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Plants and Soil Contamination with Heavy Metals in Agricultural Areas of Guadalupe, Zacatecas, Mexico

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1. Introduction

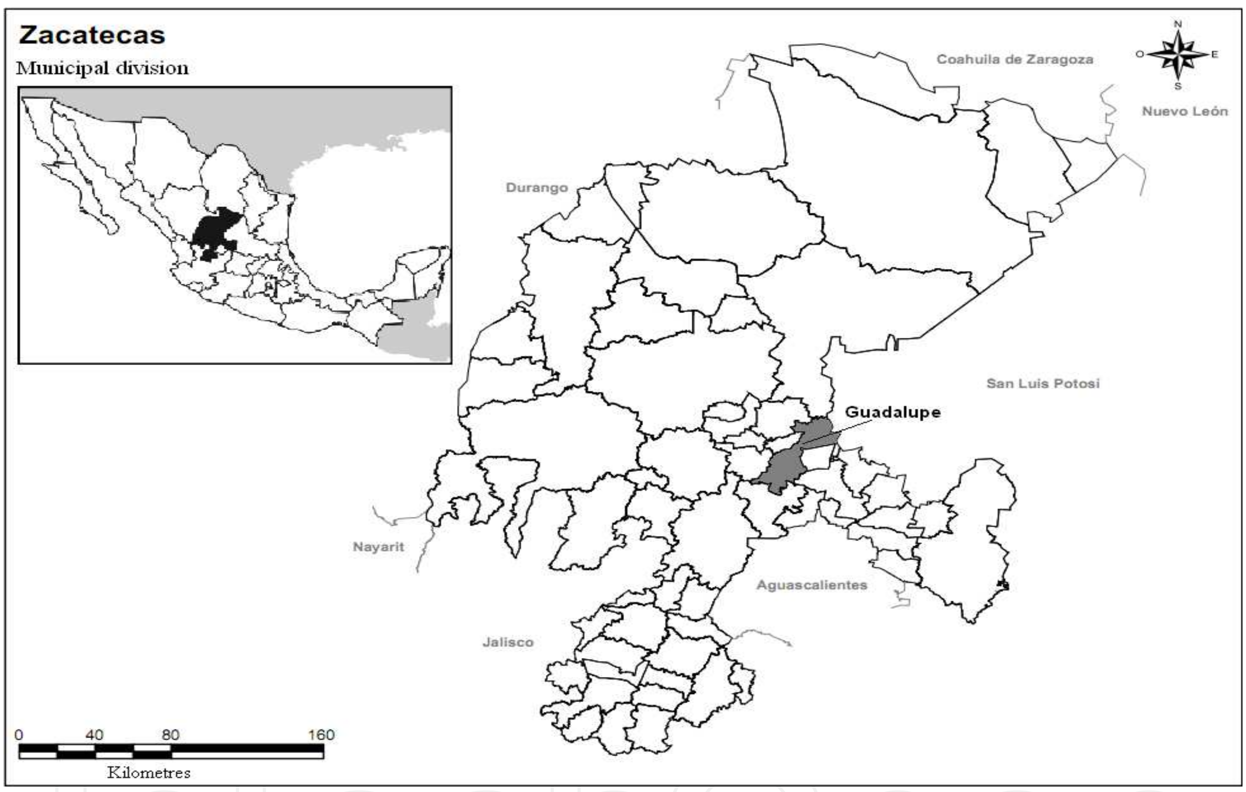
The environmental impact of mine tailings has been largely documented around the world. Deterioration and contamination of soils, groundwater and superficial water as well as alterations in the hydrological systems have been associated with mining wastes (Figueroa *et al* 2010). Heavy metal contamination of plants, soil and water affects several countries worldwide posing a serious threat to the health of millions of people. Due to its long mining history, Mexico is among the most affected countries by this serious environmental problem.

A geochemical comparative study was conducted in the municipality of Guadalupe in Zacatecas, Mexico. The objectives were to measure the bioconcentration factor in plants of agronomic interest in function of their heavy metal absorption, to identify the toxicity order of heavy metals in plants of agronomic interest, to assess potential environmental impacts taking into account the particularities of the selected crop and to evaluate the potential consequences on the region's food security.

Zacatecas state is located in north central Mexico (see figure 1). There, metallic ores are abundant and diverse. The state has 450 years of mining tradition with the consequent accumulation of mining tailings (Salas–Luévano *et al* 2009). Currently, Zacatecas state is the most important silver producer in Mexico. During the year 2010, 1,855,145 kilograms of silver were produced in Zacatecas (INEGI 2011). Amalgamation for silver extraction, also known as patio process, consists in adding mercury to the silver ore in order to obtain a silver amalgam as the final product. Amalgamation was used extensively throughout the period from 1570 to 1820. Most of the heavy metals lost via amalgamation were carried by rivers and deposited in the plain areas of the Zacatecan valley in what is now the Guadalupe municipality. Most of these areas are currently used for crop farming since there are no restrictions imposed by the Mexican authorities (Santos–Santos *et al* 2006).

Previous studies have found high levels of Pb, As, Hg and F^- in groundwater extraction wells that supply Guadalupe municipality (Leal & Gelover 2002; Castro *et al* 2004; González Dávila 2011). In addition to drinking water health risks, there is also risk of potential levels of heavy metals entering the food chain via absorption by crops from contaminated soil and water. Heavy metal contaminated crops could aggravate human health risk when consumed along with heavy metal contaminated drinking water (Brammer 2008; Duxbury 2007; Santos–Santos *et al* 2006).

The most important staple food in Mexico is maize (*Zea mays L.*). Meals are based on maize, with tortillas providing much of the caloric intake both in rural and urban areas. Due to its importance for the food security of the region, it was decided to analyse the contents of heavy metals in maize plants.



Source: INEGI. Marco Geoestadístico Municipal 2005

Fig. 1. Location of Guadalupe municipality in Zacatecas State

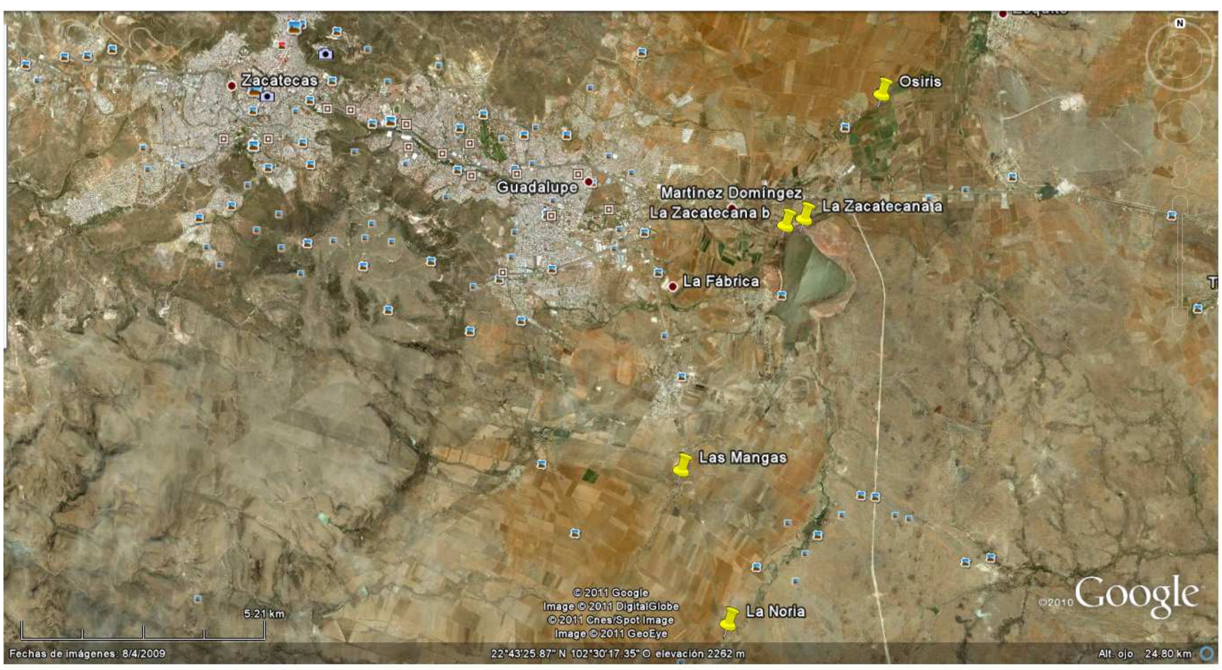
2. Methods and materials

2.1 Geographical delimitation

Soil and maize plant samples were collected from agricultural areas from the municipality of Guadalupe, Zacatecas. Guadalupe municipality is located at an average 2,280 metres above sea level (lat 22° 45' N and long 102° 31' O). The site is characterized by a climate arid sub tropic tempered, throughout the year. The average annual temperaturee is 17°C. The average maximum temperature is 30°C and occurs during May. The average minimum temperature is 3°C and occurs in January. There is an average annual precipitation of 463 mm (CONAGUA 2010:25). Due to Zacatecas' climate and environmental conditions, irrigation is very important in maize production. According to the Service of Agrifood and Fishery Information (SIAP 2010), in Zacatecas 34,918 hectares of land producing maize were irrigated during 2010. Soil and plant samples were collected from 5 different irrigation zones in the municipality during June 2011. In the southern part of the municipality, samples were collected from agricultural land in Noria Blanca and Las Mangas. In the central part, samples were collected from La Zacatecana and in the northern part samples were collected from agricultural land in Osiris. The coordinates of sampling points can be found in table 1. The map in figure 2 shows each of the collection points.

	Zone	Alt	lat N	long W
1	La Noria	2267	22° 40´ 02.1´´	102° 28´ 52.5´´
2	Las Mangas	2254	22° 41´ 46.5´´	102° 29´ 28.1´´
3	La Zacatecana a	2220	22° 44´ 37.2´´	102° 27´ 55.5´´
4	La Zacatecana b	2223	22° 44´ 32.1´´	102° 28´ 09.6´´
5	Osiris	2190	22° 46´ 02.2´´	102° 26´ 56.8´´

Table 1. Sampling points coordinates



Source: Mapped with Google Earth using the authors' data

Fig. 2. Plants and soil sampling points

2.2 Sample size

The number of samples n was calculated with the formula: n = $[Z\alpha^2 * p * (1-p)] / d^2$. A 95% confidence level was established and a $Z\alpha$ of 1.96 was obtained. Following Santos-Santos *et al* (2006), a proportion value p of 0.05 and a precision factor d of 8.5% were selected. Thus, the number of samples n was calculated as 25.26 samples. Thus, it was decided to collect five maize plant and soil samples in a 100 m^2 area of agricultural land in each irrigation zone. Nevertheless, 2 extra samples were collected because mine tailings were found next to agricultural land in zone 3.

2.3 Soil samples analysis

Soil pH was measured in soil-H_2O suspension (1:2.5, w/w) and electrical conductivity was measured in a 1:5 soil to water suspension using an HI 9828 Multiparameter portable (HANNA instruments) with intelligent probe and T.I.S. Total N was determined using the Kjeldhal method (Black 1965). Organic matter content was determined by the Walkley and Black procedure (Nelson & Sommers 1982). Available P was measured colorimetrically by the molybdenum blue method (Olsen & Sommers 1982). Soil samples were dried at 60 °C for 75 h; then each sample was crushed, sieved (< 325 µm), homogenized, and weighed. Soil particle size distribution was measured using the hydrometer method (Allen et al 1974). Carbonate content was determined following Horton & Newson (1953) methodology. Available (DTPA-extractable) heavy metal concentrations (Pb, Cd, Fe, Cu and Mn) were determined by atomic absorption spectrophotometry. Total heavy metals in soil and plant samples were measured by energy-dispersive X-ray fluorescence spectrometry, using a NITON XL3t of Thermo Fisher Scientific. X-ray spectra were analyzed with Niton Data Transfer software suite. The spectrometer was calibrated for heavy metals using certified standards from NIST (National Institute of Standards and Technology) Montana soil 2711 and 2710a and peach in plants. Intermediate and high heavy metal concentration standards, traceable to NIST, were prepared in our facility to have a wide range calibration curve. Heavy metals concentrations in the samples were measured three times. Arsenic (a metalloid) in soils and plants samples was also determined using energy-dispersive X-ray fluorescence. This technique has been accepted by the U.S. Environmental Protection Agency to measure arsenic in dry solid samples (Melamed 2004:4).

2.4 Plant samples analysis

Plant samples were collected from the top layer (0-30 cm) of agricultural land. They contained a mix of spoil and soil. Thus, samples were washed thoroughly in the laboratory with running tap water, followed by three rinses with deionized water (18 MΩcm-1, Milli-Q Millipore) and a rinse of tri-distilled water. All plant samples were carefully divided into shoots and roots. They were dried at 60°C for 75h. The oven-dried plant samples were then crushed, sieved (< 325 µm), homogenized, and weighed. Later, arsenic and heavy metal concentrations were determined by energy dispersive X-ray fluorescence. The translocation factor (TF) for metals within a given plant was calculated as metal concentration in shoot divided by that in root (Tu et al 2003; Rizzi et al 2004). The bioconcentration factor (BFC) was expressed by the ratio of metal concentration in plant above ground part to total metal concentration in soil (Rotkittikhun et al 2006).

3. Results

3.1 Soil samples results

Table 2 shows the results of total concentrations for the following elements: Pb, As, Hg, Zn, Cu, Fe, Mn and K. All the results are expressed in ppm. Tests for Cd, Ag and Ni were also conducted but the concentration levels were in all samples under the limit of detection. In zones 1 to 4, at least five soil samples were collected. In zone 5, three soil samples were collected. Sample 17 corresponds to a tailing sample collected in zone 3 from a tailing pond located next to agricultural land (see figure 3).

Zone	Sample	Pb	As	Hg	Zn	Cu	Fe	Mn	K
1 La Noria	zac-1	28.69	< BDL	< BDL	72.78	< BDL	21828.6	481.24	11771.6
	zac-2	26.02	< BDL	< BDL	74.26	< BDL	23137.2	506.34	11193
	zac-3	29.13	< BDL	< BDL	76.33	< BDL	23575.2	581.25	12148.7
	zac-4	26.17	< BDL	< BDL	87.78	< BDL	21849.3	494.12	8126.95
	zac-5	23.34	< BDL	< BDL	69.91	< BDL	23030	519.22	10738.2
	zac-6	22.60	< BDL	< BDL	73.64	< BDL	21620.9	495.55	8555.12
2 Las Mangas	zac-7	52.04	15.92	< BDL	109.4	< BDL	19778.2	527.64	14058.3
	zac-8	28.44	12.91	< BDL	64.54	< BDL	18523.3	622.17	12772.8
	zac-9	20.93	< BDL	< BDL	72.4	< BDL	19323.8	365.46	12529.6
	zac-10	27.25	13.14	< BDL	70.06	< BDL	19240.8	560.97	14183.9
	zac-11	36.43	14.06	< BDL	98.65	< BDL	22773.7	525.42	11743.6
3 La Zacatecana A	zac-12	534.94	87.4	16.69	997.27	95.41	36453.5	928.08	13191.9
	zac-13	660.34	163.34	20.73	1392.47	113.17	37976.4	927.29	11631.4
	zac-14	644.52	143.82	18.58	1233.23	114.26	38234.1	895.54	12067.5
	zac-15	518.84	85.53	< BDL	882.36	105.6	35873	812.61	13470.3
	zac-16	552.36	94.51	< BDL	946.45	95.36	35726.3	914.2	11438.5
	zac-17*	**5660.25**	**289.9**	**505.9**	**10086.5**	**1323.82**	**55330.6**	**1792.39**	**10466.4**
4 La Zacatecana B	zac-18	540.39	70.64	< BDL	889.6	113.49	34742.6	783.97	12821.7
	zac-19	572.71	68.82	21.92	955.41	107.81	35413.9	859.98	11564
	zac-20	661.17	90.95	17.9	1110.74	146.63	36420.7	945.89	14131.8
	zac-21	634.74	59.41	25.27	1049.17	136.21	36023.1	818.63	12606.4
	zac-22	625.63	77.22	25.51	1042.01	145.5	39214	824.22	12492.4
	zac-23	639.82	68.28	20.5	982.33	132.9	35100	749.13	11480.9
	zac-24	540.39	70.64	37.69	1303.11	147.76	35619.1	1189.53	12795.9
5 Osiris	zac-25	105.58	< BDL	< BDL	182.35	56.2	40001.9	780.22	9100.29
	zac-26	88.65	21.39	< BDL	161.41	55.2	40888.1	707.06	9434.11
	zac-27	105.96	< BDL	< BDL	188.72	64.5	44801.5	816.88	9836.79

Results for Pb, As, Hg, Zn, Cu, Fe, Mn and K are in ppm. Areas were defined according to fig. 2
* Sample 17 corresponds to a mine tailing sample collected in zone 3.
< BDL = Below detection limit.

Table 2. Arsenic and heavy metal concentrations (ppm) in agricultural soils of Guadalupe, Zacatecas.

Table 3 shows the pH and electrical conductivity in the soil samples. The samples collected in zones 1, 2 and 5 are moderately alkaline. Soil samples from zones 3 and 4 are slightly alkaline. The organic matter was also determined. It should be noted that the percentage of organic matter in soils samples collected in zones 3 and 4 is higher than in the rest. This can be explained by the fact that wastewater irrigation is a common practice in that specific area. The other parameters shown in the table are total nitrogen, phosphorous and calcium carbonate. The high levels of phosphorus and total nitrogen found in samples from zones 3 and 4 are congruent with the levels of organic matter found. Table 4 shows the available (DTPA-extractable) heavy metal concentrations in ppm. It should be noted that the availability of such elements is higher in zones 3 and 4. This is congruent with the information shown in table 2.

Zone	pH	EC dS/m	OM %	TN %	P (ppm)	$CaCO_3T$ %
1 La Noria	8.288	1.206	1.294	0.062	20.55	1.814
2 Las Mangas	7.872	0.538	1.628	0.127	16.08	0.602
3 La Zacatecana A	7.686	3.570	3.868	0.192	59.10	3.058
4 La Zacatecana B	7.602	2.704	4.062	0.208	74.71	3.152
5 Osiris	8.304	1.678	1.494	0.072	8.48	1.458

Areas were defined according to fig. 2. EC=Electrical Conductivity, OM= Organic Matter, TN = Total Nitrogen.

Table 3. Chemical analysis of agricultural soils of Guadalupe, Zacatecas.

Zone	Pb	Cd	Fe	Cu	Mn
1 La Noria	0.562	0.013	3.560	0.588	17.380
2 Las Mangas	2.314	0.086	8.664	1.344	29.844
3 La Zacatecana A	67.940	5.036	74.228	35.808	23.440
4 La Zacatecana B	85.656	4.284	33.306	29.688	26.810
5 Osiris	4.138	0.574	3.528	5.546	15.214

Results for Pb, Cd, Fe, Cu and Mn are in ppm. Areas were defined according to fig. 2

Table 4. Available (DTPA-extractable) heavy metals in agricultural soils of Guadalupe, Zacatecas.

Fig. 3. Tailing pond close to agricultural land in Guadalupe, Zacatecas.

3.2 Plant samples results

The concentrations of Pb, As, Zn, Cu, Fe and Mn in the roots and shoots of maize plants collected in the study area are summarized in table 5. In zones 1 to 4, at least five maize plant samples were collected. In zone 5, three maize plant samples were collected. Tests for Cd, Hg, Ag and Ni were also conducted. However, the levels of those elements were under the limit of detection in all samples.

Zone	Samples	Pb	As	Zn	Cu	Fe	Mn
1	Roots	NA	15.26	153.97	74.45	11174.63	295.83
	Shoots	NA	NA	94.38	69.87	766.66	324.03
2	Roots	NA	NA	31.13	42.75	1053.51	NA
	Shoots	NA	NA	89.02	81.58	956.74	271.69
3	Roots	293.24	98.15	849.74	111.49	25359.64	629.71
	Shoots	21.39	NA	688.63	121.71	2196.75	150.1
4	Roots	79.77	44.14	462.5	213.63	11357.48	223.24
	Shoots	16.8	NA	438.07	120.35	1565.75	263.69
5	Roots	18.55	NA	236.69	89.84	13233.08	318.83
	Shoots	NA	NA	177.69	104.57	1992.08	485.14

Table 5. Arsenic and heavy metal concentrations (ppm) in roots and shoots of maize plants collected in Guadalupe, Zacatecas. NA=Not available

3.3 Bioconcentration and translocation factors in plant samples

Table 6 shows the bioconcentration and translocation factors for metals in maize plant samples. The toxicity order is discussed in section 4.2.

Zone	Factor	Pb	As	Zn	Cu	Fe	Mn
1	BCF	NA	NA	2.02	NA	0.49	0.57
	TF	NA	NA	0.61	0.94	0.07	1.1
2	BCF	NA	NA	0.38	NA	0.05	NA
	TF	NA	NA	2.86	1.91	0.91	NA
3	BCF	0.5	0.85	0.78	1.06	0.69	0.7
	TF	0.07	NA	0.81	1.09	0.09	0.24
4	BCF	0.13	0.6	0.44	1.64	0.32	0.24
	TF	0.21	NA	0.95	0.56	0.14	1.18
5	BCF	0.19	NA	1.33	1.53	0.32	0.42
	TF	NA	NA	0.75	1.16	0.15	1.52

Table 6. Bioconcentration and translocation factors. NA=Not available

4. Discussion

4.1 Soil contamination

The Mexican Official Norm NOM-147-SEMARNAT/SSA1-2004 (SEMARNAT 2007) established the following guideline values for arsenic and heavy metals in agricultural soil in 2007:

Element	Guideline value (ppm)
As	22
Cd	37
Hg	23
Ag	390
Ni	1600
Pb	400

Table 7. Mexican guideline values for arsenic and heavy metals in agricultural soil

This study has identified arsenic, lead and mercury contamination in agricultural soil from Guadalupe, Zacatecas (see table 2). Table 8 presents the mean, standard deviation (SD) and range of Pb, As and Hg concentrations found in the five sampling zones. Zones 3 and 4 located in La Zacatecana are the most contaminated. All the soil samples collected in those areas are above the 400 ppm maximum allowed level of Pb in soils established by the Mexican Official Norm. Although Pb concentrations are lower than those reported in other mining regions in Mexico (see for example Gutiérrez-Ruiz *et al* 2007 that report a Pb range of 972-16,881 ppm), the Pb contamination levels are unquestionably high and toxic. Arsenic concentrations were also high in the studied areas -ranging from 15.92 to 163.34 ppm- even compared to those reported in other mining regions from Mexico (see for example Mendoza-Amézquita et al. 2006 that report As concentrations of 21-36 ppm) and North America (Moldovan et al. 2003 report As concentrations of 56-6,000 ppm). It should be noted that all the samples in zones 3 and 4 are above the 22 ppm As guideline. However, As concentrations found in this study were low compared to concentrations reported by Méndez & Armienta (2003) in Zimapan, Hidalgo, Mexico (2,550-14,600 ppm) and Ortega-Larrocea *et al* (2009) for the same area (up to 2,869 ppm). On the other hand, three soil samples from zone 4 were above the 23 ppm Hg guideline. Hg contamination is not evident in zones 1,2 and 5. Table 9 shows that there is a strong positive correlation between the presence of Pb and As in soils of the region. The correlation is significant at the 0.01 level. This relationship suggests a common source of contamination and it is very likely that it is related to the same kind of mining activities. It is very important to mention that during the fieldwork the authors found that a local mining company dug a tailing pond and was filling it with mining waste just 13 meters away from agricultural land in zone 3 “La Zacatecana A” (see figure 3). High heavy metal levels were found in the tailing sample collected there.

In their exploratory study, Santos–Santos *et al* (2006) reported that the main source of heavy metal contamination in Guadalupe’s soil is related to old mining activities carried out in the surrounding area of Osiris and La Zacatecana. However, it was found that new mine tailings in the area are recklessly managed and there is an alarming lack of enforcement mechanisms to oblige the mining companies to obey the environmental laws and regulations. Those new tailings are undoubtedly a source of heavy metal contamination of the neighbouring agricultural land. Although Manzanares *et al* (2003) reported normal levels of lead and mercury in blood of sampled people at La Zacatecana, it is very likely that those concentrations have increased over time. Two heavy metal exposition routes can be identified. In the first place, there is a respiratory intake of particles and dust from contaminated soil. Second, as it is explained in the following section, there is a deposition of heavy metals in crops aimed for human consumption. Therefore, a blood study should be conducted again among the people of the region. Due to the presence of the new mine tailings in the region, a higher exposure to heavy metals is expected.

Zone	n	Pb				As				Hg*			
		Mean	SD	Range	% > 400 ppm Pb	Mean	SD	Range	% > 22 ppm As	Mean	SD	Range	% > 23 ppm As
1	6	25.99	2.67	22.60 - 29.13	0	<BDL	NA	< BDL	0	< BDL	NA	< BDL	0
2	5	33.02	11.98	20.93 - 52.04	0	14.01	1.37	12.91 - 15.92	0	< BDL	NA	< BDL	0
3	5	582.20	65.44	518.84 - 660.34	100	114.92	36.12	85.53 - 163.34	100	18.67	2.02	16.69-18.58	0
4	7	602.12	50.02	540.39 - 661.17	100	72.28	9.76	59.41 - 90.95	100	24.80	6.95	17.9-37.69	43
5	3	100.06	9.89	88.65 - 105.96	0	21.39	NA	21.39	0	< BDL	NA	< BDL	0

Results for Pb, As and Hg are in ppm. Areas were defined according to Figure 2. < BDL = Below detection limit. NA=Not available. * For the mean and SD calculation for Hg samples under the limit of detection were excluded.

Table 8. Mean Lead, Arsenic and Mercury levels in soil samples collected in five different risk areas of Guadalupe, Zacatecas

		Pb	As
Pb	Pearson Correlation	1	.865**
	Sig. (2-tailed)		.000
	N	27	18
As	Pearson Correlation	.865**	1
	Sig. (2-tailed)	.000	
	N	18	18

**. Correlation is significant at the 0.01 level

Table 9. Correlation levels of Lead and Arsenic

4.2 Plants contamination

Soils from zones 3 and 4 have the highest levels of heavy metal concentrations (see tables 2 and 4). High levels of heavy metals were also found in plants collected in those areas. Plants from zones 1 and 2 showed lower heavy metal concentrations than plants from the other 3 zones. Toxic levels of Cu and Zn in plants were found in all zones except zone 2. One of the objectives of this study was to measure the bioconcentration and the transference factor in maize plants and to indicate the toxicity order of heavy metals in the plants. It was found that the amount of metals was higher in roots and shoots of plants growing in the most contaminated soil of zones 3 and 4. Consistently with other works (Bidar et al 2007; Marques et al 2009), heavy metal accumulation occurred more frequently in roots than in shots. The BCF shows that there is a higher accumulation of Zn and Cu in maize plants. In some zones, Zn concentration exceeded by two of times the critical limits proposed by Kabata-Pendias (2001) (see table 10). The BCF factor in zone 1 was 2.02 for Zn, followed by 0.57 for Mn and 0.49 for Fe. The other metals were not detected. In zone 2 the BCF was 0.38 for Zn and 0.05 for Fe. In zone 3, the BCF was Cu>As>Zn>Mn>Fe>Pb. The BCF in zone 4 was Cu>As>Zn>Fe>Mn>Pb. And in zone 5, the BCF was Cu>Zn>Mn>Fe>Pb>As. The order of the sampled sites in relation to their BCF from lower to higher is: zone 2 < zone 1 < zone 5 < zone 4 < zone 3.

In regards to the translocation factor (TF), in zone 1 it was Mn>Cu>Zn>Fe>Pb>As. In zone 2 it was Zn>Cu>Fe>Mn>Pb>As. In zone 3 it was Cu>Zn>Mn>Fe>Pb>As. The TF in zone 4 was Mn>Zn>Cu>Pb>Fe>As and in zone 5 it was Mn>Cu>Zn>Fe>Pb>As. The TF shows a higher concentration of Cu, Zn and Mn in the shoots of maize plants and a lower concentration of Pb and As.

Element	Ranges of toxic concentrations in plants (ppm)
Pb	30-300
As	5-20
Hg	1-3
Zn	100-400
Cu	20-100
Mn	400-1000

Source: Kabata-Pendias (2001)

Table 10. Ranges of heavy metals reported to be toxic for plants

4.3 Implications for food security

According to the FAO (2003), **food security** exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. The very fact that new mine tailings have been found next to agricultural land in the study area should be considered as a threat to food safety. It is very important to highlight that in zones 3 and 4 the accumulation of Pb and As in plants is very high. Those metals are highly toxic and could be bioaccumulated and transferred to the food chain. This is of particular relevance because of the potential adverse effects on health and food security of people in the region. A second reason of concern is the high levels of Mn, Zn and Cu found both in soils and plants. It should be noted that Cu and Zn are not considered toxic for humans but are toxic for plants and for this reason some countries have posed restrictions to their concentrations in soil. This is of particular relevance because a higher concentration of

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these elements hinders the development of plants and could reduce land productivity and access to food.

5. Conclusions

The aim of this research was to provide an assessment of heavy metal contamination in five agricultural zones of the Guadalupe municipality in Zacatecas, Mexico. High levels of arsenic, lead and mercury contamination in agricultural soil were found in two irrigation zones. High levels of Zn and Cu were found both in soils and plants in all the areas. Heavy metal absorption in maize plants aimed for human consumption was calculated using the bioconcentration and the translocation factors. The accumulation of Pb and As in plants was very high. Those metals are highly toxic and could be bioaccumulated and transferred to the food chain. Further, high levels of Zn and Cu were found both in soils and plants. Although they are not considered toxic for humans, they are toxic for plants. Several studies have found that high concentrations of these elements hinder the development of plants and could reduce land productivity. A strong and positive correlation of concentration of arsenic and lead in soil suggests that there is a common source of such contaminants. In several areas of Zacatecas state mining activities (some of them using cianuration) and tailing reprocessing activities are currently being developed. It was found that new mine tailings in the area are recklessly managed and there is an alarming lack of enforcement mechanisms to oblige the mining companies to obey the environmental laws and regulations. Those new tailings are undoubtedly a source of heavy metal contamination of the neighbouring agricultural land. This should be considered as a threat to health and food safety of the people in the region. Considering the high concentration levels found for arsenic, lead and mercury in soils of two irrigation zones of Guadalupe, mitigation activities should be implemented. Respiratory and ingestion routes are the most important sources of heavy metal exposure. There is an urgent need to conduct more research on potentially contaminated agricultural areas. Further health and environmental risk assessments should be promptly conducted in the region.

6. Aknowledgements

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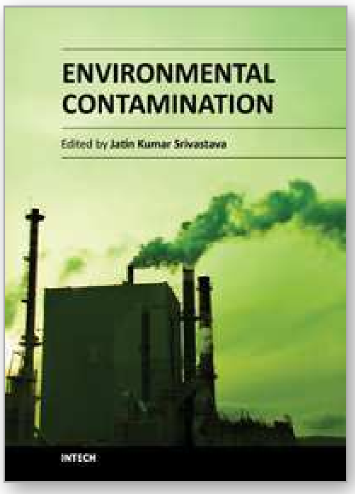

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Nature minimizes the hazards, while man maximizes them. This is not an assumption, but a basic idea of the findings of scientists from all over the world. The last two centuries have witnessed the indiscriminate development and overexploitation of natural resources by man causing alterations and impairment of our own environment. Environmental contamination is the result of the irrational use of resources at the wrong place and at the wrong time. Environmental contamination has changed the lifestyle of people virtually all over the world, and has reduced the extent of life on earth. Today, we are bound to compromises with such environmental conditions, which was not anticipated for the sustenance of humanity and other life forms. Let us find out the problem and its management within this book.

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