Pollution of Water for Domestic Use and Human Consumption, by Heavy Metals Pb, Cd, Cr, Zn and As, Derived from Mining Activity in Hidalgo Del Parral, Chihuahua, Mexico

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ABSTRACT

Research was done with the objective of evaluating the quality of the water supplied to the potable water system in Hidalgo Del Parral, which comes from two main supply sources: wells from Valle del Verano, which provide water to the east side of the city, and the Water Treatment Plant, which receives water from different mines and supplies the west side of the city. When this plant is overcome on its capacity of treatment, a part of the water from the mines is fed directly to the northwest part of the city. The metals lead (Pb), chromium (Cr), cadmium (Cd), zinc (Zn), and arsenic (As) were analyzed by atomic absorption (AA) technique, based in the United States Environmental Protection Agency (EPA) Method 7000B (Revision 2, February 2007). The digestion process was done according to the guidelines established in Method NMX-AA-051-SCFI-2001, Analysis of Water-Determination of Metals by Atomic Absorption, developed by the National Standardization Technical Committee for Environmental Protection (Mexico). The samples were collected from the following points: 13 wells and 2 re-pumping stations of Valle del Verano, the inlet and outlet of the Water Treatment Plant and domestic faucets. The east side of the city, supplied by the wells of El Verano, is metal-pollution free. The water that comes from the mines contains high concentrations of As, Zn, Cd and Pb, with levels that can get to 0.12, 32.6, 0.26 and 3.5 mg/L, respectively. This water pollution generated by mining can be concluded from the high levels found in the domestic samples in which, for several points, the concentrations exceed the parameters set by the current guideline. According to the results, it is vital to set a plan of remediation for the water that comes from the mines, because there is a great risk for health in the consumption of this water.

INTRODUCTION

Hidalgo del Parral Chihuahua is located at 26.9324 degrees north latitude and105.6661 west longitude in the southern part of the State of Chihuahua, northern Mexico. The climate of the area is classified as semi-humid and warm with temperatures ranging between 32^{o}C and -12^{o}C with a rain fall of 450 mm per year on average [1].

The water pollution in this area began with the Industrial Revolution [2], creating problems on quality as well as the amount of available water [3, 4]. The efforts to eliminate the anthropogenic pollutants have not been able to adjust to the increasing rhythm of production of industrial waste and demographic explosion, which has induced the transformation of the oceans', lakes' and rivers' water into deposits of waste matter, resulting in a severe natural imbalance [5, 6].

The soil of Parral contains vetiform mineralized structures whose origin is hydrothermal with north – south general orientation, related to normal faults, where the mineral stones are galena, sphalerite and chalcopyrite with important amounts of gold (Au), silver (Ag), lead (Pb), zinc (Zn) and copper (Cu).

The mining represented, for over three centuries, one of the most important sources for the economic development of this area, creating significant amounts of waste derived from the very process, with a high content of heavy metals. Tailing deposits are extremely toxic for living creatures and they also act as inhibitor of ecological factors, affecting the growth of plants and the ecosystem life.

Heavy metals cannot be naturally eliminated from the aquatic ecosystems because they are not biodegradable [7]. They also are indicators of the ecological quality of the whole water flow due to their toxicity and especially to their bio-accumulative behavior [8, 9].

The Environmental Protection Agency (EPA) of the United States of America includes elements such as Cr, As, Co, Ni, Cu, Zn, Ag, Cd, Ti, Se and Pb in a group of metals that potentially represent a risk to human health in specific concentrations, or combined with other elements or environment factors. The metals accumulated on the surface of the soil are slowly reduced by lixiviation, plants consumption and erosion. These processes can result in pollution to the aquifer, health risk to humans through ingestion of polluted food, and decreasing air quality due to the presence of heavy metals eroded from the tailing deposits which become airborne and transport to different points away from the source. This phenomenon may overstate the problem by having a greater area of impact
Near the deposits, the concentrations of the metals and other products of mines can be rather high[10]. Gutiérrez-Ruiz *et al.* (2007) reported values of Cu, As, and Ba up to 2,415 mg/kg, 3,281 mg/kg, and 586 mg/kg respectively, in the mining zone of Santa Barbara Chihuahua. However, the concentrations of these metals in shallow underground water were under the permissible limits for human consumption water. According to Klaasen and Watkins III explanation, [11] metals are naturally distributed into the environment by both biological and geological cycles.

Given that there is a great amount of tailings in the research area, which can lead to health problems in high concentrations, it was decided that the analysis of the concentrations of As, Cd, Cr, Pb and Zn in the different sources was necessary.

EXPERIMENTAL METHODS

Sampling Plan

Using the zones established by the Junta Municipal de Agua (ZA1, ZA2 and ZA3) and the water sources as references, samples were taken from the following points:

- 13 Wells and 2 points of re-pumping of Valle del Verano, which feed the east side of the city (ZA3)
- Water of the mines at the inlet and outlet flow of the water treatment plant, which feed the west part of the city.(ZA2)
- Storage Tank Vésper, which feeds the north side of the city (ZA1)

Figures 1 and 2 show the city divided into the three zones as well as the wells of El Verano. In addition, different samples from domestic faucets were taken in order to evaluate the quality of the water that goes to the population in each one of the distribution zones; including the wells inside the city which sell bottled water. The distribution map of the sampling points and wells of the city are shown in Figure 3.

Figure 1. Delimitation of the water distribution zones in Parral.

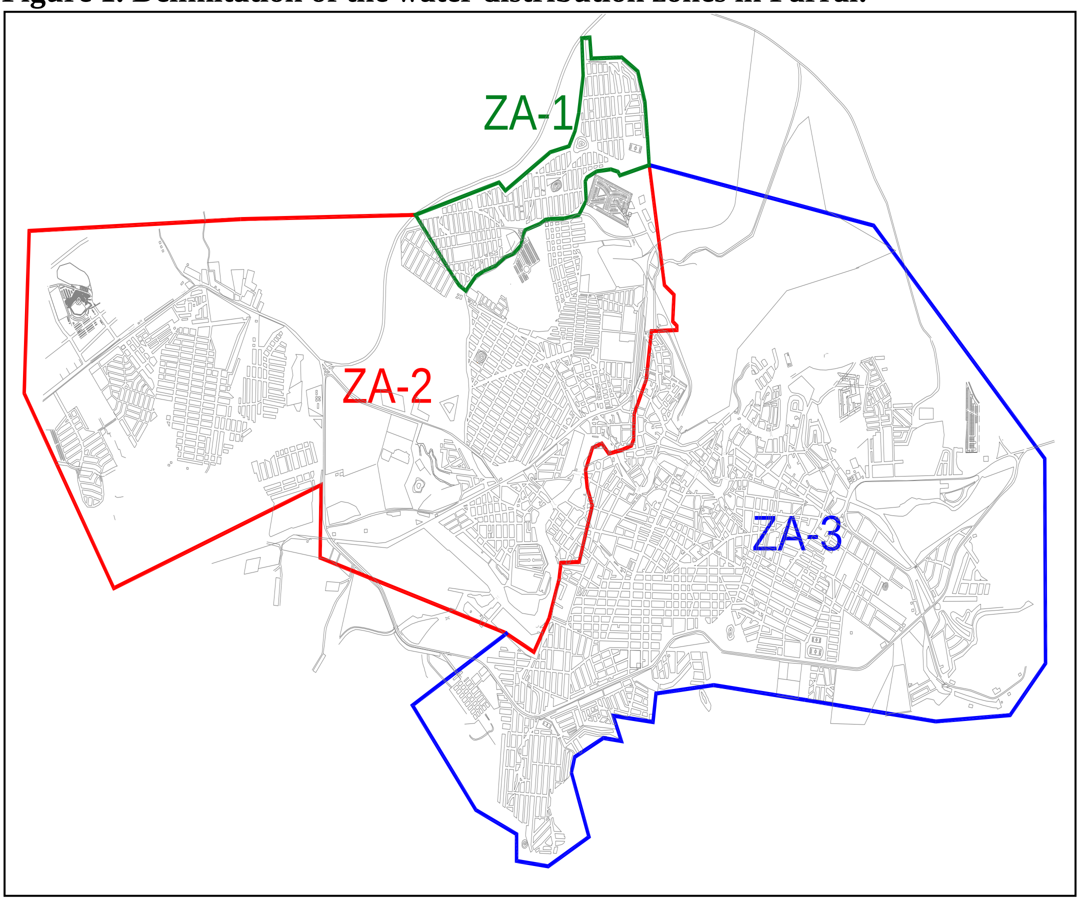


Figure 2. General description of the water supply system in Hidalgo del Parral.

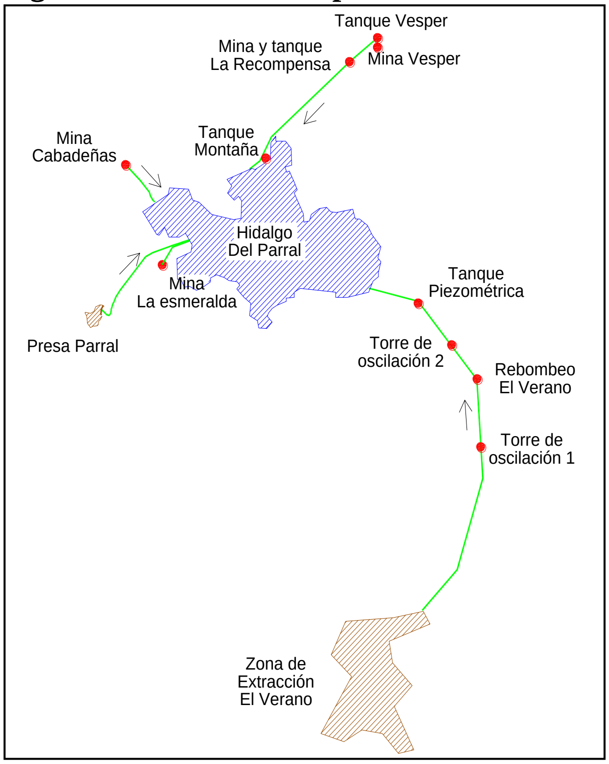
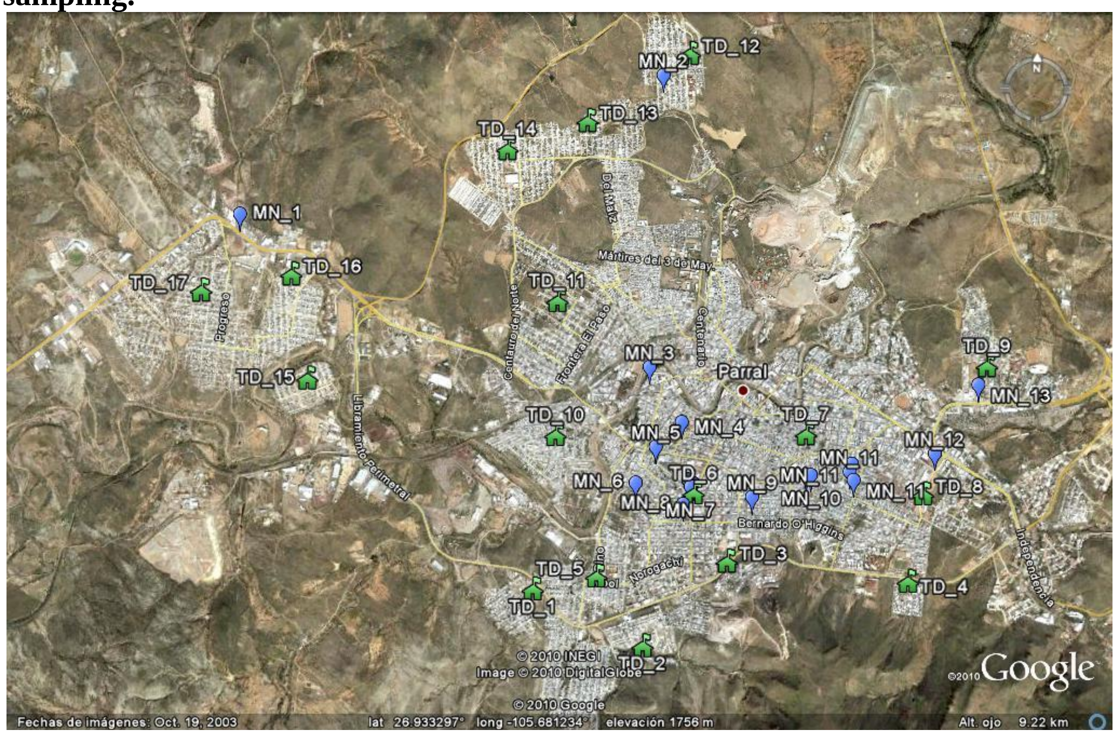


Figure 3. Monitoring points for domestic faucets and wells located within the urban area sampling.



*TD: Domestic Faucets (Tomas Tomiciliares); *MN: Wells located within the urban area (Muestras en Norias)

The volume of our samples was of 1 liter (L); they were preserved with nitric acid within a pH < 2 and stored in refrigeration, according to the guidelines established in the NOM-051-SCFI-2001.

Determination of the Concentrations of Heavy Metals in Water

Laboratory tests were conducted in Atomic Absorption Spectrophotometer GBC brand, model Avanta Σ. Digestion and sample preparation were performed according to the specifications of the standard NMX-AA-051-SCFI-2001, and the analysis of the concentrations was based on EPA Method 7000B-2007. The results of the readings of the samples were compared with the permissible limits established in NOM-127-SSA1-1994, to gauge the potential damage to health.

RESULTS

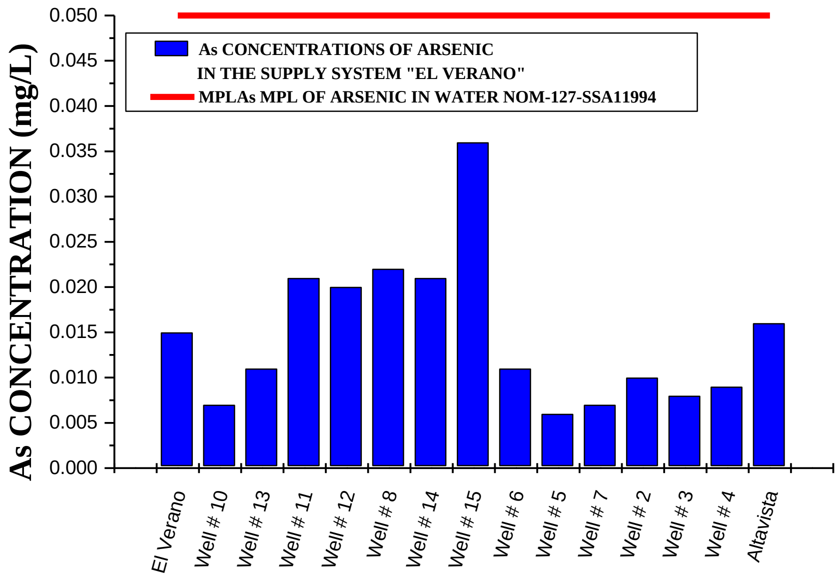
Heavy Metals in Wells from Valle del Verano

Table 1 summarizes the monitoring sites and heavy metals results in wells from Valle del Verano investigated in this study. Figure 4 graphically depicts the arsenic results.

Table 1. Identification of monitoring sites and concentration levels of heavy metals in wells from Valle del Verano.

Sampling Site	ID Site	Location		Height (masl)	As (mg/L)	Zn (mg/L)	Cd (mg/L)	Cr (mg/L)	Pb (mg/L)
		LON	LAT						
El Verano Repumping	1A	-105.6054	26.8945	1808	0.015	ND	ND	ND	ND
Well # 10	2A	-105.324	26.8223	1734	0.007	0.3	ND	ND	ND
Well # 13	3A	-105.6347	26.802	1749	0.011	3.666	ND	ND	ND
Well # 11	4A	-105.641	26.7907	1760	0.021	ND	ND	ND	ND
Well # 12	5A	-105.6404	26.786	1752	0.02	ND	ND	ND	ND
Well # 8	6A	-105.6465	26.79	1759	0.022	ND	ND	ND	ND
Well # 14	7A	-105.656	26.7983	1769	0.021	ND	ND	ND	ND
Well # 15	8A	-105.6614	26.795	1768	0.036	ND	ND	ND	ND
Well # 6	9A	-105.6395	26.8004	1754	0.011	ND	ND	ND	ND
Well # 5	10A	-105.644	26.8207	1748	0.006	ND	ND	ND	ND
Well # 7	11A	-105.3504	26.615	1759	0.007	0.22	ND	ND	ND
Well # 2	12A	-105.6487	26.8043	1751	0.01	ND	ND	ND	ND
Well # 3	13A	-105.6437	26.8083	1755	0.008	ND	ND	ND	ND
Well # 4	14A	-105.6384	26.8129	1763	0.009	ND	ND	ND	ND
Repumping Altavista	15A	-105.6694	26.9191	1785	0.016	ND	ND	ND	ND

Figure 4. Arsenic concentration in samples taken from the supply system "El Verano"



Heavy Metals in Domestic Faucets

Table 2 summarizes the monitoring sites and heavy metals results from domestic faucets investigated in this study. Figures 5, 6, 7, and 8 graphically depict the arsenic, zinc, cadmium, and lead results, respectively.

Table 2. Identification of monitoring site and concentration levels of heavy metals in domestic faucets.

Sampling Site	ID Site	Location		As (mg/L)	Zn (mg/L)	Cd (mg/L)	Cr (mg/L)	Pb (mg/L)
		LON	LAT					
Miguel Hidalgo	TD-1	-105.6837	26.9152	0.019	ND	ND	ND	ND
Ampliación Juárez	TD-2	-105.6737	26.9135	0.021	ND	ND	ND	ND
Bella Vista	TD-3	-105.6673	26.92	0.017	ND	ND	ND	ND
Cerro Blanco	TD-4	-105.6537	26.9188	0.015	ND	ND	ND	ND
Juárez	TD-5	-105.6765	26.9185	0.017	3.23	ND	ND	ND
Alta Vista	TD-6	-105.669	26.9225	0.016	ND	ND	ND	ND
Conejo	TD-7	-105.6613	26.9289	0.012	1.064	ND	ND	ND
Kennedy	TD-8	-105.6529	26.9233	0.015	0.25	ND	ND	ND
Tecnológico	TD-9	-105.6453	26.9329	0.017	ND	ND	ND	ND
La Peña	TD-10	-105.684	26.928	ND	9.13	0.066	ND	0.208
Loma linda-Progreso-Potrero	TD-11	-105.6791	26.9356	ND	8.552	0.06	ND	0.214

Montañas	TD-12	-105.6709	26.9536	0.104	0.436	ND	ND	ND
Heroes 1	TD-13	-105.6781	26.9489	0.061	0.985	ND	ND	ND
Heroes 2	TD-14	-105.6848	26.9499	ND	8.92	0.05	ND	ND
Tierra y Libertad	TD-15	-105.7017	26.9313	ND	7.788	0.056	ND	ND
UACH	TD-16	-105.6988	26.9392	0.018	7.664	0.048	ND	0.424
PRI	TD-17	-105.7034	26.9348	ND	5.478	0.038	ND	ND

Figure 5. Arsenic concentrations in samples taken from domestic faucets

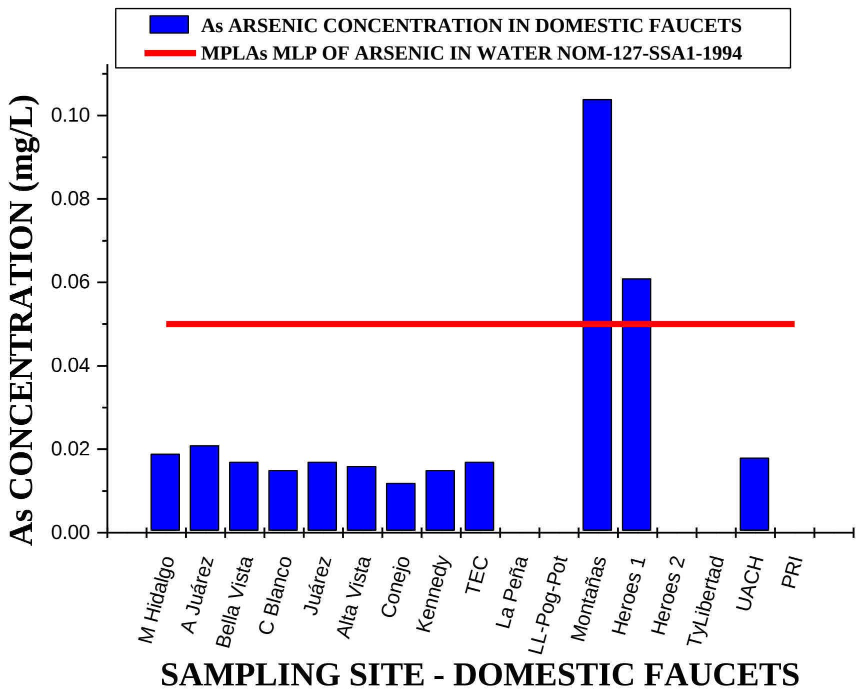


Figure 6. Zinc concentrations in samples taken from domestic faucets.

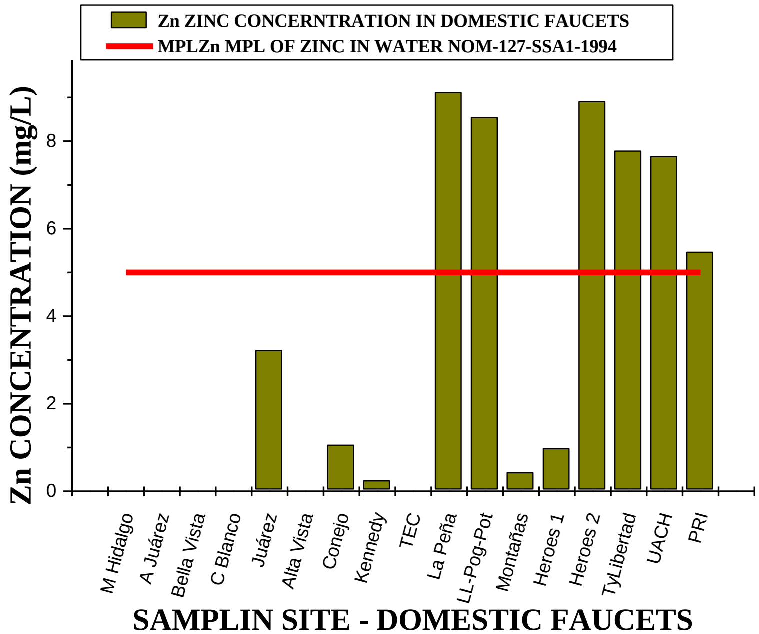


Figure 7. **Cadmiun concentrations in samples taken from domestic faucets.**

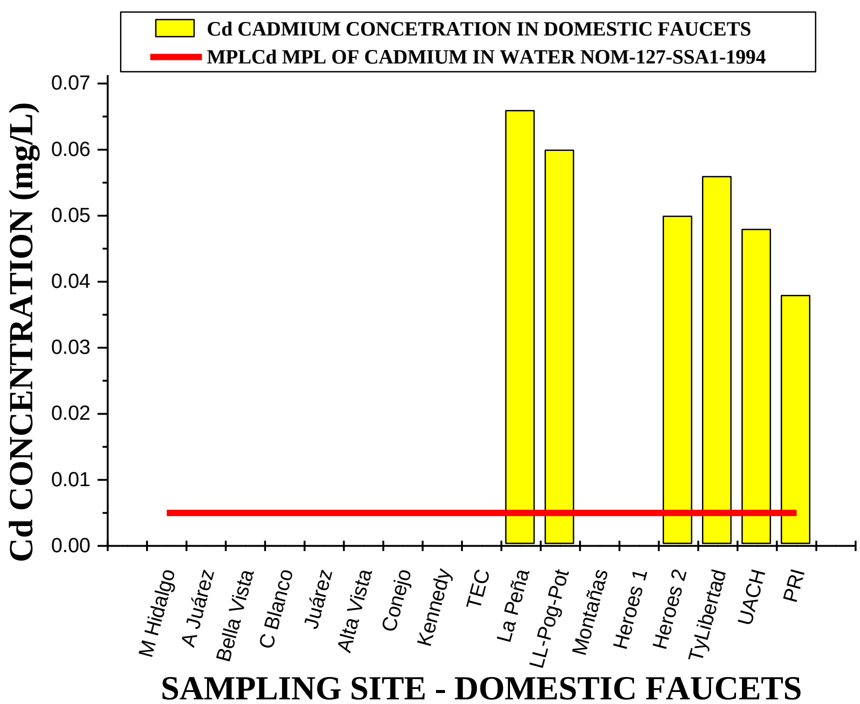
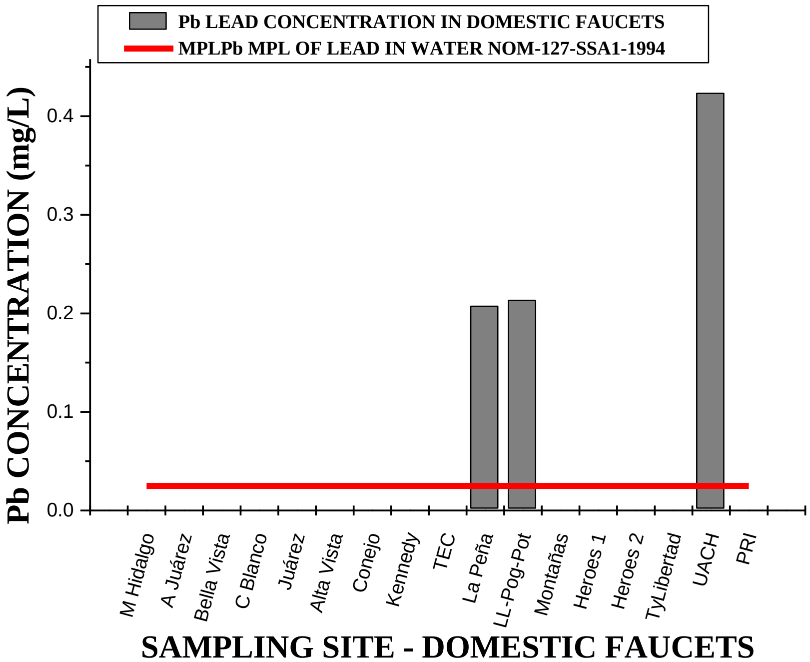


Figure 8. Lead concentrations in samples taken from domestic faucets.



Heavy Metals in City Wells

Table 3 summarizes the monitoring sites and heavy metals results from City wells investigated in this study. Figures 9, 10, and 11 graphically depict the arsenic, zinc, and cadmium results, respectively.

Table 3. Identification of monitoring sites and concentration levels of heavy metals in City wells.

Sampling Site	ID Site	Location		As (mg/L)	Zn (mg/L)	Cd (mg/L)	Cr (mg/L)	Pb (mg/L)
		LON	LAT					
Pureza	MN-02	-105.6540	26.9243	ND	ND	ND	ND	ND
JV	MN-03	-105.6739	26.9327	ND	ND	ND	ND	ND
Los Ángeles	MN-05	-105.6738	26.9272	ND	ND	ND	ND	ND
Hermanos Ruíz	MN-06	-105.6764	26.9243	ND	4.095	0.022	ND	ND
Diamante	MN-07	-105.6705	26.9247	0.02	ND	ND	ND	ND
San José del Parral	MN-08	-105.6715	26.9231	ND	ND	ND	ND	ND
San Gabriel	MN-09	-105.6676	26.9236	ND	ND	ND	ND	ND
Brisa	MN-10	-105.6537	26.9229	ND	ND	ND	ND	ND
Jazmin	MN-11	-105.6533	26.9241	0.017	ND	ND	ND	ND
Los Arcos	MN-12	-105.6531	26.9279	ND	ND	ND	ND	ND
Clarissima	MN-13	-105.6467	26.9316	0.012	ND	ND	ND	ND

Figure 9. Arsenic concentrations in wells in the City.

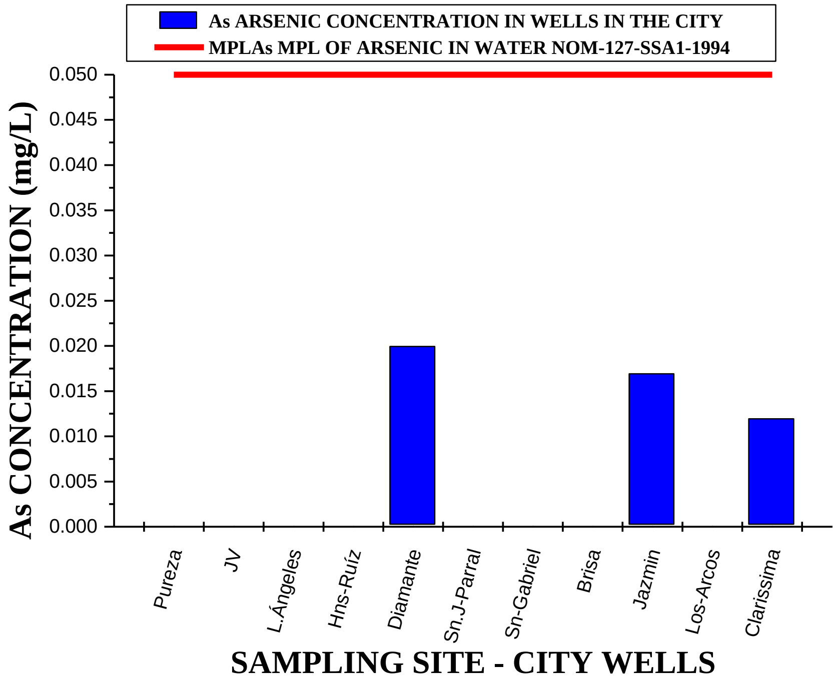


Figure 10. Zinc concentrations in wells in the City.

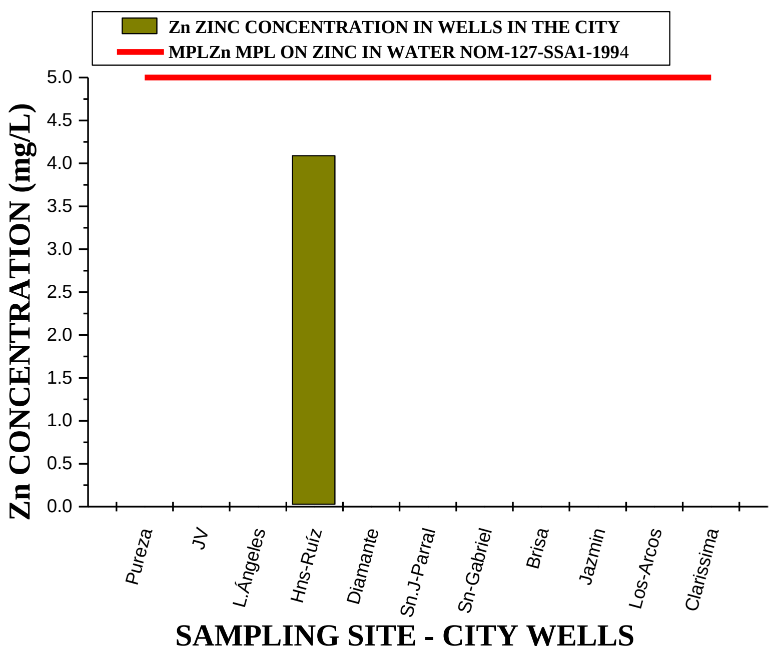
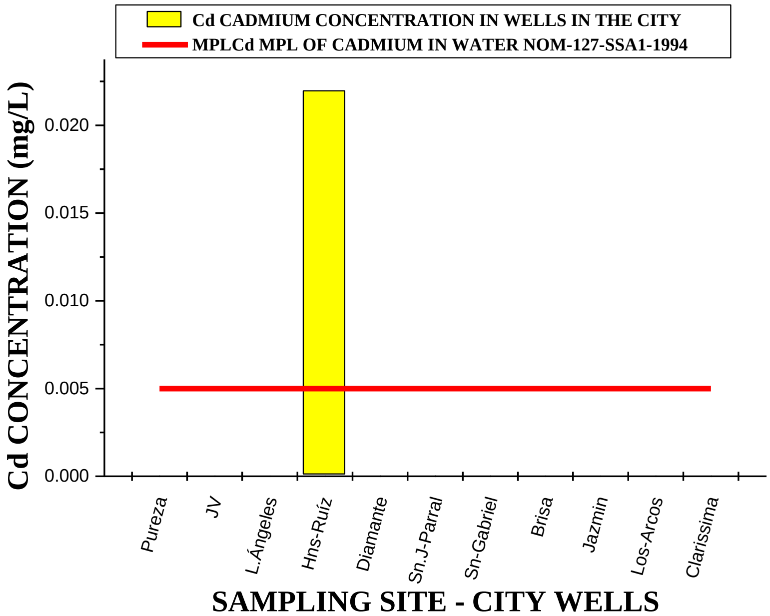


Figure 11. Cadmium concentrations in wells in the City.



Heavy Metals in the Water Treatment Plant and Mines of the Area of Study

Table 4 summarizes the monitoring sites and heavy metals results from the Water Treatment Plant and mines of the area of study. Figures 12, 13, 14, and 15 graphically depict the arsenic, zinc, cadmium, and lead results, respectively. Tables 5, 6, and 7 show calculation results for estimated human doses.

Table 4. Identification of monitoring sites and concentration levels of heavy metals in the Water Treatment Plant and mines of the area of study.

Sampling Site	ID Site	Location		As (mg/L)	Zn (mg/L)	Cd (mg/L)	Cr (mg/L)	Pb (mg/L)
		LON	LAT					
Potabilizadora (Esmeralda Mine)	16A	-105.6886	26.932	ND	32.61	0.159	ND	0.317
Cabadeña Mine	17A	-105.7224	26.9519	ND	3.502	0.05	ND	3.502
Veta Colorada Mine	18A	-105.7283	26.9919	0.025	ND	0.02	ND	ND
Arbolito Mine	19A	-105.7096	26.9536	0.014	0.248	ND	ND	0.248
Recompensa Mine	20A	-105.6492	26.9814	0.095	ND	ND	ND	ND
Vesper Mine	21A	-105.6491	26.9814	0.028	0.832	0.26	ND	0.832
Entrance to Water Treatmente (Arbolito & Cabadeña Mines	22A	-105.6889	26.9324	ND	1.334	0.03	ND	0.21
Out of the Water Treatment Plant	23A	-105.6889	26.9317	0.004	8.28	0.054	ND	ND

Figure 12. Arsenic concentrations in water from mines and from Water Treatment Plant

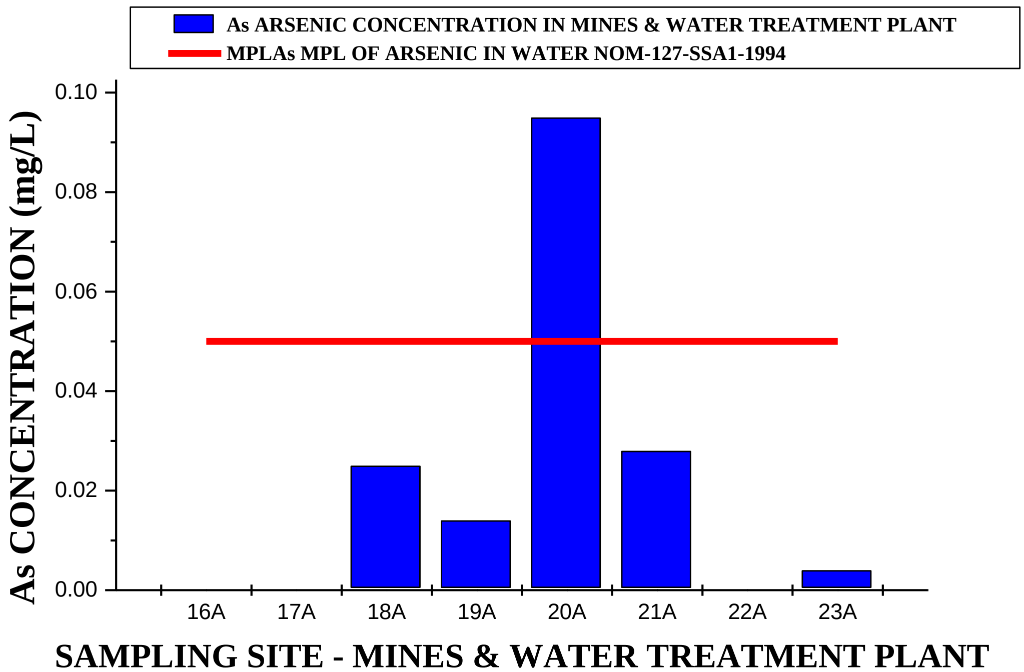


Figure 13. Zinc concentrations in water from mines and from Water Treatment Plant

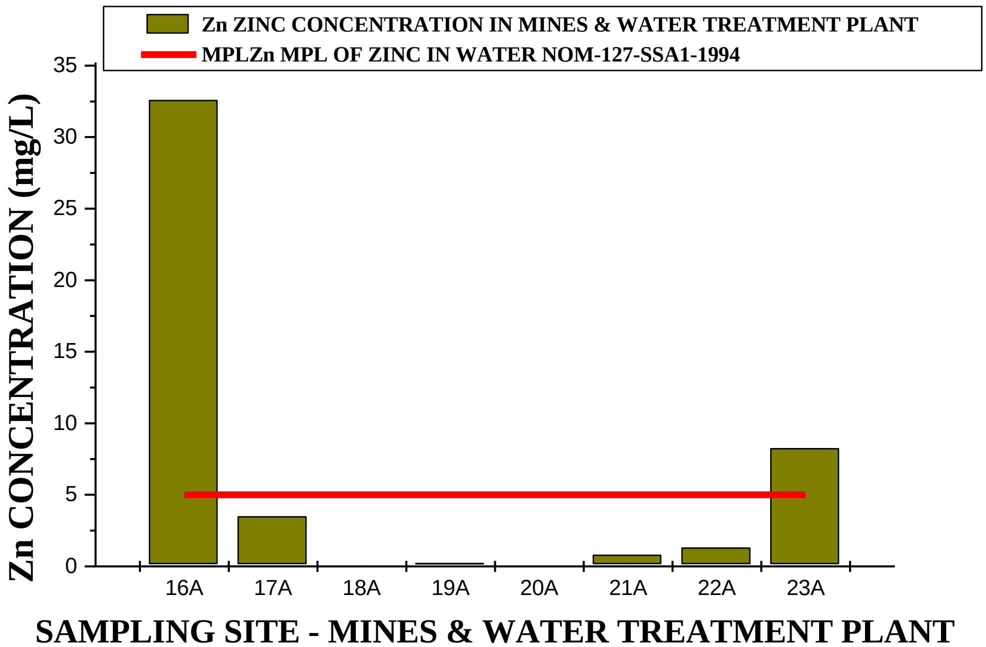


Figure 14. Cadmium concentrations in water from mines and from Water Treatment Plant

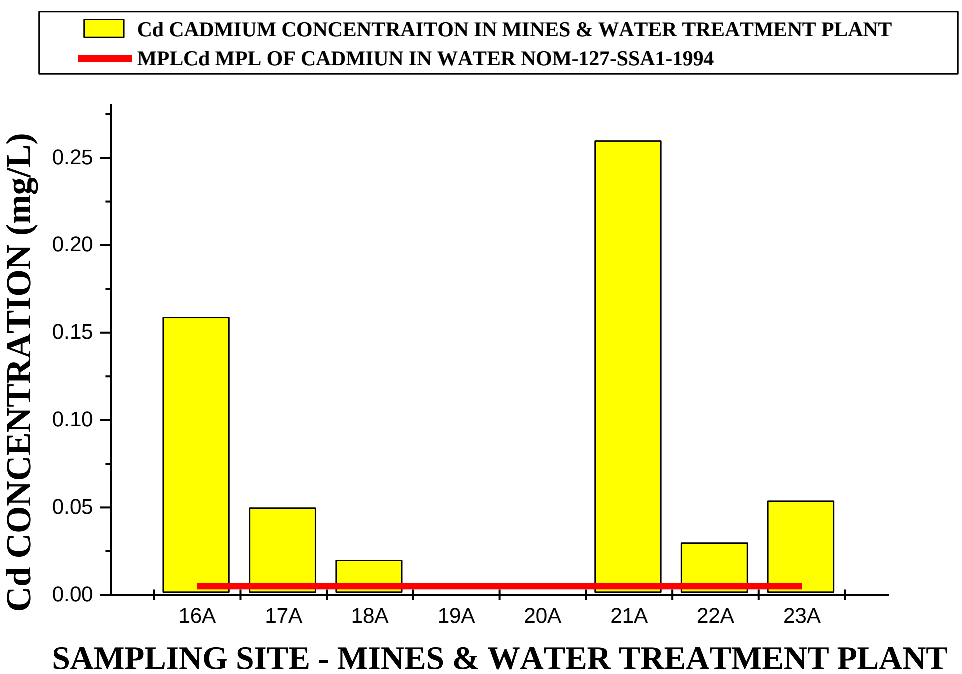


Figure 15. Lead concentrations in water from mines and from Water Treatment Plant (*NOTE: Please refer to Table 4 for identification of the sampling sites in Figures 12 through 15*)

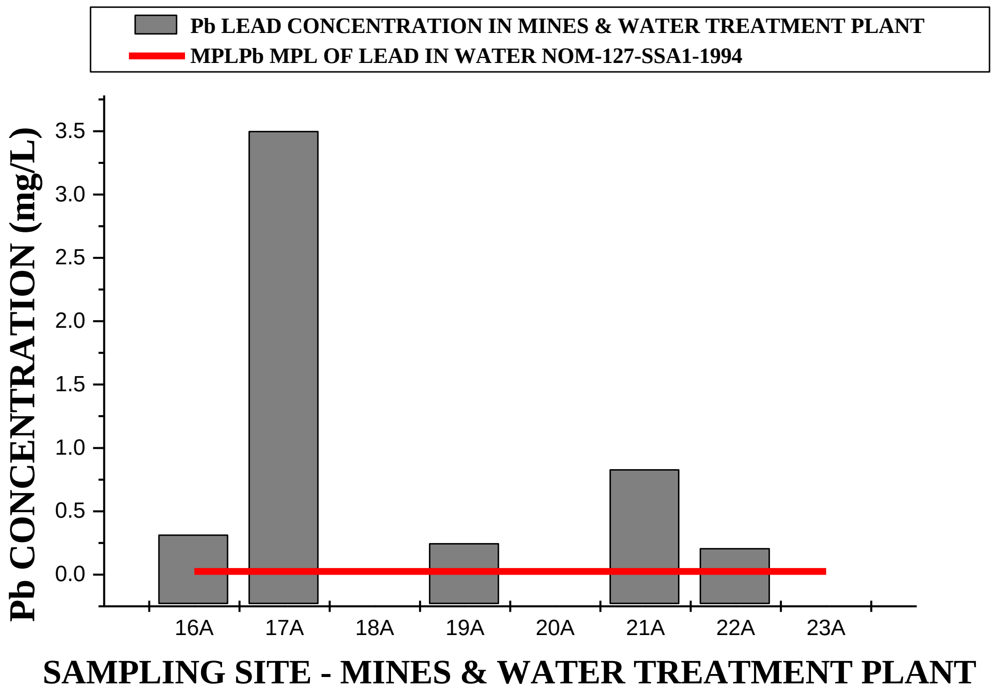


Table 5. Calculation of the estimated intake dose (ED) for the output of the Water Treatment Plant.

		CONC SITE 23A (mg/L)	ED ADULT 75Kg (mg/Kg)	ED CHILD 25Kg (mg/Kg)
OUTPUT FROM WATER TREATMENT PLANT.	Arsenic	0.004	5.33E-05	0.00008
	Zinc	8.28	0.213	0.319
	Cadmium	0.054	0.001	0.002
	Chromium	0	0	0
	Plomo	0	0	0

Table 6. Calculation of the estimated intake dose (ED) for Repumping Altavista.

		CONC SITE 15A (mg/L)	ED ADULT 75 Kg (mg/Kg)	ED CHILD 25 Kg (mg/Kg)
REPUMPING ALTAVISTA	Arsenic	0.016	0.0004	0.0006
	Zinc	0	0	0
	Cadmium	0	0	0
	Chromium	0	0	0
	Lead	0	0	0

Table 7. Calculation of the estimated intake dose (ED) for Recompensa Mine.

		CONC SITE 20A (mg/L)	ED ADULT 75 Kg (mg/Kg)	ED CHILD 25 Kg (mg/Kg)
RECOMPENSA MINE	Arsenic	0.095	0.0014	0.0021
	Zinc	0	0	0
	Cadmium	0	0	0
	Chromium	0	0	0
	Lead	0	0	0

DISCUSSION

The concentration of heavy metals Cd, Pb and Zn in the west side of Parral is above the permissible limit established by current regulations, reaching values up to 0.26 mg / L for cadmium, 3502 mg/ L for lead and 32.61 mg / L for zinc.

Arsenic in the west side is beyond the permissible limit in 1 of 8 analyzed sources, corresponding to the storage tank Vesper, representing 12.5% of total samples in that area.
In the east side, which is served by water wells from Valle del Verano; all the analyzed parameters are within the limits set by current standards for drinking water.
The wells located within the urban area that distribute drinking water are also within permissible limits on the content of heavy metals established by national and international standards.

In order for water to be considered potable, in terms of arsenic content, it cannot deliver a higher dose than 0.0003 mg / kg / day (* Agency for Toxic Substances and Disease Registry (ATSDR), (U.S. Department of Health and Human Services). However, a dose up to 0.00128 mg / kg / day calculated for an average weight of 75 kg was identified from domestic faucets supplied by the water treatment plant. In homes whose source is the storage tank Vesper, the exposure dose of arsenic was calculated to be 0.0022 mg / kg / day. These results indicate that the water treatment process conducted in the water treatment plant does not eliminate heavy metals in the water that comes from the mines.

In the east side, although the source has a concentration of arsenic within the acceptable limits, when calculating the dose per exposure in the residential area, it reaches a maximum of 0.00056 mg / kg / day, which may affect human health.

The estimated intake dose for the different samples and analyzed metals shows a water pollution problem that may pose a long-term health risk for population.

Zinc that was found in the domestic faucets of the east area can be derived from a process of wear and corrosion of repumping systems.

The water treatment plant receives water from various mines and Dam Parral. This allows a dilution process that attenuates the concentrations of heavy metals coming out from the water treatment plant, so that in dry seasons, this process of dilution is decreased by the low supply volumes from the dam, increasing the concentrations of heavy metals in the water supplied to the western part of the city.

The importance of heavy metals is their high persistence and bioaccumulation within living organisms. These effects are difficult to detect in the short term.

SUMMARY

The study for the diagnosis of heavy metals contamination resulting from mining activities in the water supplies for domestic use and human consumption to the population of Hidalgo del Parral was completed. The results show a potential risk to health in the north and west portions of the city, as long as significant concentrations of heavy metals such as lead, arsenic, cadmium and zinc were detected. The estimates of effective doses from the concentrations found in the samples collected are important indicators that require further research to give greater certainty and allow sizing, with greater support, the problem of water pollution by heavy metals in Parral, in order to establish plans and programs for mitigation or remediation to improve the life quality and expectancy of the population and its environment.

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