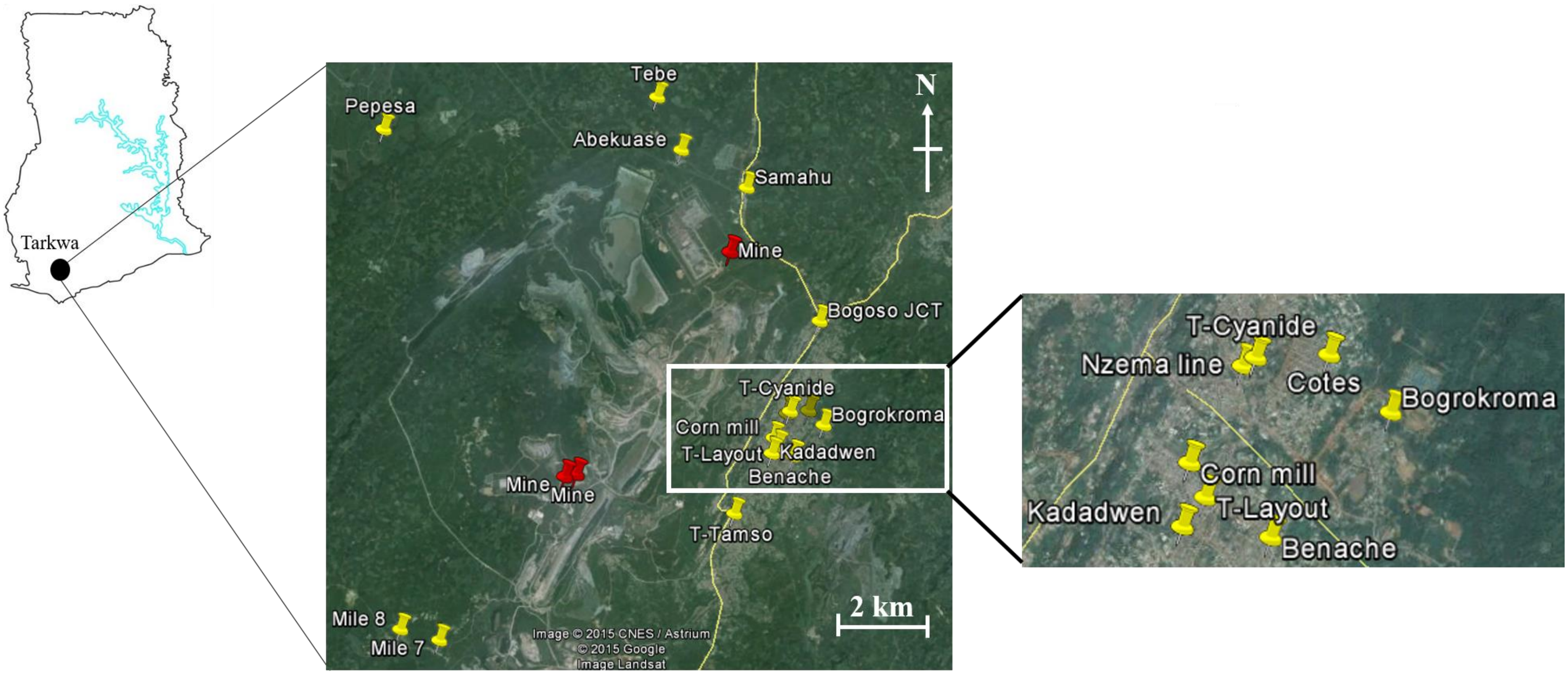

Figure 1. Map showing wild rats sample locations in Tarkwa, Ghana (yellow and red and pins indicate sampled communities and gold mines, respectively).

arsenic (As), cadmium (Cd), and lead (Pb) were 0.003, 0.025, 0.154, 0.0004, 0.024, 0.007, 0.226, 0.002, 0.001 and 0.001, respectively. Concentrations of metals were expressed in mg/kg dry weight (mg/kg dw).

Quality assurance and quality control

For heavy metals and metalloid, replicate blanks and reference materials, DORM-3 (Fish protein, The National Research Council, Canada) and DOLT-4 (Dogfish liver, The National Research Council, Canada) were used for method validation and quality control. Replicate analysis of these reference materials showed good accuracy (relative standard deviation, RSD, ≤ 3%) and recovery rates ranged from 80 to 115%.

Statistical analysis

Statistical analyses were performed using SPSS 20.0 (IBM SPSS Inc., Chicago, USA). Kolmogorov-Smirnov (K-S) and Shapiro-Wilk's (S-W) tests were used to determine the normality of data and was considered statistically significant if *p* value was less than 0.05. Statistical analyses were carried out after data were log transformed (normalized). Student's T-test was used to compare distribution of metals between livers and kidneys, and differences were considered statistically significant with *p* value < 0.05. Pearson's correlations were used to determine the relationship between concentrations of metals and body weight, and significant level was *p* value less than 0.05. Principal component analysis (PCA) based on log transformed data was done to determine the distribution pattern and possible route of heavy metals exposure to wild rats, using JMP statistical software v. 10

Table 1. Mean concentrations (± SD) and ranges of heavy metals and a metalloid (mg/kg dw) in the livers and kidneys of wild rats in Tarkwa, Ghana.

Samples		n	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Liver	Mean	46	2.59[a]	0.198[a]	0.198[a]	0.147[a]	18.9[a]	5.50[a]	0.869[a]	1.05[a]	263[a]
	SD		2.81	0.321	0.207	0.0908	14.0	2.86	0.522	2.23	95.2
	Minimum		0.0699	0.0213	0.0784	0.0166	7.59	2.54	0.219	0.0532	112
	Maximum		12.6	1.45	1.21	0.406	71.8	19.1	2.11	10.7	524
Kidney	Mean	46	1.91[a]	1.41[b]	0.382[b]	0.375[b]	14.3[a]	4.09[b]	2.02[b]	3.97[b]	117[b]
	SD		2.33	3.57	0.333	0.327	4.57	2.79	1.85	8.15	41.7
	Minimum		0.102	0.0039	0.0741	0.0773	9.17	1.53	0.172	0.044	64.3
	Maximum		14.0	21.1	1.62	1.72	39.5	16.8	7.85	41.6	284

n: number of samples; SD: standard deviation; different letters (a and b) between groups indicates significant difference (Student's T-Test; $p < 0.05$.

(SAS Institute). The principal components were extracted with eigenvalues > 1.

RESULTS AND DISCUSSION

Levels of heavy metals and a metalloid

Mean concentrations of heavy metals and a metalloid in livers of wild rats in Tarkwa decreased in the order; Zn > Cu > Mn > As > Pb > Ni > Cr > Co = Cd; and the order in the kidney was Zn > Cu > Mn > Pb > Ni > As > Cd > Co = Cr (Table 1). All metals measured were detected in 100% of liver and kidney samples. K-S and S-W's tests for normality showed a significant variation ($p < 0.001$) in metal distribution in livers and kidneys of wild rats in Tarkwa. Distribution of Cd, Co, Cr, Mn, Ni, Pb, and Zn between livers and kidneys differed significantly (Student's T-test; $p < 0.05$) (Table 1). The following paragraphs discusses As, Pb and Cd which were classified as the first, second and seventh most hazardous substances (Agency for Toxic Substances and Disease Registry (ATSDR), 2013), and Mn because Tarkwa is also noted for Mn mining.

Mean concentration of As was higher in livers (2.59 ± 2.81 mg/kg dw) than kidneys (1.91 ± 2.33 mg/kg dw) (Table 1). The liver is a major target organ of As carcinogenesis (Waalkes et al., 2003) and could be the reason for the higher As levels. As is toxic and most hazardous substance (ATSDR, 2013) and due to its non-biodegradable nature, it could accumulate in soil, food and water (Amonoo-Neizer et al., 1995), through which wild rats could be exposed since they pick food and water mainly from the ground. Levels of As in soils, drinking water and organs of free-range chickens raised health risk concerns for both humans and animals in some communities in Tarkwa with food and water picking being the dominant sources in chicken (Bortey-Sam et al., 2015a, b, d). The levels were attributed to processing of the ore which involves roasting, and this result in the production of arsenic trioxide gas which is distributed throughout the study area by air current (Amonoo-Neizer et al., 1995).

As shown in Table 1, the mean levels of Cd in the kidneys (1.42 ± 3.57) was seven times higher ($p < 0.05$) compared to the liver (0.198 ± 0.321) of wild rats in Tarkwa. There have been suggestions that animals exposed to Cd accumulate it in their kidneys because of the presence of free protein-thiol groups which leads to a strong fixation of the metal (Pompe-Gotal and Crnic, 2002). Cd concentrations in blood, urine and kidney have been recognized as good indicators of exposure (Brzoska et al., 2004). Cd could increase excretion of calcium and reduce the generation of active vitamin D in kidney. Consequently, calcium uptake and absorption in gastrointestinal gut are decreased (Chen et al., 2013). Bone lesions, apart from kidney damage, are the main health consequences of chronic exposure to Cd. Osteopenia, osteomalacia and osteoporosis with pathological fractures have been reported in Cd-exposed humans (Jarup, 2002; Alfven et al., 2000; Honda et al., 2003) and experimental animals (Whelton et al., 1997; Uriu et al., 2000).

Levels of Pb were higher ($p < 0.05$) in kidneys (3.97 ± 8.15 mg/kg dw) than livers (1.05 ± 2.23 mg/kg dw) (Table 1). In previous studies, high levels of Pb was found in *Manihot esculenta* (cassava), soils and chickens from some communities around mining areas in Tarkwa, which could cause health risk to residents and especially children (Bortey-Sam et al., 2015a, c, d). The levels of Pb in organs of free-range chickens in Tarkwa emanated from contamination of soil, feeds and/or water sources (Bortey-Sam et al., 2015d), and these could be the same route through which wild rats were exposed.

Livers (5.50 ± 2.86) accumulated higher ($p < 0.05$) levels of Mn than kidneys (4.09 ± 2.79) (Table 1). This is because, the liver is key for maintaining Mn homeostasis (Finley, 1998), and among organs with highest Mn levels (Dorman et al., 2006) as it produces two of the main

Table 2. Sex differences in accumulation of heavy metals and a metalloid (mg/kg dw) in the livers and kidneys of wild rats in Tarkwa, Ghana.

Organ	Sex		As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Livers	Male	Mean	0.573[a]	0.066[a]	0.132[a]	0.185[a]	19.8[a]	5.45[a]	0.921[a]	0.237[a]	256[a]
		SD	0.586	0.027	0.045	0.078	23.2	6.65	0.607	0.217	103
		Minimum	0.070	0.021	0.088	0.071	8.95	2.54	0.219	0.053	164
		Maximum	1.92	0.098	0.210	0.294	71.8	19.1	1.72	0.666	433
	Female	Mean	1.08[a]	0.117[a]	0.163[a]	0.198[a]	15.3[a]	4.60[a]	0.894[a]	0.292[a]	301[a]
		SD	2.53	0.181	0.194	0.106	7.27	1.21	0.605	1.34	111
		Minimum	0.113	0.040	0.078	0.094	7.59	2.60	0.269	0.093	177
		Maximum	12.6	1.45	1.21	0.406	30.9	6.66	2.12	10.7	524
Kidneys	Male	Mean	0.645[a]	0.292[a]	0.332[a]	0.410[a]	18.1[a]	5.21[a]	4.82[a]	1.24[a]	122[a]
		SD	0.603	0.283	0.316	0.247	9.55	3.53	1.99	1.69	68.7
		Minimum	0.103	0.004	0.074	0.128	11.6	1.53	1.82	0.044	64.3
		Maximum	1.89	0.867	1.62	0.816	39.5	16.8	7.85	5.17	284
	Female	Mean	0.905[a]	0.650[a]	0.244[a]	0.513[a]	13.7[a]	4.32[a]	2.52[b]	1.53[a]	140[a]
		SD	1.32	1.15	0.172	0.508	1.85	1.70	1.33	2.69	45.6
		Minimum	0.159	0.107	0.082	0.077	10.2	2.29	0.939	0.305	81.6
		Maximum	14.0	21.1	0.519	1.72	16.4	6.89	5.03	41.6	284

SD: standard deviation; different letters (a and b) between male and female rats within the same organ indicates significant difference (Student's T-Test; $p < 0.05$).

plasma transport proteins of Mn-albumin and transferrin (Crossgrove and Zheng, 2004). Excess Mn causes neurotoxicity, production of reactive oxygen species and disturbance of mitochondrial dynamics (Barhoumi et al., 2004; Martinez-Finley et al., 2013). In the offal and muscles of free-range chickens, goat and sheep in Tarkwa, the mean concentrations of Mn were above the WHO (1996) maximum levels (0.5 mg/kg) except in chicken muscle, and levels were attributed to proximity of the sample sites to the Mn mine (Bortey-Sam et al., 2015d).

Sex differences in heavy metal and metalloid accumulation

Bio-accumulation of heavy metals in animals vary according their sex, size and/or age (Hunter et al., 1989; Sawicka-Kapusta et al., 1995; Damek-Poprawa and Sawicka-Kapusta, 2004). Although, we could not determine the ages of wild rats in this study, the results of sex differences in the accumulation of metals showed no statistical variation ($p > 0.05$) except Ni in kidneys (Table 2). However, levels of As, Cd and Zn were higher in the livers of female rats compared to males, while in livers of male rats, Cu and Mn were higher ($p > 0.05$). Co, Cr, Ni and Pb levels were similar in livers of both sexes (Table 2). This trend was similar for the kidneys except for Ni which was higher in male rats compared to females (Table 2). Study of Blagojevic et al. (2012) in skull of mice from two localities in Serbia revealed that no gender dependent variation was detected for Fe, Mn, Co, Cd, Zn, Ni, Pb and Cu.

Although not significant ($p > 0.05$), average Cd levels in livers (0.12 mg/kg dw) and kidneys (0.65 mg/kg dw) of females were two times higher than in males (liver [0.07 mg/kg dw] and kidney [0.29 mg/kg dw]), respectively. Absorption of Cd is through the gastrointestinal tract (GIT), however this can be affected by several factors, such as age, sex, nutritional status, and preceding Cd burden. Among these, young age, iron deficiency, and being female are reported to accelerate the absorption of Cd through the GIT in both humans and animals (Berglund et al., 1994; Flanagan et al., 1978; Hamilton and Valberg, 1974; Kowel, 1988; Taguchi and Suzuki, 1981) and these could be the reasons why Cd levels were higher in females than males.

Heavy metals correlation with body weight of wild rats

Levels of Ni in the livers and kidneys negatively correlated ($p < 0.05$) with body weight of rats (Table 3). Ni is a carcinogen and overexposure could cause decreased body weight and damage to the heart and liver (Homady et al., 2002). On the other hand, body weights

Table 3. Pearson's correlation between heavy metals and body weight of wild rats in Tarkwa, Ghana.

Metal	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	Body weight/g
As	1	**0.518***	**0.516***	**-0.003**	**0.152**	**0.215**	**-0.553***	**0.531***	**0.704****	**0.318**
Cd	0.333	1	**0.393**	**0.167**	**-0.195**	**0.255**	**-0.631****	**0.704****	**0.480**	**0.599***
Co	0.225	0.531*	1	**0.355**	**0.553***	**0.066**	**-0.166**	**0.112**	**0.394**	**0.444**
Cr	0.398	0.058	0.511*	1	**0.204**	**0.562***	**0.313**	**0.128**	**0.097**	**-0.315**
Cu	0.324	-0.153	0.217	0.328	1	**0.298**	**0.283**	**0.004**	**0.305**	**0.045**
Mn	0.420	-0.506*	0.045	0.359	0.733**	1	**0.219**	**0.590***	**0.395**	**-0.374**
Ni	-0.349	-0.526*	0.199	0.212	0.319	0.380	1	**-0.418**	**-0.469**	**-0.725****
Pb	-0.061	-0.049	0.167	-0.264	-0.017	0.064	0.090	1	**0.653****	**0.253**
Zn	0.076	0.075	-0.394	-0.357	0.032	-0.068	-0.022	-0.236	1	**0.449**
body weight/g	0.350	0.864**	0.538*	0.076	-0.149	-0.391	-0.580*	0.078	-0.047	1

*: Correlation is significant at the 0.05 level.**: Correlation is significant at the 0.01 level. Bold indicates correlations between heavy metals and body weight in kidneys of wild rats otherwise for livers.

correlated positively ($p < 0.05$) with Cd (both livers and kidneys) and Co (livers only). In exposure studies of Brzoska et al. (2004) and Chen et al. (2013), increase in the body weights of rats was noted when exposed to Cd. Wronski et al. (1987) demonstrated that increased body weight provides a partial protection against the development of osteopenia in the long bones of ovariectomized (OVX) rats. Nevertheless, the protective effect of obesity against osteopenia in OVX rats is only partial and that marked osteopenia develops in the long bones of OVX rats regardless of body weight. This trend suggests that the increased body weight of obese OVX rats may have provided an additional stimulus for bone formation in the weight-bearing long bones (Wronski et al., 1987). The findings of Wronski et al. (1987) were consistent with reports of diminished bone loss in obese postmenopausal women (Saville and Nilsson, 1966; Daniell, 1976; Lindsay et al., 1984). These trends could explain the significant positive correlation ($p < 0.05$) between Cd levels in livers and kidneys and body weight of rats.

Possible sources of heavy metal and metalloid in wild rats

PCA was used to trace the possible route of heavy metals and a metalloid exposure to wild rats in Tarkwa. Soil, bore hole drinking water and foodstuff (cassava and *Musa paradisiaca* [plantain]) data on heavy metals in communities in Tarkwa, used for PCA was obtained from Bortey-Sam et al. (2015a, b, c). As shown in Figure 2, component 1 (PC1) makes up 40% of the PCA and score plot has high loadings of livers, kidneys (of wild rats), soils and borehole drinking water, with some highly associated with all the studied metals. This suggests that exposure of wild rats to metals were through soils and borehole drinking water, which is similar to conclusion of Bortey-Sam et al. (2015d) on the sources of metals in free-range chickens in Tarkwa. This is obvious because like chickens, these wild rats also pick food and water from the ground which contains heavy metals and/or metalloids. There was a strong association between the livers and kidneys with borehole drinking water from Tarkwa, which was also highly associated with Cu, Cd and Zn (Figure 2).

Toxicological significance

The levels of heavy metals and metalloid in this study were compared with studies by Nakayama et al. (2013), Soewu et al. (2014) and Guerrero-Castilla et al. (2014) on the accumulation and biological effects (oxidative stress) of metals in wild rats and mice around mining and industrial communities in Zambia, Nigeria and Colombia, respectively. Among the livers and kidneys, levels of As, Ni, Zn and Cd (observed only in kidneys) were higher in this study compared to studies by Soewu et al. (2014), Nakayama et al. (2013) and Guerrero-Castilla et al. (2014) (Table 4). Exposure of wild rats to Ni, Zn and Cd in Tarkwa could have resulted from mining/smelting, municipal waste and/or the use and sometimes abuse of phosphate fertilizers and organic manures. Other sources may include leachates from Ni-Cd based batteries and Cd plated items which are so carelessly discarded by battery chargers and users in Ghana as indicated by Bortey-Sam et al. (2015a, d). Recently, electronic wastes are disposed and often burnt at refuse dumps.

Nakayama et al. (2013) studied heavy metals in wild rats and reported to cause toxicological effects, since the accumulated metals caused induction of metallothionein (MT) in the livers and kidneys. Similarly, levels of metals in exposed mice from coal mining areas in Colombia

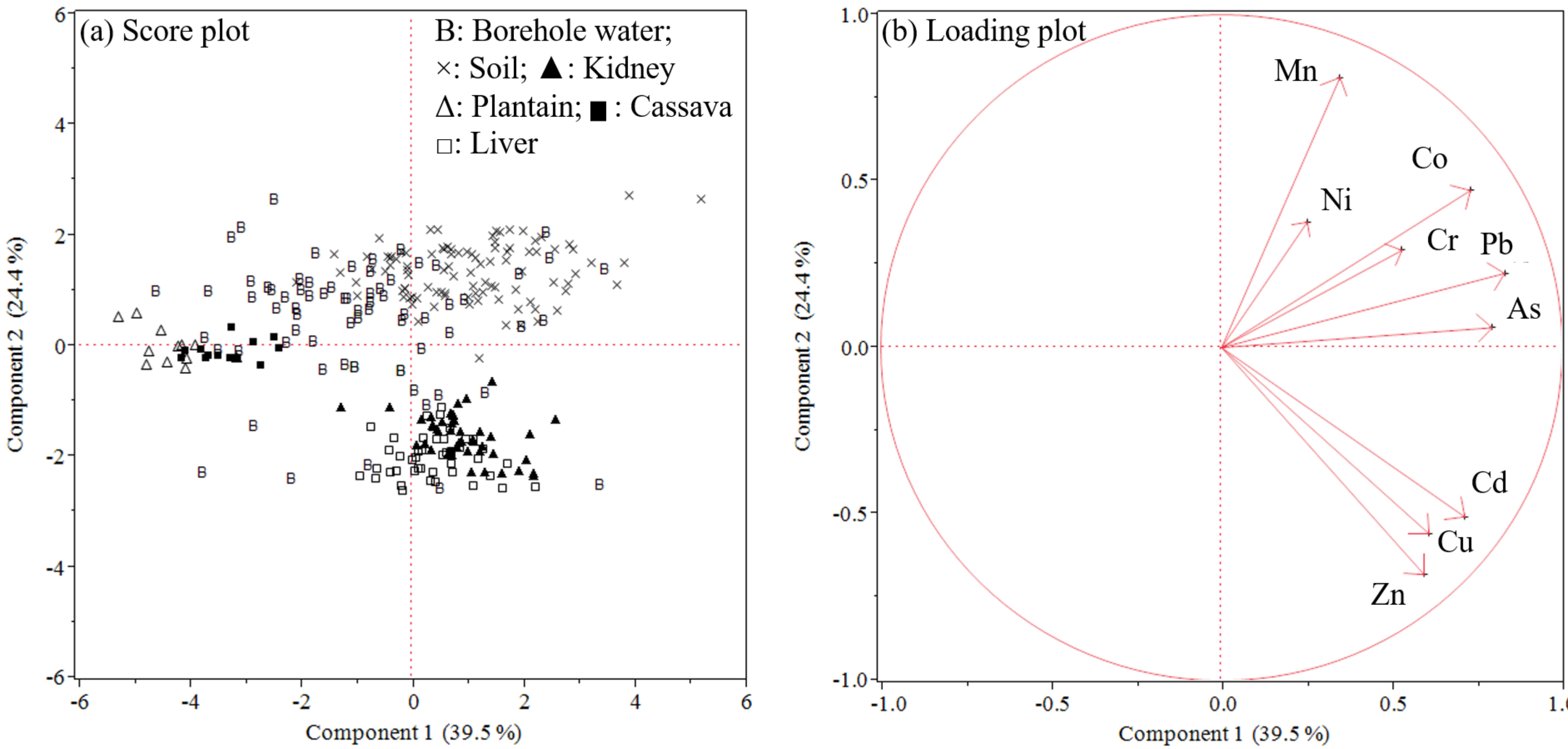

Figure 2. Distribution pattern of heavy metals and a metalloid in cassava, plantain, borehole drinking water, soils, livers and kidneys of wild rats in Tarkwa characterized by PCA.

caused a significant increase ($p < 0.05$) in mRNA expression of genes related to oxidative stress, metal transport and DNA damage (Guerrero-Castilla et al., 2014).

Concentrations of Cd in both organs of this study were below the critical renal intoxication level (119 mg/kg dw) which leads to subclinical symptoms for small mammals (Tohyama et al., 1987; Ma et al., 1991). Similarly, a critical liver concentration of 20 to 30 mg/kg leads to hepatocyte damage (Godowicz, 1988; Swiergosz-Kowalewska, 2001). The toxicity of As in mammals was found to be related with levels above 3 mg/kg in the liver and kidney(Gupta, 1998) and animal data suggest that As exposure may have chronic effects on the kidneys (WHO, 1981). Liu et al. (2000) recorded that glomerular swelling is one of the degenerative changes that

Table 4. Comparison of mean concentrations (mg/kg dw) of heavy metal and a metalloid with other studies.

Organ	Sample site/country	Site description	n	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Livers	Tarkwa, Ghana (This study)	Gold and Mn mining	46	2.59	0.198	0.198	0.147	23.0	5.50	0.869	1.05	263
	Kabwe, Zambia*	Pb and Zn mining	20	0.5	0.12	0.22	0.28	10.2		0.11	1.19	151
	Chingola, Zambia*	Co and Cu mining	13	0.07	0.05	1.72	0.15	29.5		0.05	0.41	115
	Lusaka, Zambia*	University campus	18	0.57	0.03	0.37	0.78	14		0.69	0.14	141
	La Jagua, Colombia#	Coal mining		0.35	2.36			22.2			0.18	2.2
	La Loma, Colombia#	Coal mining		0.24	0.55			13.8			0.35	16.7
	Omo forest, Nigeria*#	Undisturbed site	4		0.00		0.77	8.55	6.16		0.77	103
	Mosinmi ecotome*#	Oil and gas industries	4		0.58		0.00	8.05	16.2		0.00	87.1
	Ibese ecotome*#		4		0.00		2.16	11.9	8.64		0.00	77.1
	Agbara ecotome*#	Industrial	4		0.00		0.80	11.9	11.5		0.00	114
Kidneys	Tarkwa, Ghana (This study)	Gold and Mn mining	46	1.91	1.41	0.382	0.375	14.3	4.09	2.02	3.97	117
	Kabwe, Zambia*	Pb and Zn mining	20	0.52	0.64	0.26	0.93	11.5		0.64	5	91
	Chingola, Zambia*	Co and Cu mining	13	0.28	0.71	1.88	0.82	23		0.63	2.85	109
	Lusaka, Zambia*	University campus	18	1.72	0.14	0.98	0.75	14		0.59	0.39	0.39
	Omo forest, Nigeria*#	Undisturbed site	4		0.00		1.44	13.5	5.76		1.45	93.2
	Mosinmi ecotome*#	Oil and gas industries	4		0.00		1.08	13.8	11.0		0.96	95.7
	Ibese ecotome*#		4		0.00		2.04	13.9	6.72		0.00	86.4
	Agbara ecotome*#	Industrial	4		0.32		2.16	15.3	5.76		0.00	97.0

n: number of samples; * indicates study by Nakayama et al. 2013 in wild rats; # indicates study by Guerrero-Castilla et al. 2014 in wild house mice and concentrations were in mg/kg fresh weight; *# indicates study by Soewu et al. 2014 in cane rats (wild grass cutters).

usually occur in mice chronically exposed to As. These changes were also observed in livers and kidneys of mice at concentrations of 1.79 ± 0.946 and 3.89 ± 0.817 mg/kg dw, respectively (Pereira et al., 2006). In the present study, concentrations of As in both organs were higher in 47 and 9% of livers and kidneys, respectively, compared with levels observed by Pereira et al. (2006) and could cause glomerular swelling in 9% of rats.

Levels of Pb in the livers and kidneys of wild rats in this study were higher than study by Guerrero-Castilla et al. (2014) but comparable with levels in Kabwe, Zambia, which was a Pb-Zn mine area (Nakayama et al., 2013) (Table 4). Ma (2011) reported that kidney Pb level >15 mg/kg dw caused structural and functional kidney damage, while concentrations >120 mg/kg dw caused body weight loss in adults rats. In histopathological studies, changes in the kidney, such as Pb intranuclear inclusion bodies and karyocytomegaly in the proximal tubular cells were detected in wild brown rat (*R. norvegicus*) at kidney Pb concentrations > 2.5 mg/kg dw (Ceruti et al., 2002). In this study, the average concentration of Pb in kidneys (3.97 mg/kg dw) exceeded this histopathological threshold (2.5 mg/kg dw) and was higher in 29% of wild rats in Tarkwa. Moreover, 3 kidney samples (6%) exceeded the structural and functional kidney damage level (> 15 mg/kg dw) (Ma, 2011). The high levels of metals detected in the livers and kidneys of wild rats in Tarkwa could cause health risk to mammalian wild life.

Conclusions

Wild rats in Tarkwa, a mining community in Ghana, have been exposed to heavy metals and a metalloid through borehole drinking water and soils; and livers accumulated higher levels of As than kidneys but the reverse was for Cd and Pb. In both organs As, Cd and Zn levels were higher in female than the male rats. The strong positive correlation between body weight and concentrations of Cd in livers and kidneys of wild rats reflects a mechanism of protection against the development of osteopenia in the long bones, although biological effects remain a concern. Concentration of Pb in kidneys caused intranuclear inclusion bodies and karyocytomegaly in the proximal tubular cells in 29% of wild rats in Tarkwa; and structural and functional kidney damage in 6%. Concentrations of As in kidneys of these wild rats caused glomerular swelling in 9% of rats. With the rapid increase in mining in Ghana and high concentrations and possible risk of metals to wild life, it is recommended that the government considers the following:

1. Educate the public on environmental pollution and management.
2. Continuous screening and monitoring of heavy metals and metalloids in the study area.
3. Set policies to curb the rate of metal pollution in Ghana.

Conflict of Interests

The authors have not declared any conflict of interests.

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