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RESEARCH ARTICLE

Analysis of Zn, Cd, As, Cu, Pb, and Fe in snails as bioindicators and soil samples near traffic road by ICP-OES

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Abstract Snails are used as biological indicators of the environment pollution for heavy metals. Living snail samples were collected from different sites at the city of Irbid-Jordan and classified according to their morphological features including *Helix pelasga*, *Eobania vermiculata*, *Xeropicta derbentina*, *Oychilus*, *Xerocrassa seetzenii*, *Xerocrassa simulata*, and *Pila*. Zn, Cd, As, Cu, Pb, and Fe levels were measured by inductively coupled plasma-optical emission spectroscopy. Results indicated that metal concentrations in all snail shell samples were with an average and range for Zn 22.4 (6.5–105.5) μg g^{-1}, Cd 7.8 (0.4–48.1) μg g^{-1}, As 25.9 (0.7–248.5) μg g^{-1}, Cu 15.1 (1.6–69.0) μg g^{-1}, Pb 0.4 (0.2–1.7) μg g^{-1}, and Fe 119.6 (14.0–1102.0) μg g^{-1}, whereas, in soil samples, the average and range for Zn 204.0 (12.0–709.0) μg g^{-1}, Cd 5.7 (0.2–39.5) μg g^{-1}, As 3.2 (1.8–5.2) μg g^{-1}, Cu 22.1 (2.3–77.4) μg g^{-1}, Pb 0.2 (0.1–0.3) μg g^{-1}, and Fe 242.4 (25.0–680.0) μg g^{-1}.

Keywords Heavy metals · Analysis · ICP-OES · Snails · Soil

Introduction

Heavy road traffic may introduce a huge amount of pollutants to the ecosystem (air, water, and soil) and can pose serious threats, dangerous impacts, and toxic effects to environmental health because they tend to bioaccumulate in terrestrial ecosystems including toxic metals such as Pb, Cd, As, and other elements (Viard et al. 2004; Divrikli et al. 2006; ATSDR 2007, 2008; Nica et al. 2012). Many studies have shown contamination by trace metals in soil and dust samples at the vicinity of highways (Soylak and Turkoglu 1999; Narin and Soylak 1999; Zhang et al. 1999; Massadeh and Snook 2002; Turer and Maynard 2003; Massadeh et al. 2004; Jaradat et al. 2005; Khan et al. 2011).

Previous studies revealed that metal levels were decreased with increasing distance from the highway. The spreading of heavy metals into the roadside soil is influenced by traffic volume and other meteorological factors (Piron-Frenet et al. 1994; Narin et al. 1997; Garcia and Millan 1998; Soylak and Turkoglu 1999; Massadeh and Snook 2002; Massadeh et al. 2004; Viard et al. 2004; Jaradat et al. 2005).

In order to assess the contamination by metals at the surrounding area of highways, several land invertebrates, such as pulmonate gastropods and snails, were used as bioindicators of metallic contaminations (Berger and Dallinger 1993; Newman et al. 1994; Gomot and Pihan 1997; Coeurdassier et al. 2007; Yap and Cheng 2013; Mahmoud and Abu Taleb 2013; Larba and Soltani 2014) as well as for laboratory experiments on effects and bioaccumulation of metals (Viard et al. 2004; Nica et al. 2012; Yap and Cheng 2013; Mahmoud and Abu Taleb 2013; Larba and Soltani 2014).

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Snails were previously used for the evaluation of the heavy metal remediation techniques used in waste management (Pihan and de Vaufleury 2000). In fact, snails are a suitable tool for the diagnostic of sites contaminated with heavy metals and can concentrate high levels of metals in their soft tissue without revealing any major metabolic disorders (Swaileh et al. 2001; Notten et al. 2005; Yap and Cheng 2013; Mahmoud and Abu Taleb 2013; Larba and Soltani 2014).

The reason for choosing land snails as bioindicators is that they represent prey species for many predators of different groups such as invertebrates and mammals. Thus, snails are an important link in the transfer and accumulation of heavy metals in terrestrial ecosystems. This study aimed to investigate the accumulation of heavy metals including Zn, Cd, As, Cu, Pb, and Fe in local snail shells dispersed near road traffic and to evaluate their possible role as bioindicators for heavy metals in soils. Thus, seven land snails including *Helix pelasga*, *Eobania vermiculata*, *Xeropicta derbentina*, *Oxychilus*, *Xerocrassa seetzenii*, *Xerocrassa simulate*, and *Pila* were used in the present study.

Materials and materials

Reagents and standard solution

All chemicals and reagents were of analytical grade. High-quality concentrated **69 %** HNO_3 was obtained from Merck, Darmstadt, Germany, and 60 % $HClO_4$ was obtained from Scharlau, Spain. Working standards for inductively coupled plasma-optical emission spectroscopy (ICP-OES) analysis were prepared from proper standard solutions containing 1000 ppm for each tested element obtained from PerkinElmer, USA. To reduce the risk of contamination from ambient air and dust, all work was performed on a clean bench. Glassware and polyethylene containers were effectively cleaned and soaked in 10 % HNO_3 for 48 h and then rinsed thoroughly with de-ionized water.

Collection of samples

Living land snail samples were collected from different sites of Irbid City near traffic roads as well as a representative number of soil samples from the same sites (Table 1).

Classification of snail samples

Land snail samples were identified with the help of museum specimens preserved at Jordan Natural History Museum at Yarmouk University and based on Archiv full Molluuskenkunde (1982). Snail samples are classified according to their different morphological features (Table 1).

Table 1 Classification, morphology, and site of different snail samples

Sample number	Classification	Shell diameter	Locality with reference to soil
1	*Helix pelasga*	~1.5 cm	a, b, i
2		~2 cm	
3		~2.5 cm	
4		~3 cm	
5	*Eobania vermiculata*	~1.5 cm	b, c, j
6		~2 cm	
7		~2.5 cm	
8		~3 cm	
9	*Xeropicta derbentina*	~0.5 cm	c, d, k
10		~1 cm	
11		~1.5 cm	
12		~2 cm	
13	*Oxychilus*	~0.25 cm	d, e, l
14		~0.5 cm	
15		~0.75 cm	
16		~1 cm	
17	*Xerocrassa seetzenii*	~1 cm	e, f, m
18		~1.5 cm	
19		~2 cm	
20	*Xerocrassa simulate*	~1.5 cm	f, g, m
21		~2 cm	
22	*Pila*	~4 cm	g, h, i
23		~5 cm	

Chemical pre-treatment of samples

Each snail sample was heated in an oven at 105 °C for 18 h. A weight of 0.5 g of each snail sample was treated with a mixture of 3 mL of 69 % HNO_3 and 1 mL of 60 % $HClO_4$ to enable acid digestion and was conducted at 200 °C until dryness. An aliquot of 5 mL of 1 % HNO_3 was added to each sample and filtered through 0.45-μm filter paper. The filtrate was made up to 25 mL with de-ionized water, kept in a polyethylene bottle, and stored at 4 °C until analysis.

Instruments

ICP-OES (model VISTA-MPX, CCD simultaneous ICP-OES, Varian, nebulizer type glass concentric with pressure of 200 kPa) was operated under suitable conditions including choosing the suitable wavelength for each element (Zn 213.857 nm, Cd 214.439 nm, As 188.980 nm, Cu 327.395 nm, Pb 220.350 nm, and Fe 238.204 nm) with plasma argon flow rate of 12 L min^{-1}, auxiliary argon flow rate of 0.6 L min^{-1}, nebulizer argon flow rate of 0.4 L min^{-1}, integration time 100 s, read delay 20 s, and peristaltic pump flow rate of 1 mL min^{-1}.

Calibration curves for Zn, Cd, As, Cu, Pb, and Fe were constructed from standard solution of each element. The linearity for these elements was good with R^2 values of 0.9991, 0.9991, 0.9987, 0.9984, 0.9990, and 0.9986 for Zn, Cd, As, Cu, Pb, and Fe, respectively.

Results

In this study, different types of snails were evaluated for Zn, Cd, As, Cu, Pb, and Fe accumulations in their shells. In addition, different soil samples were analyzed for these elements. The results obtained in this study are displayed in details below.

Zinc concentrations in snail and soil samples

Zinc concentrations in all tested snail samples ranged between 6.5 μg g^{-1} (samples 8 and 19) and 105.5 μg g^{-1} (sample 20) with an average level of 22.4 μg g^{-1}, whereas Zn concentrations in soil samples ranged between 12.0 and 709.0 μg g^{-1} with an average level of 204.0 μg g^{-1}. These variations may be due to the variation from site to another based on the different Zn deposition and car emissions. These findings are in a good agreement with Coeurdassier et al. (2007), who studied the Zn and other metal transfer from soil to snail.

Results obtained that are shown in Fig. 1a revealed that Zn concentrations in most snail samples were lower than Zn levels in soil samples. For example, *Xenocrassa simulata* had the highest variation in Zn accumulation. This may be due to the variation of shell diameter and age of snail. Figure 1b represents the 95 % confidence interval for Zn levels (μg g^{-1}) for snail- and soil-tested samples.

Cadmium concentrations in snail and soil samples

Cadmium concentrations in all snails ranged between 0.4 μg g^{-1} (sample 10) and 48.1 μg g^{-1} (sample 5) with an average level of 7.8 μg g^{-1}. Also, high Cd levels were achieved in snail samples, 35.8 μg g^{-1} (sample 6), 28.9 μg g^{-1} (sample 7), 7.9 μg g^{-1} (sample 11), and 26.1 μg g^{-1} (sample 17). Results obtained are inconsistent with other researchers who indicated that snail (*Helix aspersa*) is used for monitoring of some heavy metal soil contaminations including Cd (Larba and Soltani 2014). In soil samples, Cd concentrations ranged between 0.2 μg g^{-1} (sample g) and 39.5 μg g^{-1} (sample i) with an average level of 5.7 μg g^{-1}. Other soil samples had high levels of Cd 7.2 μg g^{-1} (sample b) and 7.5 μg g^{-1} (sample l).

Results obtained are shown in Fig. 2a. Cd concentrations in snail samples were lower than their levels in soil samples. For example, *Eobania*, *Xenocrassa*, and *Pilla* had the highest variation in Cd accumulation. This may be due to the variation of diameter shells and age of snail. Figure 2b represents the 95 % confidence interval for Cd levels (μg g^{-1}) for snail- and soil-tested samples.

Arsenic concentrations in snail and soil samples

Arsenic concentrations in all snail samples ranged between 0.7 μg g^{-1} (sample 1) and 248.5 μg g^{-1} (sample 6) with an average level of 24.6 μg g^{-1}. Also, high As levels were achieved in snail samples, 21.2 μg g^{-1} (sample 2), 27.0 μg g^{-1} (sample 3), 356.8 μg g^{-1} (sample 4), 129.7 μg g^{-1} (sample 5), and 10.3 μg g^{-1} (sample 3). As concentrations in soil samples ranged between 1.8 μg g^{-1} (samples f and g) and 5.2 μg g^{-1} (sample j) with an average level of 3.2 μg g^{-1}. Other soil samples had high levels of As 3.3 μg g^{-1} (sample a), 3.9 μg g^{-1} (sample b), 4.0 μg g^{-1} (sample d), 2.0 μg g^{-1} (sample c), 3.8 μg g^{-1} (sample e), 3.1 μg g^{-1} (sample h), 2.9 μg g^{-1} (sample i), 4.2 μg g^{-1} (sample k), and 2.4 μg g^{-1} (sample l).

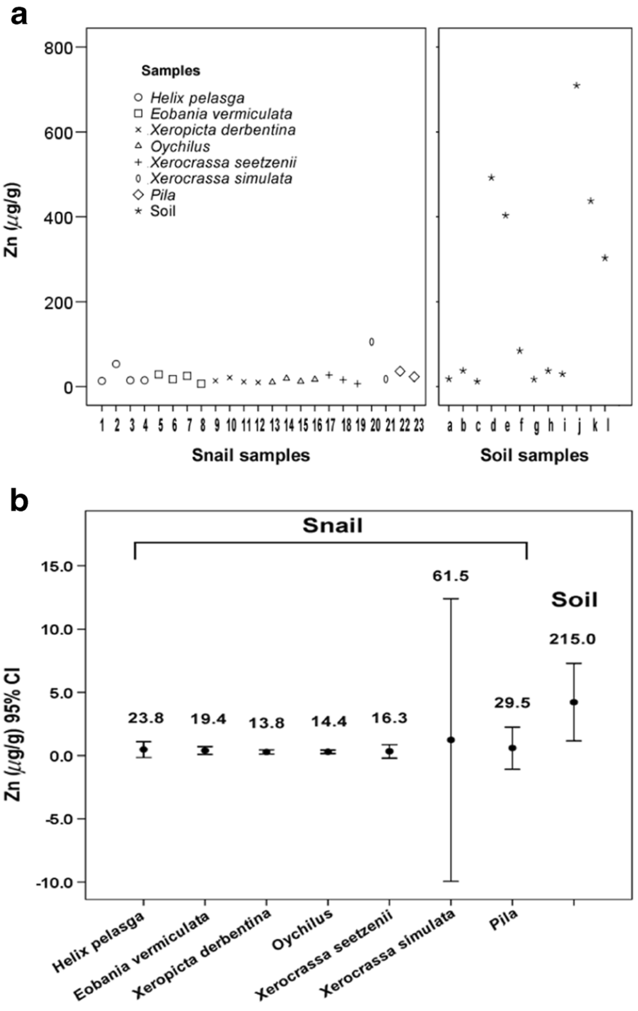

Fig. 1 **a** Zinc concentrations (μg/g) in all types of snail and soil samples. **b** A 95 % confidence interval for Zn concentrations (μg/g) in different types of snail and soil samples

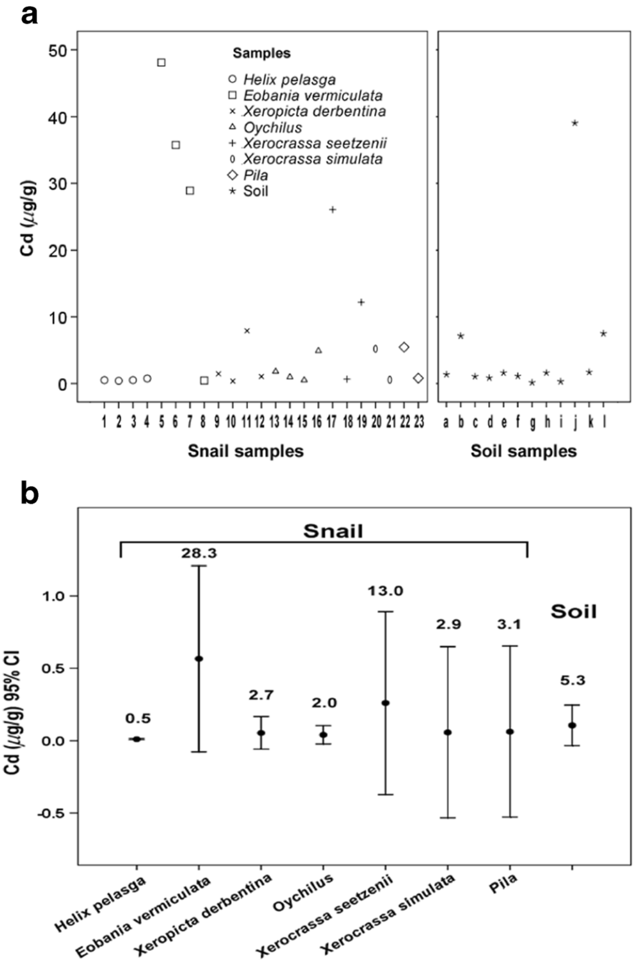

Fig. 2 **a** Cadmium concentrations (μg/g) in all types of snail and soil samples. **b** A 95 % confidence interval for Cd concentrations (μg/g) in different types of snail and soil samples

Results obtained that are shown in Fig. 3a revealed that As concentrations in most snail samples were higher than As levels in soil samples. For example, *Helix* and *Eobania* had the highest variation in As accumulation. Figure 3b represents the 95 % confidence interval for As levels (μg g^{-1}) for snail- and soil-tested samples.

Copper concentrations in snail and soil samples

Copper concentrations in all snails ranged between 1.6 μg g^{-1} (sample 12) and 69.0 μg g^{-1} (sample 3) with an average level of 15.1 μg g^{-1}. Moreover, high Cu levels were achieved in snail samples, 66.2 μg g^{-1} (sample 1), 46.9 μg g^{-1} (sample 4), 19.4 μg g^{-1} (sample 8), 26.3 μg g^{-1} (sample 18), and 11.8 μg g^{-1} (sample 22). Our results revealed that there were variations in Cu bioaccumulations from snail type to another, and these findings are inconsistent with other study which compared the bioaccumulation capacities of Cu and Zn in two snail subspecies of *H. aspersa* (Gomot and Pihan 1997). In soil samples, Cu concentrations ranged between 2.3 μg g^{-1} (sample c) and 77.4 μg g^{-1} (sample j) with an average level of 22.1 μg g^{-1}. Other soil samples had high levels of Cu 32.8 μg g^{-1} (sample e), 12.4 μg g^{-1} (sample h), 45.8 μg g^{-1} (sample k), and 29.2 μg g^{-1} (sample l).

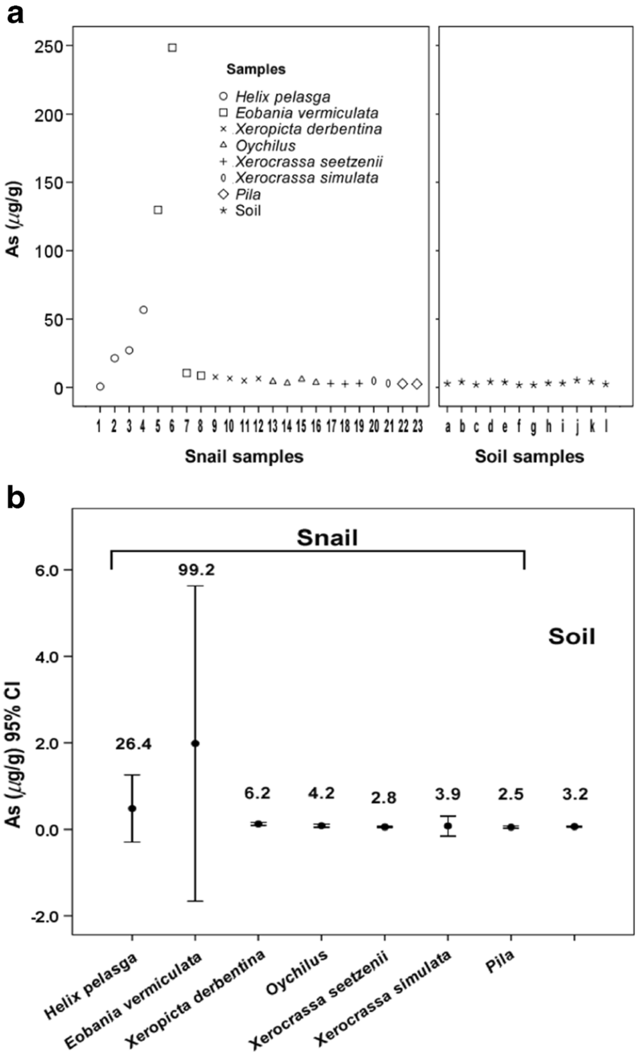

Fig. 3 **a** Arsenic concentrations (μg/g) in all types of snail and soil samples. **b** A 95 % confidence interval for As concentrations (μg/g) in different types of snail and soil samples

Results obtained that are shown in Fig. 4a indicated that Cu concentrations in all snail samples were lower than Cu levels in soil samples except in *H. pelasga*. The highest variation in Cu accumulation was seen in *Xerocrassa simulata* followed by *Helix*, *X. seetzenii*, and *Pilla*. Figure 4b represents the 95 % confidence interval for Cu levels (μg g^{-1}) for snail- and soil-tested samples.

Lead concentrations in snail and soil samples

Lead concentrations in all snail samples ranged between 0.2 μg g^{-1} (samples 14 and 21) and 1.7 μg g^{-1} (sample 1) with an average level of 0.4 μg g^{-1}. In soil samples, Pb

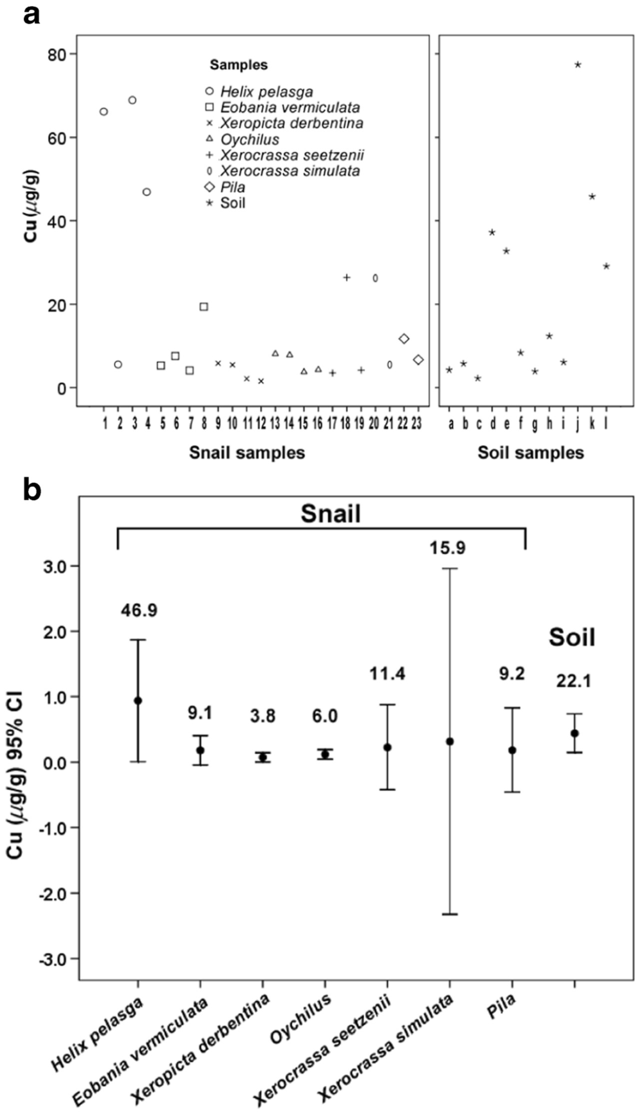

Fig. 4 **a** Copper concentrations (μg/g) in all types of snail and soil samples. **b** A 95 % confidence interval for Cu concentrations (μg/g) in different types of snail and soil samples

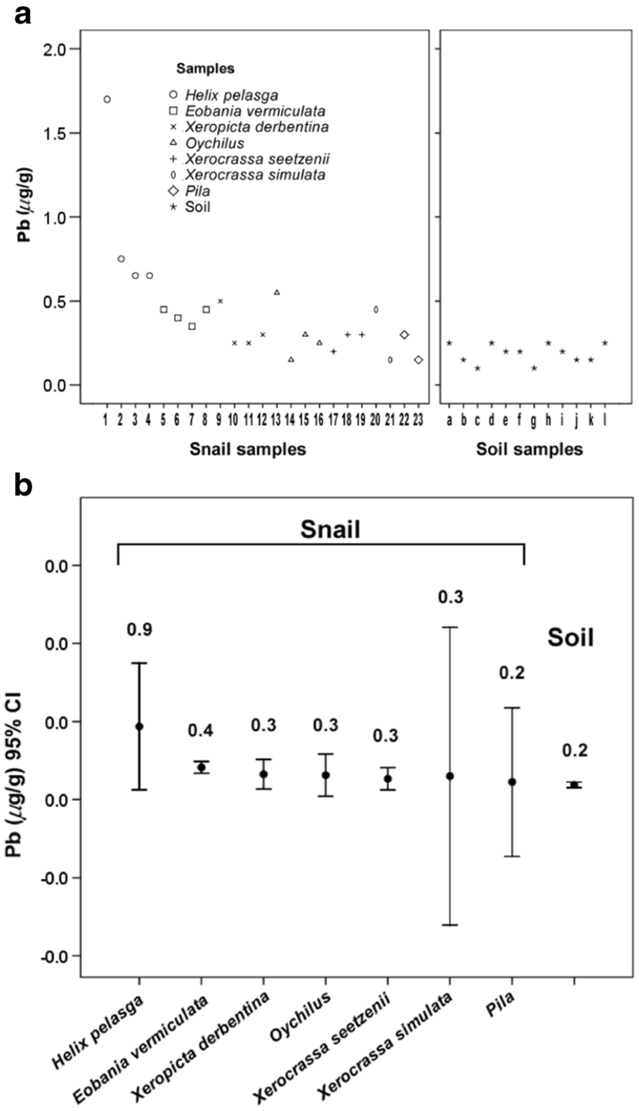

Fig. 5 **a** Lead concentrations (μg/g) in all types of snail and soil samples. **b** A 95 % confidence interval for Pb concentrations (μg/g) in different types of snail and soil samples

concentrations ranged between 0.1 μg g^{-1} (samples c and g) and 0.3 μg g^{-1} (samples a, d, h, and m) with an average level of 0.2 μg g^{-1}.

Results obtained that are shown in Fig. 5a revealed that Pb concentrations in most snail samples were higher than Pb levels in soil samples. The highest variation in Pb accumulation was seen in *X. simulata* followed by *Pilla* and *H. pelasga*. Results obtained indicated that tested snails in this study are good bioindicators for Pb and other elements in soil, and this finding is inconsistent with other studies, revealing that snail (*H. aspersa*) exposed and possibly adapted to lead as reflected in shell composition, and it is used for monitoring of some heavy metal soil contaminations including Pb (Newman et al. 1994; Larba and Soltani 2014). Figure 5b represents the 95 % confidence interval for Pb levels (μg g^{-1}) for snail- and soil-tested samples.

Iron concentrations in snail and soil samples

Iron concentrations in all snail samples ranged between 14.0 μg g^{-1} (sample 7) and 1102.0 μg g^{-1} (sample 9) with an average level of 119.6 μg g^{-1}. Also, high Fe levels were achieved in snail samples, 115.5 μg g^{-1} (sample 4), 229.0 μg g^{-1} (sample 10), 118.5 μg g^{-1} (sample 13), 195.0 μg g^{-1} (sample 17), 110.0 μg g^{-1} (sample 18), and 125.5 μg g^{-1} (sample 20). In soil samples, Fe concentrations ranged between 25.0 μg g^{-1} (sample f) and 680.0 μg g^{-1} (sample j) with an average level of 242.4 μg g^{-1}. Other soil samples had high levels of Fe 110.0 μg g^{-1} (sample a), 125.5 μg g^{-1} (sample c), 363.5 μg g^{-1} (sample g), 580.0 μg g^{-1} (sample h), 212.0 μg g^{-1} (sample i), 533.0 μg g^{-1} (sample k), and 121.5 μg g^{-1} (sample l).

Results obtained that are shown in Fig. 6a indicated that Fe concentrations in all snail samples were lower than Fe levels in soil samples except *X. derbentina*. The highest variation in Fe accumulation was seen in *X. derbentina* followed by *X. simulate*. Figure 6b represents the 95 % confidence interval for Fe levels ($\mu g\ g^{-1}$) for snail- and soil-tested samples.

Statistical analysis of results

Analysis of variance (ANOVA) was used for analysis of the results obtained statistically. Results indicated that there was a significant difference between Zn and Pb concentrations in snail and soil samples ($p < 0.05$), whereas no significant differences were found between Cd, As, Cu, and Fe concentrations in snail and soil ($p > 0.05$) as displayed in Table 2.

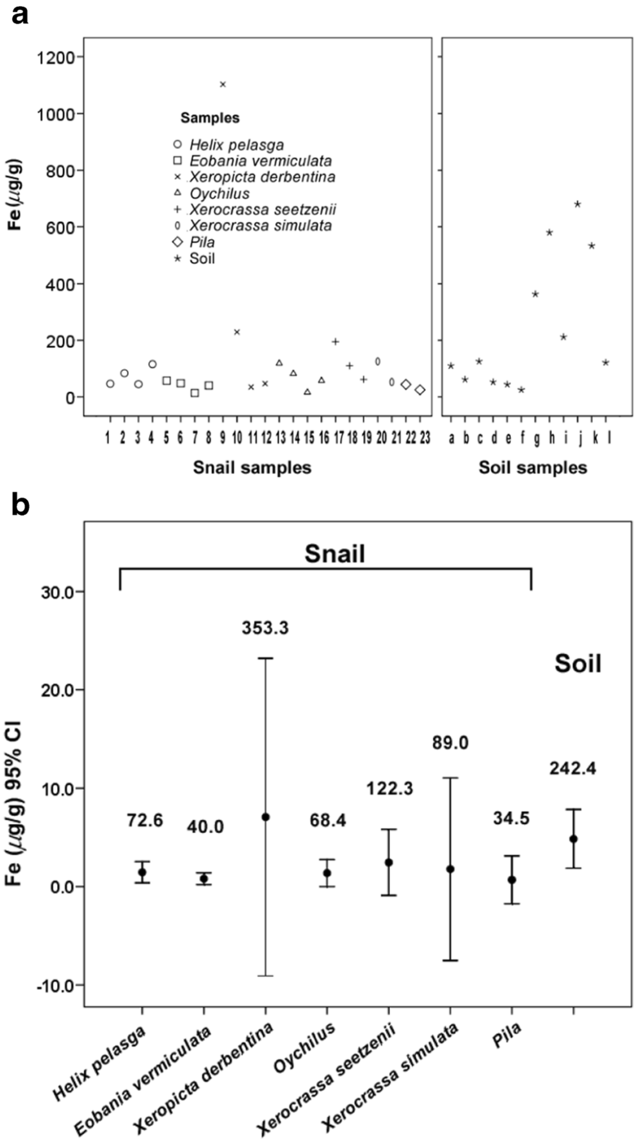

Fig. 6 **a** Iron concentrations (µg/g) in all types of snail and soil samples. **b** A 95 % confidence interval for Fe concentrations (µg/g) in different types of snail and soil samples

Table 2 Differences (p values) in heavy metal concentrations between snail and soil samples

Element	F_{cal}	P value*
Zn	14.69	0.0005
Cd	0.3810	0.5413
As	1.714	0.1995
Cu	0.8938	0.3532
Pb	6.317	0.0170
Fe	2.335	0.1360

$F_{crit} = 4.139$ for 34 df

*$p < 0.05$ is significant

Positive correlations were found between element and another element in snail samples (Zn with Cd, Cu, and Pb; Cd with As; As with Pb; Cu with Pb; and Pb with Fe) as shown in Table 3. Moreover, positive correlations were found between elements in soil samples (Zn with Cd, As, Cu, Pb, and Fe; Cd with As, Cu, and Fe; As with Cu, Pb, and Fe; and Cu with Pb and Fe) as displayed in Table 4.

Discussion

In the literature, there is no experimental data concerning the snail shell size and soil metal concentration. Furthermore, most studies focus on a single type of snails, which is less plausible for comparison and makes it hard to assess the efficiency of several types of snails as bioindicators (Larba and Soltani 2014). Researchers reported that the differences in metal distribution could be attributed to the differences in tissue physiology and metal handling, storage, and detoxification strategies (Yap and Cheng 2013).

Results presented in this study indicated that the Zn accumulation levels in most snail samples were lower than those in soil samples. This might indicate that snail shells have limited accumulation abilities for Zn. The Zn accumulated in soft tissue (living tissue) according to previous studies may interpret the limited capacity of snail shells for metal accumulation. Compared with Zn, the Cd accumulation levels in some snail samples were higher than those in soil samples, which might indicate that snail

Table 3 The correlation between the element concentrations in snail samples

	Zn	Cd	As	Cu	Pb	Fe
Zn	1					
Cd	0.06952	1				
As	−0.02174	0.677352	1			
Cu	0.012344	−0.27692	−0.02461	1		
Pb	0.015884	−0.12419	0.038891	0.713766	1	
Fe	−0.03124	−0.11754	−0.0912	−0.10604	0.026358	1

Table 4 The correlation between the element concentrations in soil samples

	Zn	Cd	As	Cu	Pb	Fe
Zn	1					
Cd	0.638612	1				
As	0.760767	0.611309	1			
Cu	0.973134	0.751141	0.786155	1		
Pb	0.083497	−0.16942	0.057969	0.028028	1	
Fe	0.338333	0.528927	0.412858	0.517694	−0.22493	1

shells are good bioindicators for Cd accumulation. On contrary, *H. pelasga* had very limited accumulation levels of Cd.

The As level accumulations in most snail samples were higher than those in soil samples, which might indicate that snail shells are classified as a good indicator for As. *Helix*, *Eobania*, *Xeropicta*, *Oychilus*, and *X. simulata* species can be categorized as bioindicators for As accumulation. Whereas, *H. pelasga* might be good candidates as bioindicators for Cu. Almost all species of snail can be good candidates as bioindicator for Pb. This may be due to the variation of diameter shells and age of snail, and *X. derbentina* might be a good bioindicator for Fe.

The average metal concentrations in all snail samples were distributed in the following order: Fe (119.6) μg g^{-1} > As (24.6) μg g^{-1} > Zn (22.4) μg g^{-1} > Cu (15.1) μg g^{-1} > Cd (7.8) μg g^{-1} > Pb (0.4) μg g^{-1}.

There were variations in metal concentrations in snail samples that were collected from different sites. The concentration of Fe in snail samples ranged between 14.0 μg g^{-1} (sample 7) and 1102.0 μg g^{-1} (sample 10). This may be due to the fact that snail (sample 10) was in a higher contamination site than snail (sample 7). This source of Fe may be coming from air particulate deposition or other anthropogenic sources. Moreover, the soil sample from which the snail (sample 10) was collected has Fe level (680.0 μg g^{-1}) more than Fe concentration (25.0 μg g^{-1}) in the soil sample from which the snail (sample 7) was collected.

Zn, Cd, As, Cu, and Pb concentrations in snail samples ranged between 6.5 μg g^{-1} (sample 8) and 105.5 μg g^{-1} (sample 8), 0.4 μg g^{-1} (sample 10) and 48.1 μg g^{-1} (sample 5), 0.7 (sample 23) and 248.5 μg g^{-1} (sample 6), 1.6 μg g^{-1} (sample 12) and 69.0 μg g^{-1} (sample 3), and 0.2 μg g^{-1} (sample 14) and 1.7 μg g^{-1} (sample 1) for Zn, Cd, As, Cu, and Pb, respectively. These variations in metal concentrations from a snail sample to another may be due to the metal deposition from air particulates and/ or the metal concentration in the soil sample from which snail samples were collected. Moreover, these variations in metal concentration may be due to the variation from site to another based on the different metal deposition, car emissions, and earthworms influencing metal transfer from soil to snails (Coeurdassier et al. 2007). Based on the results obtained, the snails are classified according to their efficiency as bioindicators (Table 5).

Based on the results obtained in this study, for determination of heavy metals in snail and soil samples, there is a good agreement with other studies and positive correlations were found between heavy metal levels in snail and soil samples taking into consideration the different types of snails (Berger and Dallinger 1993; Swaileh et al. 2001; Viard et al. 2004; Notten et al. 2005; Nica et al. 2012; Yap and Cheng 2013; Nica et al. 2014; Larba and Soltani 2014).

In addition, our findings for evaluation of heavy metals in roadside soil are inconsistent with other results obtained by other researchers who reported that roadside soils are polluted with heavy metals due to traffic density (Piron-Frenet et al. 1994; Narin et al. 1997; Garcia and Millan 1998; Soylak and Turkoglu 1999; Turer and Maynard 2003; Viard et al. 2004; Massadeh et al. 2004; Divrikli et al. 2006; Khan et al. 2011).

Conclusions

Concentrations of Zn, Cd, As, Cu, Pb, and Fe were determined as individuals of snail and roadside soil samples along main road. Metal levels in snail samples for Zn and Pb were differed significantly ($p < 0.05$) from those levels in soil samples, and most of tested elements were much less than those

Table 5 Classification of snails according to their efficiency as bioindicators for heavy metals

	Order according to mean	Order according to minimum	Order according to maximum
Snail			
Helix pelasga	Fe > Cu > As > Zn > Pb > Cd	Fe > Zn > Cu > (As, Pb) > Cd	Fe > Cu > As > Zn > Pb > Cd
Eobania vermiculata	As > Fe > Cd > Zn > Cu > Pb	Fe > As > Zn > Cu > Cd > Pb	As > Fe > Cd > Zn > Cu > Pb
Xeropicta derbentina	Fe > Zn > As > Cu > Cd > Pb	Fe > Zn > As > Cu > Cd > Pb	Fe > Zn > Cd > As > Cu > Pb
Oxychilus	Fe > Zn > Cu > As > Cd > Pb	Fe > Zn > Cu > As > Cd > Pb	Fe > Zn > Cu > As > Cd > Pb
Xerocrassa seetzenii	Fe > Zn > Cd > Cu > As > Pb	Fe > Zn > Cu > As > Cd > Pb	Fe > Zn > Cu > Cd > As > Pb
Xerocrassa simulate	Fe > Zn > Cu > As > Cd > Pb	Fe > Zn > Cu > As > Cd > Pb	Fe > Zn > Cu > Cd > As > Pb
Pila	Fe > Zn > Cu > Cd > As > Pb	Fe > Zn > Cu > As > Cd > Pb	Fe > Zn > Cu > Cd > As > Pb
Soil	Fe > Zn > Cu > Cd > As > Pb	Fe > Zn > Cu > A s > Cd > Pb	Zn > Fe > Cu > Cd > As > Pb

levels in roadside soils. These results suggest transfer of metals to snails from the soil.

Based on our findings, it is possible to conclude that snails are suitable species for biomonitoring of heavy metal pollution. In particular, *H. pelasga* accumulates high amounts of Pb and Cu, and *E. vermiculata* accumulates high amounts of As and Cd. Thus, snails are likely to be used in environmental monitoring studies as bioindicators of heavy metal pollution and can function as a reliable biomarker for tracking metals and bioavailability in roadside soil and polluted sites. Moreover, snails have a high capacity for metal accumulation and show different concentrations depending on metal contamination of the sampling area. In addition, snails can be used to differentiate between the degree of polluted areas with metals (non-polluted, moderate polluted, and high polluted areas on the basis of the snails' metal burden.

As a summary, conclusions from this study can be summarized in the following points:

1. Snails are good biomarkers (bioindicators) for heavy metal concentrations.
2. There was a positive correlation between metal concentration for Pb and Fe in snail samples and soil samples.
3. There was a wide variation from site to another in metal concentrations based on the type of metals.
4. For further work, it will be suggested that the environmental monitoring with snails must be extended to heavy metal mixtures since such associations are found in roadside soil samples.

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