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Notes

Arsenic and mercury in the landscape of an historic mining zone in Eastern Michoacán, Mexico

Arsénico y mercurio en el paisaje de una zona minera histórica en el oriente de Michoacán, México

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Abstract

Mining has negative effects during all the stages of the processes involved and at all ecological levels, all of which frequently cause harm to local communities. One negative effect of particular concern is the entry of heavy metals into trophic nets in mining areas, because of this is important to quantify their presence because of mining activities. The mining district of Tlalpujahua y El Oro has a mining history of more than 400 years, which ended more than 60 years ago. In this district, one method that was employed to process the minerals was flotation by mercury. Because of this, we studied its presence in water samples of Tlalpujahua. The results from sampling diverse water sources of the town indicate that mercury and arsenic concentrations are below the detection limit or below the limit established by the applicable norm. With these results and those of former studies, and environmental management proposal is made for reducing the risks to the population caused by the presence of mercury in the landscape.

Keywords: Heavy metals, contamination, mining waste.

Resumen

Las actividades mineras tienen efectos negativos en sus diferentes tiempos de actividad y en todos los niveles ecológicos, lo que en muchas ocasiones perjudica a las poblaciones aledañas. Uno de esos efectos negativos es el ingreso de metales pesados a las redes tróficas en las regiones mineras, por lo que es importante cuantificar su presencia como resultado de la actividad minera. El distrito minero de Tlalpujahua y El Oro tiene una historia de más de 400 años, que cesó hace más de 60 años. En este distrito, uno de los métodos utilizados para el beneficio del mineral fue el de flotación de mercurio. Por lo anterior, en este estudio se cuantificó dicho metal en muestras de agua de Tlalpujahua. Los resultados obtenidos del muestreo realizado en diversas fuentes de agua de la población indican que las concentraciones de mercurio (Hg) y arsénico (As) se encontraron por debajo del límite de detección o por debajo de la norma. Con los resultados obtenidos y los de estudios anteriores se hace una propuesta de manejo ambiental para reducir los riesgos derivados de la presencia de mercurio en el paisaje.

Palabras clave: metales pesados, contaminación, residuos mineros.

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Introduction

The exploitation of mineral deposits causes considerable damage to ecosystems. For example, in Mexico during 2012, reports indicate that an area of 30,872,574 hectares is affected by mining, from exploration to extraction of minerals, this represents close to 15 % of the territory of the country (Servicio Geológico Mexicano 2013).

Each stage of the mining process causes different environmental impacts, such as the alteration and destruction of habitats, destruction and fragmentation of vegetation cover, displacement of animal populations, and in some cases bioaccumulation of pollutants (Roberts & Johnson, 1978; Pratas, Prasad, Freitas, & Conde, 2005). Other consequences are eutrophication of water bodies, reduction in nutrients availability in the substrate and pollution of hydrological systems (Corona-Chávez, Uribe-Salas, Razo-Pérez, & Martínez-Medina, 2010; Corona-Chávez, Uribe-Salas, Razo-Pérez, & Martínez-Medina, 2017). Also, topographic alterations that result from mining increase erosion, slope instability, and accumulation of residues (Bradshaw 1997; Cortinas-de-Nava, 2008).

Mine deposits ("jales" in Spanish) that results from the process of extraction of metals (such as gold, silver, copper, and zinc), for the ore, usually contain potentially toxic elements sucj¿h as mercury (Hg), arsenic (As), cadmium (Cd), lead (Pb), copper (Cu) and zinc (Zn) (Romero, Armienta, & González-Hernández, 2007). Therefore, the main problem associated with these deposits is toxic drainage and the dispersion of the contaminants through runoff (Martin & Gutiérrez, 2010) polluting soils, water bodies and in some cases the aquifer (Armienta & Segovia, 2008; Jung, 2001; Lin, 1997; Johnson *et al*., 2003; Moncur, Ptaceka, Blowesa, & Jamborc, 2005).

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Tlalpujahua, Michoacán, is located in the central-West region of Mexico and is an area with a long mining history of more than 400 years. All this activity has created a landscape of mine deposits that have partially recovered a vegetation cover after almost 60 years of the end of mining operations (Corona-Chávez *et al*., 2010). The discovery of gold and silver deposits occurred in 1558. Initially, to extract these metals from the ore mercury was used in an amalgamation process, that was introduced into America in the XVI century. This methos was used in Tlalpujahua mining district for 352 years, from 1554 to (Lacerda 1997; Martínez-Medina 2009a). In 1897 the method based on cyanide extraction was introduced (McArthur Forrest process) initially for extracting gold from the amalgamation process but by 1906 all extraction was done through the new process (Uribe-Salas, 2006; Uribe-Salas, 2008). The mercury-polluted residues from these processes accumulated near the mines. Also, the rocks naturally contain high concentrations of arsenic and consequently, mine deposits contain between 3.0 to 83.9 ppm of this element (Corona-Chávez *et al.,* 2017). Mine deposits have been a constant risk for the local population, in May 27, 1937, a mine deposit collapsed, more than 300 people were killed, and pollutants were dispersed in the landscape (Macías *et al*., 2015).

Furthermore, mine deposits have lost close to 35 % of their volume through erosion (Martínez Medina, 2009b; Corona Chávez *et al*., 2010). Nowadays, people live and practice agriculture on mine deposits, in particular, maize is cultivated. In a previous study, we detected mercury in different plant tissues from different sites within the mining district (Osuna-Vallejo, Sáenz-Romero, Escalera-Vázquez, De-la-Barrera,

& Lindig-Cisneros, 2019). Results indicate that the high concentration of mercury occurs in wood (13.84 ± 3.88 ppm) from trees growing in the mine deposits, plants in forests close to the deposits show low concentrations that range from 2.2 to 4.3 ppm.

One native tree, *Juniperus deppeana,* showed the highest concentration of mercury when growing in mine deposits (16.05 ± 2.3 ppm). Mayze seeds from plants cultivated in mine deposits had concentrations of 2.2 ± 0.34 ppm (Figure 1).

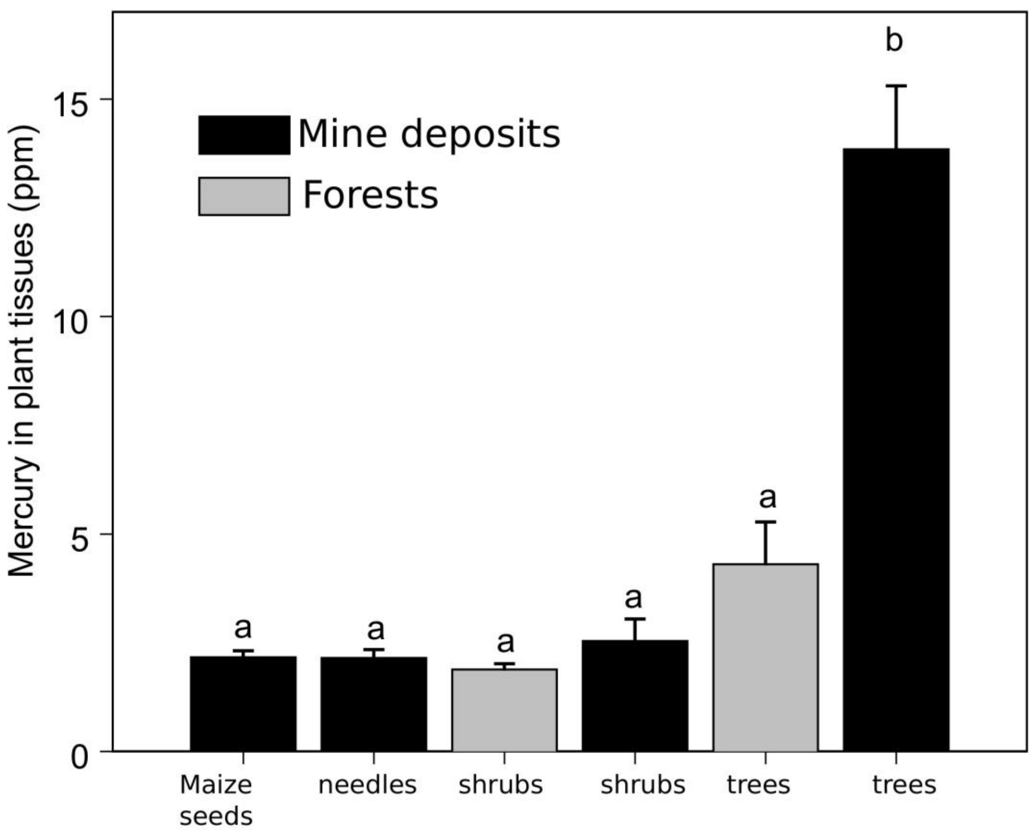

Figure 1. Mercury in plant tissues from mine deposits and surrounding forests.

Finally, it has been reported that the mine deposits of Tlalpujahua do not produce acid drainage (Corona-Chávez *et al*., 2010), and for this reason, heavy metals are not dispersed and their bioavailability is low, but as already mentioned, there is some mobility through the tropic network (Osuna-Vallejo, Sáenz-Romero, Villegas, & Lindig-Cisneros, 2017). Therefore, water analysis was carried out to evaluate potential exposure to mercury and arsenic.

Methods

Samples were collected from November 16 to 20 of 2019, from 25 sites in Tlalpujahua in collaboration with the local water authority (Organismo Operador de Agua Potable de Tlalpujahua) including the wells that provide water for the population. Sampling was done by certified technicians of CONAGUA (the federal water authority) following the procedure of the Mexican norm NOM-230-SSA1-2002. Field parameters were recorded (pH, conductivity, salinity, and REDOX potential) with Hydrolab equipment, model DS-5. Each sampling site was georeferenced with a GARMIN GPS.

Samples were analyzed in the Water Quality Laboratory of the Balsas Watershed of CONAGUA, in the city of Cuernavaca, Morelos State. This laboratory is certified by the Mexican Certification Entity and complies with the norm NMX-AA-051-SCFI-2001 for quantified heavy metals through atomic absorption (the equipment used was Perkin Elmer FIAS 100). In total, three deep wells, 1 storage tank, 2 springs, 1 waterhole, 2 points at the Tlalpujahua river, 2 water intakes near the abandoned mine, and 14 household intakes were sampled (Figure 2).

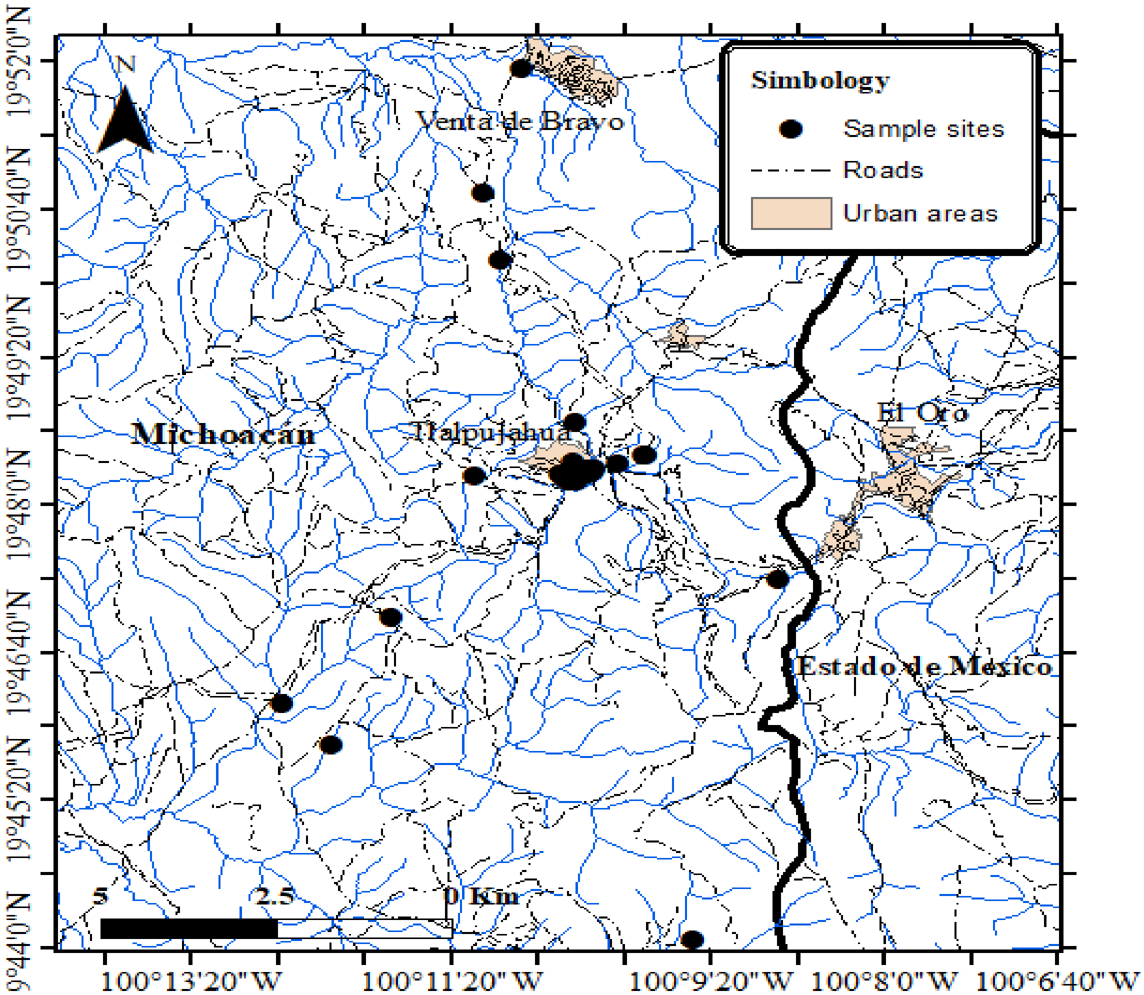

Figure 2. Water sampling points in Tlalpujahua.

Results

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Analyses results shown in Table 1 indicate that the concentrations of mercury and arsenic from the samples of deep wells used from human consumption are below the limit established by the Mexican norm NOM-127-SSA1-1994 (1996) of 0.025 ppm for As and 0.001 ppm for Hg.

Table 1. Hg and As concentrations at sampling points and parameters determined in the field (November 16-20, 2019).

Sample	**Hg mg/l**	**As**	**pH (UpH)**	**C.E. (μS/cm)**	**Salinity**	**O.D. (mg/l)**	**Latitude**	**Length**
Household intake 1	< 0.001	< 0.002	8.05	216	0.1	5.22	19.8066	-100.1732
Household intake 2	< 0.001	< 0.002	8.41	178	0.08	7.06	19.8053	-100.1735
Household intake 5	< 0.001	< 0.002	6.5	278	0.13	6.9	19.8054	-100.1715
Household intake 6	< 0.001	< 0.002	7.55	755	0.39	4.16	19.8054	-100.1715
Household intake 7	< 0.001	< 0.002	6.5	439	0.22	7.44	19.8063	-100.1676
Household intake 8	< 0.001	< 0.002	7	882	0.46	6.57	19.8077	-100.1643
Spring Ramon Rayon	< 0.001	< 0.002	7.5	1034	0.54	3.57	19.8076	-100.1639
Water Well Venta de	< 0.001	< 0.002	7.83	439	0.22	5.83	19.8659	-100.1800

Bravo								
Water tank campo del Gallo	< 0.001	< 0.002	7.01	440	0.22	5.36	19.8044	-100.1858
Water Well La Estigia	< 0.001	< 0.002	7.01	377	0.19	5.3	19.7703	-100.2106
Water Well San Isidro	< 0.001	0.063 ± 0.0005	7.13	352	0.12	-	19.7638	-100.2044
Spring Chichije	< 0.001	< 0.002	8.05	61.9	0.02	7.5	19.7831	-100.1967
Water hole	< 0.001	< 0.002	7.43	238	0.11	6.58	19.8471	-100.1848
Tlalpujahua River 1	< 0.001	0.064 ± 0.0005	7.75	1046	0.55	7.66	19.8369	-100.1825
Tlalpuja-hua River 2	< 0.001	< 0.002	7.78	300.3	0.15	4.74	19.7890	-100.1470
Aportador Mina Dos Estrellas	< 0.001	< 0.002	7.77	1825	0.97	6.34	19.8004	-100.0761
Los Cedros	< 0.001	0.0751 ± 0.0024	7.48	1864	0.99	4.46	19.7346	-100.1579
Household intake 9	< 0.001	< 0.002	7.3	173	0.08	6.83	19.8047	-100.1749
Household intake 10	< 0.001	< 0.002	7.96	245	0.12	6.94	19.8038	-100.1738
Household intake 11	< 0.001	< 0.002	7.91	216	0.1	6.53	19.8038	-100.1728

Household intake 12	< 0.001	< 0.002	7.19	72.8	0.15	6.8	19.8125	-100.1729
Household intake 13	< 0.001	< 0.002	7.12	233	0.11	6.98	19.8043	-100.1743
Household intake 14	< 0.001	< 0.002	7.47	181	0.08	7.29	19.8056	-100.1707

Samples from the river Tlalpujahua are below the limit established by the Mexican Criteria for Water Quality (CE-CCA-001/89) when considering the criteria for agricultural use that establishes a maximum for arsenic of 0.1 ppm, mercury is not regulated for this use. Following quality control standards, control samples of distilled water were handled in the same ways as the water samples from the sampling points. Each is considered as the reference value for each site, therefore, samples that have the same concentration as the control are considered as “non-detectable”. The value for arsenic was <0.0020 mg/l and for mercury < 0.0010 mg/l. Only three sites showed detectable concentrations of arsenic:

- Tlalpujahua River: As 0.0064 mg/l
- Los Cedros: As 0.0751 mg/l
- Water Well San Isidro: As 0.0063 mg/l

But the values for Río Tlalpujahua and Los Cedros are below the limit established by the norm CE-CCA-001/89 for agricultural use.

Furthermore, a sample downstream of Los Cedros (aportador de la Mina Dos Estrellas) had a non-detectable value for arsenic. The well "San Isidro" also was below the limit following the norm NOM-127-SSA1-1994 (0.025 mg/l).

Discussion and recommendation for management

The results of the current study and those of the previous study concerning mercury in vegetation (Osuna-Vallejo *et al*., 2019) indicate that this metal is present in the environment of Tlalpujahua and that the physical and chemical properties of the mine deposits make its mobilization difficult because it is mostly absent in water sources. Growing corn in mine deposits needs to be avoided because mercury was present in high concentrations in seeds (Osuna-Vallejo *et al*., 2019). The fact that trees, in particular *Junίperus deppeana*, accumulate mercury allows proposing the use of tree species to sequester this metal and keep it as much as possible out of the trophic web (Cunningham, Berti, & Huang, 1995; Wong, 2003; Petruzzelli, Pedron, Rosellini, & Barbafieri, 2013). Arsenic, which is a natural constituent of local rocks is also present in very low concentrations in the water below what the

Mexican norms establish as safe. It is known that mining activities can cause arsenic to pollute water sources (Armienta & Segovia, 2008) and in some regions of Mexico overexplotation of aquifers has increased the concentration of this element in the water (Martínez-Rodríguez, Faz-Contreras, Rivera-González, Núñez-Hernández, & De-Paul-Alvarez-Reyna, 2006; Salas-Escageda, Salas-Plata-Mendoza, Sanín, & Dena-Ornelas, 2015). Based on these facts, we propose that in the mining district of Tlalpujahua and el Oro cultivation of maize should be avoided, as well as other agricultural activities, to reduce the risk for the local population of consuming mercury and that reforestation is necessary.

In a restoration trial, it was determined that two species *Pinus pseudostrobus* y *Pinus devoniana* had the highest growth rates and that *Juníperus deppeana* had the highest survival (96 %). *Pinus devoniana* is not currently present in Tlalpujahua, it is present at lower altitudes in the watershed, but its use must be a strategy for facing climate change. At the landscape scale (Figure 3) we propose the establishment of plantations for biosequestration in mine deposits and to limit agricultural practices to areas far from them. Also, restoration of forests to increase aquifer recovery and reduce the risk of contamination by arsenic that has been observed in other sites in the country as a result of overuse of the aquifers.

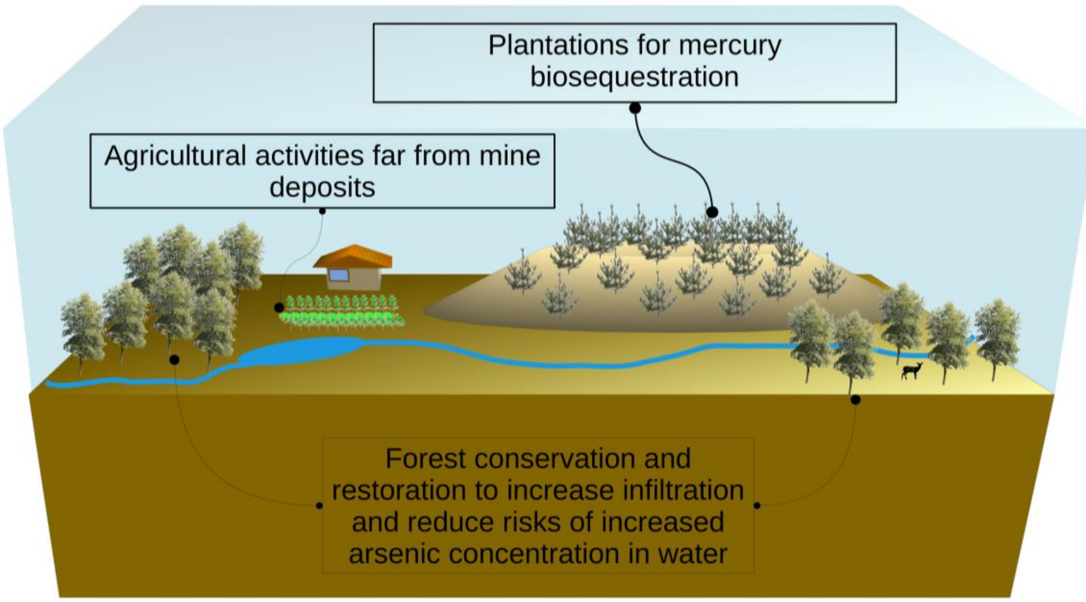

Figure 3. Landscape-level proposed management of the mining district of Tlalpujahua and el Oro to reduce the risk of exposure to mercury and arsenic to the population.

As for the pH results at the sampling sites, everything is within the permissible ranges in the Official Mexican Standard PROY NOM-250-SSA1-2014.

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