GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 11, NO. 4, SEPTEMBER 2005: 553 - 559
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HEAVY METALS CONCENTRATIONS IN *IMBRASIA BELINA* (PHANE CATERPILLAR) AROUND THE SELEBI PHIKWE Ni-Cu MINE AND SMELTER/ CONCENTRATOR PLANT, BOTSWANA.

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(Received 14 November, 2004; Revision accepted 10 February, 2005)

ABSTRACT

Samples of *Imbrasia belina* (phane caterpillar) obtained from around the Selebi Phikwe Ni-Cu mine and smelter/concentrator plant, Botswana were investigated for their heavy metals concentrations. The samples were obtained from 10 sampling sites, which included a chosen control site located 56 km from Selebi Phikwe. Chemical analyses for Cd, Co, Cr, Cu, Fe, Ni, Se and Zn concentrations in the samples of *Imbrasia belina* were measured using atomic absorption spectrometry. Concentration values obtained for heavy metals in *Imbrasia belina* were as follows: Cd was between 0.01 ppm and 0.05 ppm, Co was between 0.01 ppm and 0.6 ppm, Cr was between 0.03 ppm and 1.03 ppm, Cu was between 1 3 ppm and 9.79 ppm, Fe was between 1 ppm and 13.5 ppm, Ni was between 1.2 ppm and 4 20 ppm, Se was between 0.01 ppm and 0.03 ppm, and Zn was between 0.6 ppm and 5.79 ppm. The correlation coefficients between heavy metals in *Imbrasia belina* were generally average. Strong correlations included Fe/Cu, Ni/Cr, Se/Co, Zn/Cu and Zn/Ni. The lowest correlation coefficient was at 0.03 with Ni/Fe. The worms close to the plant; more specifically sites four, five and six were the most contaminated. Results from this baseline study calls for the need to further investigate the possible effects on human health due to the consumption of *Imbrasia belina*.

KEYWORDS: heavy metals; *Imbrasia belina*; concentrations; linear trend; nickel-copper

INTRODUCTION

Selebi Phikwe is one of the main urbanised townships of Botswana rated after Gaborone, Francistown, Maun, and Lobatse (Grant and Grant, 1995) (Figure 1). It is located in the north-eastern part of Botswana between longitudes 27° 47'E and 27° 53'E, and latitudes 22° 55'S and 22° 00'S. The study area of approximately 250 km^2 has a population of about 50,000 with a 2.4% constant growth rate since 1981 (National Census, 1991). Rapid population expansion from < 5,000 in 1971 to the present population size characterised by 52.5 % male and 47.5 % female, has led to pressure on existing social and economic infrastructures (Department of Town and Regional Planning, 1996). Large scale and small scale industries, commercial businesses and agricultural farms are other economic activities in the region

The vegetation cover of the Selebi Phikwe area is the savanna type. The area is covered with mopane, *Colophospermum mopane* and a variety of acacia species namely the *Acacia Karoo*, *Acacia galpinii*, and *Acacia tortilis*. Other identified vegetation types are *Combretum sp.*, *Zizphus mucronata*, and *Commiphora kirkia*, which are commonly found on the rocky outcrops (Timberlake *et. al.*, 1993).

The phane caterpillar, known as *Imbrasia belina*, shown in Figure 2, is also referred to in Botswana as phane worm, mopane worm and phane. The caterpillar derives its common name from its host plant, the *Colophospermum mopane*. The caterpillar is the larva stage of *Imbrasia belina*, which is commonly known as the Emperor Moth (Ditlhogo, 1996; Oberpreiler, 1995). The moth flies in the mopane veld from late December to early February, and could extend to March. Individual female moths lay single layered clusters of eggs on branches and leaf stalks of *Colophospermum mopane*. The quantity, which is laid per female at a laying period, accumulates from 30 to 355 eggs/egg mass (Ditlhogo, 1996). The eggs are hatched to larvae (the caterpillar stage of the moth's life cycle). Prior to the larvae pupating, they moult four times. At the fifth instar, the caterpillar burrows underground near the base of mopane trees and pupate.

Caterpillars usually grow for about forty days before pupating. During these days, the gregarious larvae feed on *Colophospermum mopane* (Figure 3), and sometimes defoliate entire trees. Their growth is strongly influenced by rainfall and leaf-water (Scriber 1977; Taylor and Moss, 1982). Eclosion is from underground pupae. Both sexes of the moth fly at night with males coming into lights around midnight, which is the scenting time of the females. The ova are deposited in clusters and the larvae remain gregarious throughout their feeding cycle. The larvae are leathery yellow, have blackheads and extensive speckling.

Botswana is the largest producer of phane worm for the open market (Caterpillars and Campfires, 2000). Until recently, before the exploitation of worms has been commercialised, it was done at subsistence level (Ditlhogo, 1996). The women and children are gainfully engaged in the harvesting and selling of phane worms. In Botswana, it is harvested mostly in the north-eastern part of the country, and Selebi Phikwe is considered to be a high-density area of occurrence. Local women engage in the harvesting, processing, marketing and storage of phane. The worms are harvested in two periods: from late December/January for about three weeks, and small crops in March/April/May depending on the availability of rain (Caterpillars and Campfires, 2000).
Mopane caterpillars are easily harvested, dried, and have a long shelf life; an important factor to be considered in rural environments where refrigeration and modern day storage facilities might be lacking. Mopane worms can be exchanged for other food items such as sugar, tea, oil, maize meal and sorghum. Primate, birds and insects as well as human beings feed on the worms, whereas the buried mopane pupae are dug out from the ground and eaten by jackals, foxes, warthogs and ant bears (Allotey *et. al.*, 1996).

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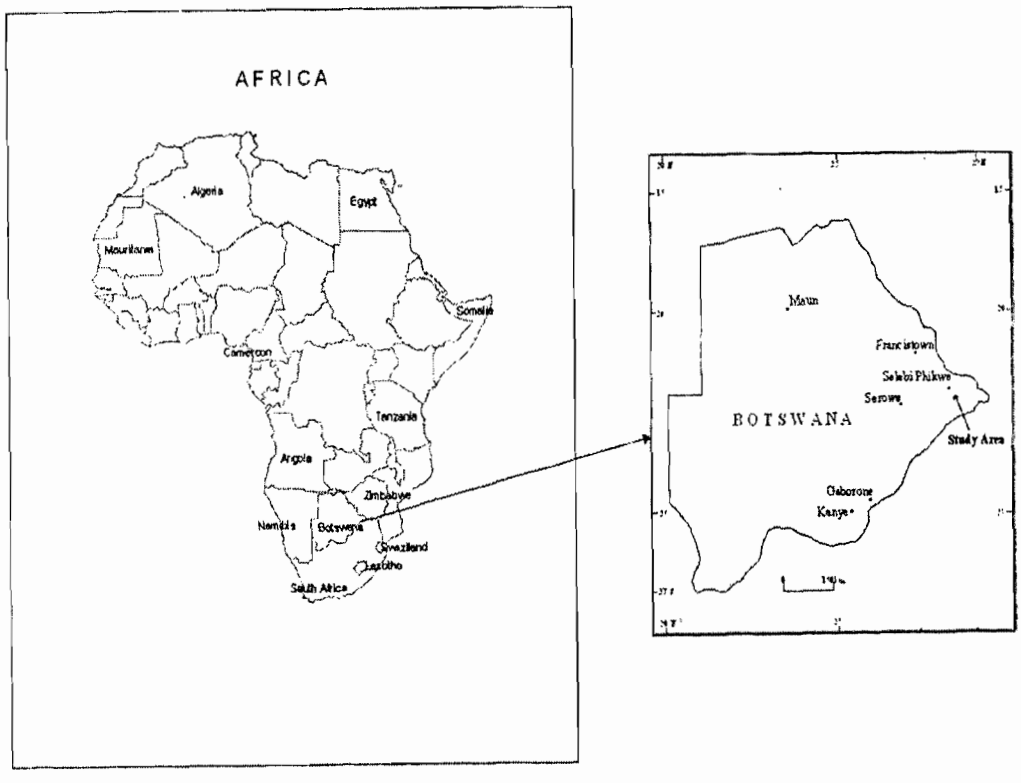


Figure 1: Map of Africa indicating Botswana, and of Botswana showing where Selebi Phikwe is located

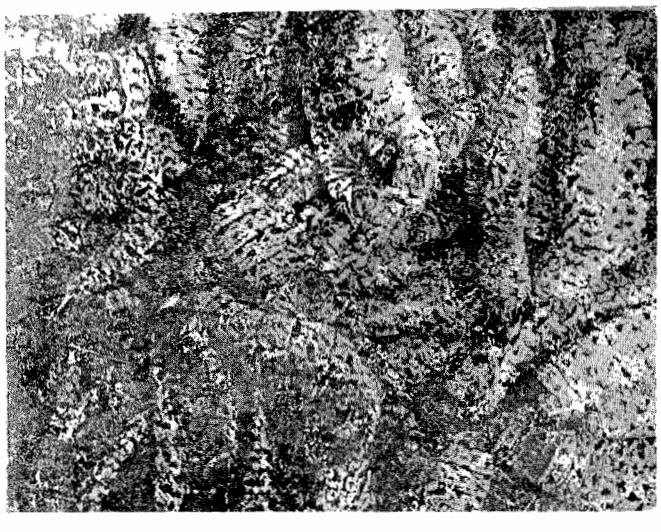


Figure 2: A collection of the mopane caterpillar, *Imbrasia belina* from Selebi Phikwe area.

Figure 3: Partially eaten green glossy leaves of a mopane tree by phane caterpillar.

Several local inhabitants in Botswana, Zimbabwe, Mozambique, South Africa and Namibia consider the larvae as a valuable protein source (Caterpillars and Campfires, 2000), and also contain significant amounts of phosphorus (P), iron (Fe), and calcium (Ca) (Allotey *et. al.*, 1996). Although *Imbrasia belina* has been harvested for several years at the Selebi Phikwe area, no documented study has so far been carried out to establish possible health effects to its consumers. In this baseline study, we determined the concentration levels of Cd, Co, Cr, Cu, Fe, Ni, Se and Zn in *Imbrasia belina*. Furthermore, an attempt was made to establish linear trends of the concentration levels of the heavy metals from mining and smelting activities within the Selebi Phikwe study area.

Experimental Procedures

Sampling and samples

There were 10 sampling areas, which included a chosen control site located close to the road juncture leading to Selebi Phikwe from the Gaborone-Francistown main road (Table 1). This juncture is about 56 km from Selebi Phikwe. The soil lithology and vegetation cover of the control sampling site were very similar to those of Selebi Phikwe area. Nine sampling

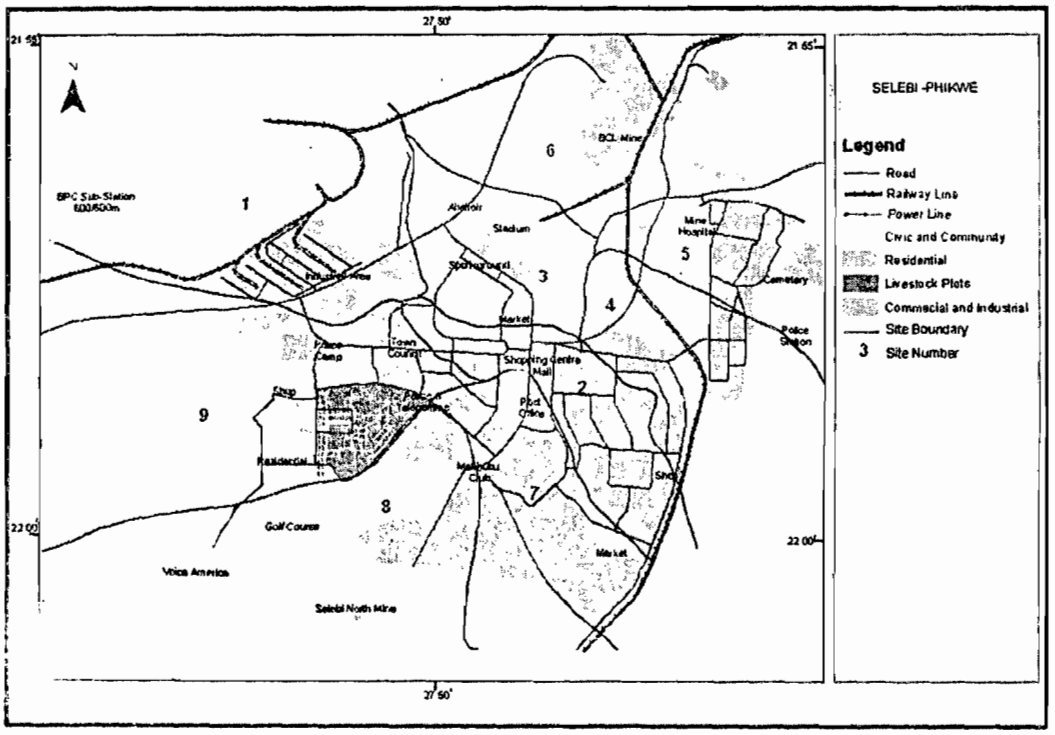


Figure 4: Map of Selebi Phikwe showing the different sampling sites

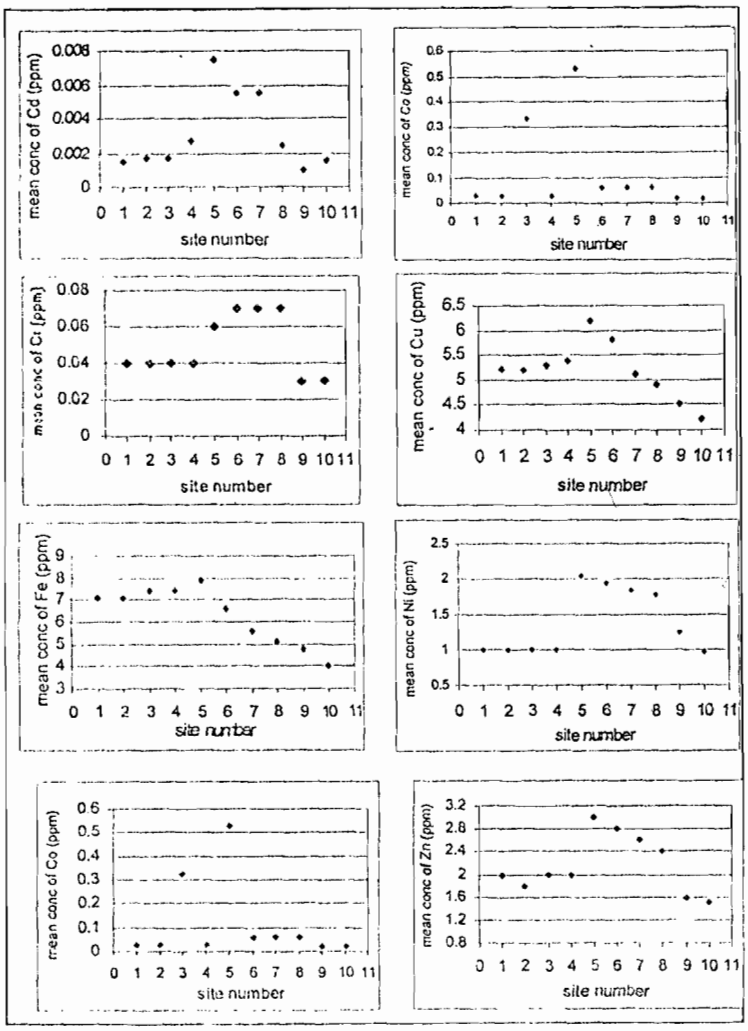


Figure 5: Mean concentrations of heavy metals in phane ... ar around the Selebi Phikwe study area.

Table 1: Location/characteristics of sampling sites at the Selebi Phikwe study site area.

Sampling site	Distance of site from mine and smelter/ concentrator plant (km)	Location/Characteristics
1	1.7	Industrial area (150 m after the railway crossing)
2	1.6	Bosele Hotel (Commercial area) and new township
3	1.3	Between the township stadium and the mine (behind the Botswana Power Corporation, BPC)
4	1.2	Between Township boundary and the railway line (directly behind a Community Junior Secondary School, CJSS)
5	1	Opposite the Mine hospital, close to old township
6	0.5	Between the mine and explosive storage facilities (close to old township)
7	6	Towards the airport (about 250 m from the Airport-Sefophe-Selebi Phikwe Road juncture)
8	7	Off untarred road leading to the Selebi North mine (100 m out of township boundary, adjacent to the new township)
9	8	Close to the second bridge before entering into the Selebi Phikwe township
10	56	Control site located close to the road juncture leading to Selebi Phikwe from the Gaborone-Francistown main road

Table 2: Minimum, maximum and mean concentrations, and standard deviation of heavy metals in phane caterpillar.

	Cadmium				Cobalt				Chromium				Copper			
Site	Min con	Max conc	Mean	Std dev	Min conc	Max conc	Mean	Std dev	Min conc	Max conc	Mean	Std dev	Min conc	Max conc	Mean	Std dev
1	0.001	0.002	0.002	0.001	0.02	0.03	0.03	0.001	0.03	0.04	0.04	0.01	5.01	5.25	5.16	0.09
2	0.001	0.002	0.002	0.0004	0.02	0.03	0.04	0.005	0.03	0.04	0.04	0.005	5.15	5.25	5.17	0.05
3	0.001	0.002	0.002	0.0004	0.03	0.04	0.03	0.004	0.03	0.04	0.04	0.005	5.31	5.35	5.34	0.02
4	0.002	0.003	0.003	0.0004	0.02	0.04	0.03	0.007	0.03	0.04	0.04	0.004	5.37	5.41	5.39	0.01
5	0.007	0.008	0.008	0.0005	0.05	0.06	0.05	0.004	0.06	0.07	0.06	0.004	6.10	6.19	6.16	0.03
6	0.005	0.006	0.006	0.0005	0.05	0.07	0.06	0.007	0.06	0.07	0.07	0.005	5.16	6.09	5.83	0.39
7	0.005	0.006	0.006	0.0005	0.05	0.07	0.06	0.007	0.06	0.07	0.07	0.005	5.06	5.15	5.10	0.03
8	0.002	0.003	0.003	0.0005	0.05	0.06	0.06	0.005	0.06	0.07	0.07	0.005	4.89	5.00	4.94	0.04
9	0.001	0.001	0.001	0	0.01	0.02	0.02	0.004	0.03	0.04	0.03	0.004	4.44	4.56	4.49	0.05
10	0.001	0.001	0.002	0.0005	0.01	0.01	0.02	0.005	0.02	0.03	0.03	0.004	4.00	4.25	4.15	0.10
	Iron				Nickel				Selenium				Zinc			
Site	Min conc	Max conc	Mean	Std dev	Min conc	Max conc	Mean	Std dev	Min conc	Max conc	Mean	Std dev	Min conc	Max conc	Mean	Std dev
1	7.02	7.21	7.13	0.07	0.95	1.05	0.99	0.02	0.001	0.001	0.001	0	1.95	2.1	2.02	0.05
2	7.13	7.19	7.16	0.02	0.95	1.01	0.99	0.23	0.001	0.002	0.001	0.004	1.89	1.95	1.91	0.02
3	7.31	7.41	7.37	0.04	0.95	1.05	1.003	0.04	0.001	0.002	0.002	0.004	1.95	2.0	1.98	0.02
4	7.37	7.42	7.40	0.02	0.97	1.01	0.99	0.01	0.002	0.003	0.003	0.001	1.98	2.01	2.00	0.01
5	7.89	7.95	7.94	0.03	2.02	2.10	2.06	0.03	0.005	0.006	0.006	0.001	3.00	3.08	3.03	0.03
6	6.51	6.85	6.64	0.13	1.90	1.96	1.94	0.020	0.004	0.005	0.005	0.001	2.81	2.95	2.88	0.05
7	5.50	5.69	5.57	0.08	1.80	1.89	1.85	0.04	0.003	0.004	0.004	0.004	2.55	2.56	2.60	0.04
8	5.06	5.11	5.09	0.02	1.76	1.79	1.78	0.01	0.003	0.004	0.004	0.001	2.39	2.45	2.41	0.02
9	4.79	4.88	4.83	0.04	1.21	1.27	1.24	0.02	0.001	0.002	0.002	0.001	1.80	1.91	1.86	0.04
10	3.96	4.0	3.98	0.01	0.95	0.99	0.97	0.01	0.001	0.001	0.002	0.001	1.45	1.49	1.46	0.03

sites radiometrically distributed within the mine and smelter plant environments, and a control sampling site were identified (Figure 4).

The matured phane worms, dark brown, with length ranging from 3 cm to 5 cm were harvested. Where possible, the worms were observed as they fed on mopane leaves. These observations were carried out at the sampling sites. Ten

Table 3: Correlation coefficients between normalised heavy metals in the phane caterpillars.

	Cd	Co	Cr	Cu	Fe	Ni	Se	Zn
Cd	1							
Co	0.54	1						
Cr	0.51	0.33	1					
Cu	0.66	0.63	0.54	1				
Fe	0.17	0.54	0.11	0.85	1			
Ni	0.65	0.38	0.89	0.53	003	1		
Se	0.67	0.84	0.68	0.61	0.60	0.51	1	
Zn	0.64	0.50	0.87	0.81	0.40	0.92	0.58	1

worms were sampled per sampling area. A total of 40 sets of samples were obtained for analysis. The worms were hand-picked from the mopane plants. Most of the harvested worms were those that were found to be either eating the leaves of the mopane tree or were found close to eaten leaves of the plant. The guts of the transported fresh phane samples were squeezed out, and the worms were later dried in the oven at 105 °C for 48 hours. After drying they were stored at room temperature of about 25 °C until analyses were carried out.

Chemical analyses

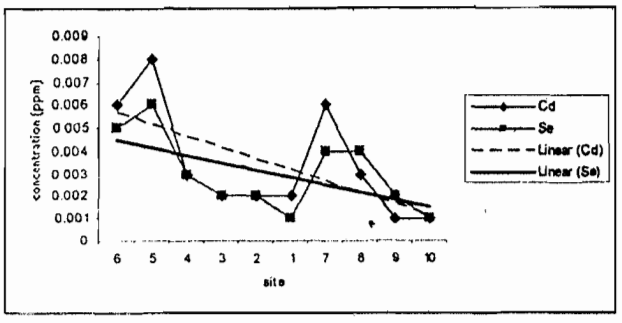
Elements associated with Ni-Cu mining and smelting included Cd, Cr, Co, Cu, Fe, Ni, Se and Zn, which were likely to be found in Ni-Cu orebodies and released into the physical environment through mining and smelting activities (Nkoma and Ekosse, 1999). Concentrations of Cd, Cr, Co, Ni and Se present in extracts of samples of worms were determined using a Varian Spectra AA 400 plus Atomic Absorption spectrometer with a Zeeman Graphite Tube Atomizer (GTA) 9[illegible]. Concentrations of Cu, Fe and Zn were measured with a Varian Spectra AA 10 Flame Atomic Absorption Spectrometer (FAAS).

The procedure for the determination of the concentrations of heavy metals was adapted from both Beach for the Zeeman GFAAS (Beach, 1989) and NIOSH manual of analytical methods for FAAS (National Institute of Occupational Safety and Health, 1995), depending on the analyte being analysed.

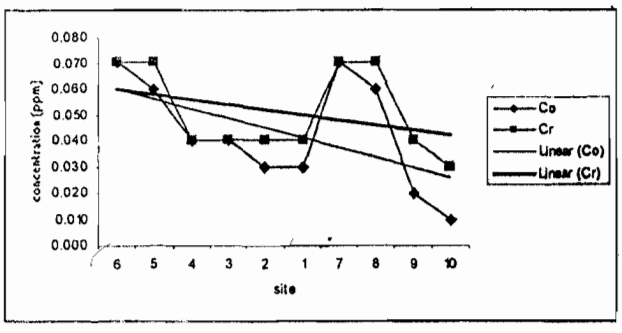
RESULTS AND DISCUSSIONS

The minimum, maximum and mean concentration values as well as the standard deviation for heavy metals in phane caterpillars are reported in Table 2. Concentration values obtained for heavy metals in phane caterpillars were as follows: Cd was between 0.01 ppm and 0.05 ppm, Co was between 0.01 ppm and 0.6 ppm, Cr was between 0.03 ppm and 1.03 ppm, Cu was between 1.3 ppm and 9.79 ppm, Fe was between 1 ppm and 13.5 ppm, Ni was between 1.2 ppm and 4.20 ppm, Se was between 0.01 ppm and 0.03 ppm, and Zn was between 0.6 ppm and 5.79 ppm.

The mean concentration values of heavy metals in worms, as reflected in Figure 5, indicated the lowest concentration values occurring at the control site. The correlation coefficients are given in Table 3. The correlation coefficients between heavy metals in phane caterpillar reflected very good associations. Strong correlations included Fe/Cu, Ni/Cr, Se/Co, Zn/Cu and Zn/Ni. The lowest correlation coefficient was at 0.03 with Ni/Fe. Other lower mean concentration values of the different heavy metals obtained for analysed samples were further away from the smelter/concentrator plant (sites seven, eight, nine and ten). The worms close to the smelter/concentrator plant; more specifically sites four, five and six were the most



a



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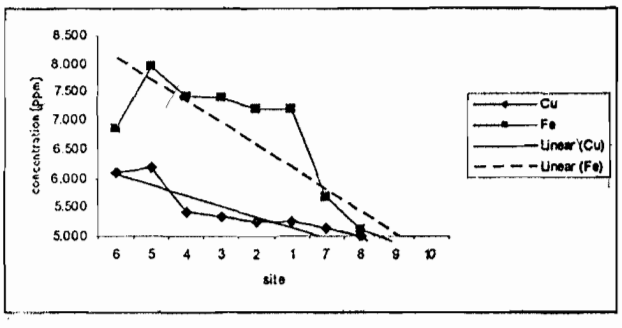

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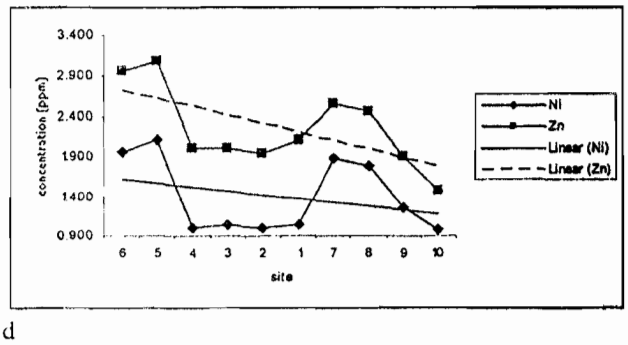

d

Figure 6: Maximum concentrations of heavy metals indicating linear trend of decrease from mine and smelter/concentrator plant to control site (a = Cd and Se, b = Co and Cr, c = Cu and Fe, d = Ni and Zn)

contaminated.

Fresh, full length, gregarious phanes were seen at sites four, five, six, seven, nine and ten. The phanes at sites one, two, three and eight were thin and shorter. The fresh phanes were observed where the mopane leaves were very rich green in colour. They fed on the juicy leaves, eating from the edges to the centre of the leaves. Only some of the leaves of the mopane plants (at sites one, two, three, and eight) were discoloured. Quite interestingly, the worms fed only on the green leaves and avoided the discoloured ones.

At sites four, five, six, seven, nine and ten there were not many worms, although it was seen that these colonies of worms were very fresh and fat. The phanes were harvested from these sites. At other sites where harvesting was not carried out, there were many caterpillars. However these caterpillars were quite small in size. The concentrated heavy metal content in the phane caterpillars at these sites was attributed to the fact that the leaves they fed on were more contaminated than leaves at other sites.

Linear trends in heavy metals concentrations showed decrease in concentration levels with corresponding increase in distance from the mine and the smelter/concentrator plant (Figure 6). The eight heavy metals were grouped in twos according to closeness of their concentration values for easy visual appraisal: Cd and Se (Figure 6a), Co and Cr (Figure 6b), Cu and Fe (Figure 6c) and, Ni and Zn (Figure 6d). Very sharp linear decrease was noticed for Fe, Cu and Zn. Very gentle slopes were observed for Ni and Cr. The slopes of Co, Cd and Se were moderate. That notwithstanding, the data depicted that concentration levels of the heavy metals decreased with increasing distance from the mine and the smelter/concentrator plant, with the control site in all cases having the lowest values. The highest values were obtained for samples from sites five and six which were the closest to the mine and the smelter/concentrator plant.

Previous x-ray powder diffraction studies of Ni-Cu orebodies (Nkoma and Ekosse, 1999; 2000) and soils (Ekosse *et. al.*, 2003), and particulate air matter (Ekosse *et. al.*, 2004) conducted on different samples obtained within the Selebi Phikwe area indicated mineral constituencies that reflected the presence of the studied heavy metals. Furthermore, studies on environmental chemistry of the Selebi Phikwe area depicted trends in heavy metals concentrations in soils and *Colophospermum mopane* [17] to be similar to those obtained for *Imbrasia belina* in this particular study.

CONCLUSIONS

This study has focussed on determining the concentration levels of heavy metals in *Imbrasia belina* and establishing their contaminant trend from the mine and the smelter/concentratator plant to the control site. Contaminant levels of heavy metals obtained by analyses after having dried and pulverised phane caterpillars showed a linear trend of concentration levels decreasing with increasing distance from the mine and the smelter/concentrator plant.

The worms were generally more contaminated than the soils, (Ekosse *et. al.*, 2004a), even though in put of heavy metals from tailings dump to soils have been established (Ekosse *et. al.*, 2004c). The soils supply plant nutrient to the mopane leaves, which serve as the principal food source for phane worms. Other observable phenomena were stunted growth of *Imbrasia belina* (phane caterpillar) as a result of high concentrations of heavy metals in their organic systems.

Results from the analyses of phane showed that heavy metals accumulated in the organic system of the worms. Consequently, through the food chain, these metals could also accumulate in the systems of human beings over time. Further work should be directed at investigating possible health effects as a result of heavy metals accumulation in phane, and influence on the food chain.

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