Determination of risk of mine tailings from a mine in the state of Durango, Mexico

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Abstract

Mining in Mexico has been practiced since the pre-Hispanic era, this being an important engine in the development of the economy of this country. In the refining processes of minerals, millions of tons of waste known as tailings are produced, which are deposited in the open and the refining process can be a health hazard and the system for the presents of Potentially Toxic Elements (EPT). The objective of this work was to determine if the tailings of the Cerro de Mercado mine represent a risk to health workers using a computer package and finding that the population close to the mine is not in danger.

Introduction

In Mexico due to mining activity there are hundreds of millions of tons of waste, which are known as tailings, these are produced during the processes of metal recovery (Megchún, 2014). The inadequate handling and disposal of these wastes, together with the climatic conditions of the site, have caused them to disperse and mobilize in a large urban and rural area. Originating problems of soil contamination by heavy metals such as: lead, zinc and cadmium, arsenic, selenium, antimony; mainly (Urbano et al., 2007).

The inadequate handling of these materials can have the consequence of contaminating soils and bodies of water in the surroundings, either as a result of unexpected events that cause their accidental dumping or their continuous release into the environment. This can be considered as a potential danger, not only for the flora and fauna of the region, but also for the human population (Alvarádo & Volke, 2004).

The potentially toxic elements (PTE) commonly reported in the mine tailings, iron, zinc and copper are essential in the composition or functioning of living organisms, but in high concentrations they can cause adverse effects. In contrast, arsenic, cadmium and lead, together with mercury, are recognized as the most toxic chemical elements in nature (Gutiérrez et al., 2007).

State of Durango (figure 1) is traditionally mining, developing this activity since pre-Columbian times. Iron deposit was discovered by Ginés Vázquez de Mercado in 1552 and the exploitation of deposit began in 19 century. Actually Cerro de Mercado mine extracts 1200 ton per day of iron using methods such as flotation and magnetic concentration (SGM, 2017)

Figure 1. State of Durango in México

Tailings dam Boleo Estrella is part of Cerro de Mercado mine, which is located in the center of Durango City, México. Dam Boleo Estrella has 15 year out of operation and an area of 162000 m^2, a deep of 80 meters and amount of 3700000 tons of tailings.

Urban development program of Durango mentions that Cerro de Mercado contaminates the population through the emission of reddish dust from the exploitation of iron ore which, due to the wind, falls on nearby houses, causing health problems.

Objetive

Investigate the inherent risk of tailings in the Cerro de Mercado mine, Durango, Mexico.

Metodologhy

Initially, the Boleo Estrella" tailings dam was sampled from the Cerro de Mercado mine, Durango, Mexico, based in Mexican standard NMX-AA-132-SCFI-2006, obtaining 27 samples (figure 2).

Figure 2. Sampling points at the Boleo Estrella dam

Characterization of the samples it was made using X ray fluorescence through US-EPA 6200 method. To determine if the tailings are generating acid mine drainage (DAM) the acid-base balance test established in NOM-141-SEMARNAT-2003 was carried out, moreover pH of the samples was determinated using Mexican standard NMX-AA-25-1984.

To analyze the health risk of people close to the mine due to the tailings of the Boleo Estrella dam, the software "Spatial Analysis of Decision Assistance (SADA)" was used.

Results

In the Boleo Estrella dam there was presence of insects such as; ants, spiders and woodlice as well as lot of vegetation (figure 3).

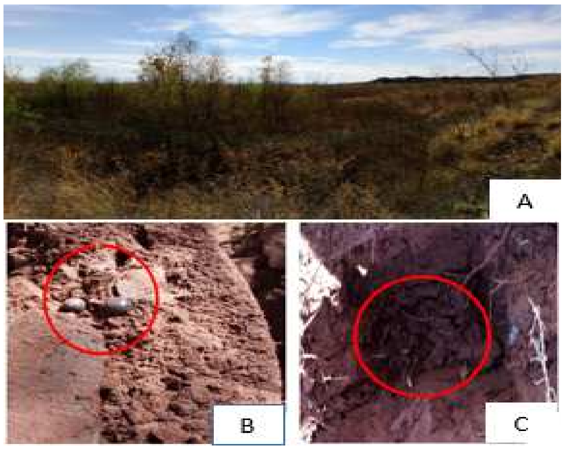


Figure 3. A) Vegetation B) Woodlice C) spider

The X-ray fluorescence analysis showed the presence of the following metals; Zr, Sr, Rb, As, Zn, Cu, Mn, Ti, Fe, Ni, Cr, V, Ba, Sb and Ca in tailings samples (figure 4). Chromium and antimony were found to be above the maximum permissible limit established by NOM-157-SEMARNAT-2009; 100 mg / kg for chromium and 10 mg / kg for antimony.

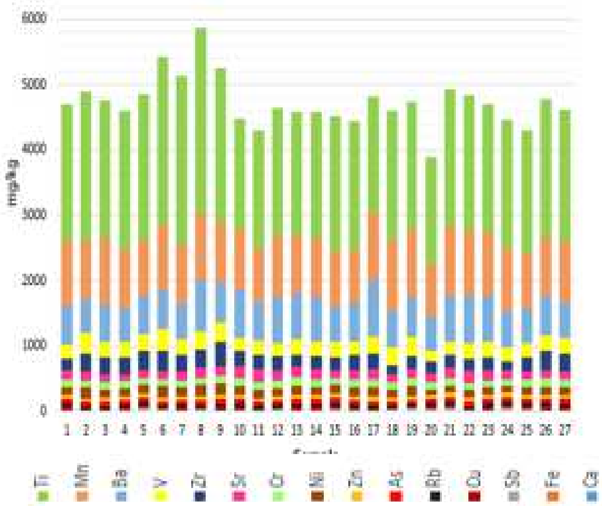


Figure 4. Elements presents in tailings

Chromium can be harmful to health according to its oxidation state (Severiche & González, 2013), to know the oxidation of this metal the NOM-147-SEMARNAT / SSA1-2004 was used. Finding that this element is found primarily as Cr^{3+}.

Zayed and Terry (2001) mention that in soils the chromium is generally in the Cr^{3+} state and under reducing conditions the Cr^{6+} can be reduced to $^{Cr3+}$, likewise the reduction of the Cr^{6+} is pH dependent, probably at low values of pH.

Adriano (2001) describes that the most important reducing agent in the soil is organic matter, in well aerated soils oxygen acts as the strongest electron acceptor followed by Fe^{2+} and sulfides. The Boleo Estrella tail dam had a large amount of organic matter which results in intense vegetation and various insect species such as those described above. According to what was reported by Adriano (2001) and Zayed and Terry (2003) it is expected that the chromium species present in the tailings dam will be the reduced (Cr^{3+}) (in the first 30 cm).

The pH of samples was determinated using the Mexican Standard NMX-AA-25-1985. The results are shown in figure 5.

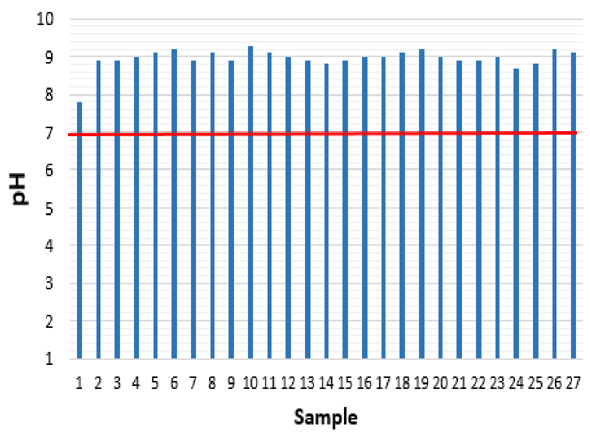
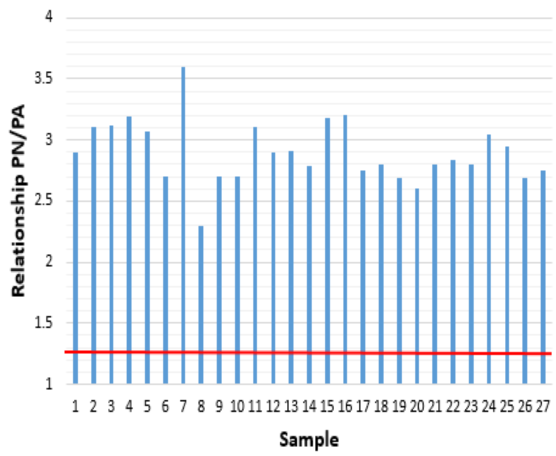


Figure 4. pH of the samples

According to Morint and Huntt (2001) the classification of drainages as a function of pH is for the case of the Boleo Estrella dam "almost neutral", which ranges from pH values of 6 to 9 or 10. For all samples the pH values are between 7 and 9, which would indicate that we are facing a type of alkaline drainage. Aduvire (2006) mentions that although it is not frequent, alkaline waters in some cases can be as harmful as acid waters.

Based on the analysis of neutralization potential (PN) and acidity potential (PA), it was obtained that the ratio of PN / PA> 1.2 (Figure 5) therefore according to NOM-141-SEMARNAT-2003, the tailings of the mine of Cerro de Mercado are not potentially generators of mine acid drainage.



Risk Determination

Initially, to know the risk to which the population surrounding the Cero de Mercado mine is exposed, the SADA software was used, taking into account a recreational scenario, in which the exposure to children and adults who spend a limited amount of time in near the site while doing outdoor activities.

The recreational use scenario is also known as the intruder or visitor site. It was considered that of the five scenarios this is the most appropriate to carry out the risk calculations since the Boleo Estrella tailings dam is close to the population and since it is an old dam the tailings present in it are dry, so they disperse easily by action of air to the population surrounding the mine.

The values fed to the software were the concentrations of metals such as: antimony, arsenic, barium, chromium (III), strontium, manganese, nickel, vanadium and zinc obtained by the X-ray fluorescence technique, besides that these were the elements with counted the SADA database.

The exposure parameters of the selected scenario used by SADA as exposure times for child and adult, life time etc. are shown in figure 6, a lifetime of 74

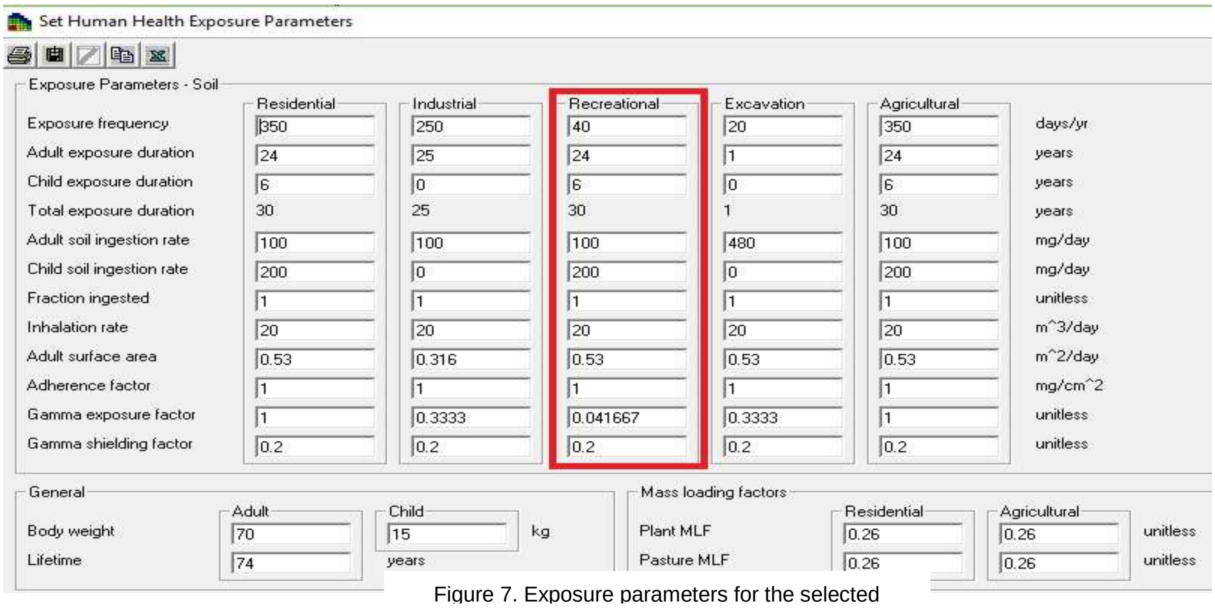


Figure 7. Exposure parameters for the selected

life time etc. are shown in figure 6, a lifetime of 74 years was used (INEGI, 2016)

For the calculations the following routes were selected: ingestion, inhalation and dermal, the previous thing is observed in the figure 8

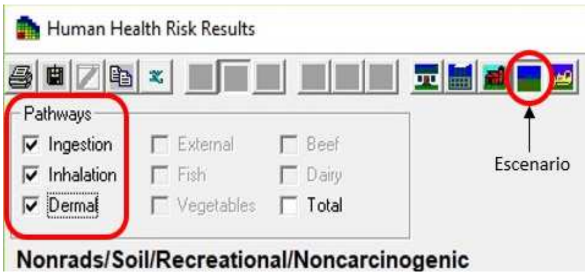


Figure 8. Pathways and scenario selected

SADA software calculates PRG (Preliminary Remediation Goals), these are the higher concentrations of a specific substance in a specific medium, in this case in soil, which guarantee the protection of health and the ecosystem. These values correspond to minimum and admissible effects in individuals that will cause minimal effects in the rest of the population or community. To perform the calculations, a hazard index (HI) of 1 was selected (figure 9) since most of the elements present in the tailings are non-carcinogenic (EPA, 2017).

Figure 9. Target risk and health index selected

An HI less than or equal to one indicates that it is not likely to experience adverse health effects from exposure to a particular chemical by all routes (inhalation, ingestion and dermal) in a given medium (water, soil, air, etc.) so the risk is negligible.

HI is used to refer the level of risk associated with the effects of non-carcinogenic substances. (EPA, 2017).

The calculations made by SADA are shown in table 1

	PRG				TCR (mg/kg)
	Intake (mg/kg)	Dermal (mg/kg)	Inhalation (mg/kg)	THI (mg/kg)	
Name	Adult	Adult	Adult	Adult	Adult
Antimony	0.0044	0.012	9.3E-7	0.0164	470
Arsenic	0.035	0.0045	-	0.0395	22
Barium	0.0015	0.0011	0.00011	0.00271	67000
Chromium III	1.2E-5	1.3E-4	1.9E-6	0.000144	1.8E+06
Strontium	3.9E-5	1E-5	-	4.9E-5	7E+05
Manganese	0.0033	0.0044	0.0016	0.0093	2.6E+04
Nickel	0.0011	2.2E-4	0.00013	0.00145	1600
Vanadium	0.0056	0.03	2.6E-5	0.0356	78
Zinc	3.2E-5	1E-5	-	0.00042	3.5E+05

In order to know if there is a risk to the adult population surrounding the Boleo Estrella tailings dam, the values of the THI columns (mg / kg) and the TRC column are compared, the data from the THI column as well as the ingestion, dermal and inhalation were the values calculated by SADA, while the values of the CRT column were obtained for the case of arsenic, barium, nickel and vanadium from Mexican Standard 157-SEMARNAT / SSA1-2004.

In which these concentrations in soil are reported as Total Reference Concentrations (TRC) and these are defined in the aforementioned standard as the mass of the regulated chemical element expressed in mg, per unit mass of the study floor, expressed in kg, above which it is considered that there is a risk of that adverse effects on health are generated. The concentrations of the remaining elements (antimony, chromium III, manganese, nickel and vanadium) were obtained from the EPA (2018).

When comparing the concentrations of each element in the THI column with their respective values in the TRC column, it is observed that the concentrations of the THI column are lower in all cases than the TRC column values, which indicates that the probability of people adults suffer from health conditions is very low for which the risk can be considered negligible (EPA, 2000).

In addition, the individual HI values for each route of exposure (ingestion, inhalation and dermal) are less than 1 in all cases, which indicates that it is very unlikely to observe health conditions of the people adjacent to the Boleo Estrella tailings dam. Whether they are exposed to any of the metals through the aforementioned exposure routes.

For the case of children, the results obtained by the software and the total reference concentrations in table 2 are shown.

Table 2. Results for children

	PRG (THQ=1)	TRC
Name	Ingestion (mg/kg)	(mg/kg)
Antimony	0.041	32
Arsenic	0.33	39
Barium	0.014	16000
Chromium III	0.00011	1.2E+05
Strontium	0.00037	47000
Manganese	0.031	1900
Nickel	0.01	1600
Vanadium	0.052	390
Zinc	0.00037	23000

Table 2 shows only one route of exposure since SADA does not have enough information and cannot calculate the missing routes. Comparing the concentration value in the route of ingestion with the CRT (EPA, 2017) (EPA, 2018) for each metal it is observed that all values are below the reference concentration so the probability of nearby children to the Boleo Estrella tailings dam they suffer health problems related to the ingestion of the metals presented in table 2, in a recreational scenario it is low so the risk can be considered negligible.

Arsenic is identified in the software database as a substance that can cause carcinogenic and non-carcinogenic effects; calculations for carcinogenic effects were selected at a risk level of 1E-6, established by the EPA (Figure 9). The results are shown in table 3.

Table 3. Results for arsenic

	PRG (Tr=1E-6)				TCR (mg/kg)
Name	Ingestion (mg/kg)	Dermal (mg/kg)	Inhalation (mg/kg)	TI (mg/kg)	
Arsenic	1.7E-5	8.2E-7	9.7E-9	**1.8E-5**	**0.68**

Table 3 shows that the IT concentration value is lower than that of CRT. Accordingly, the general population bordering the aforementioned tailings dam would not develop any type of cancer related to arsenic exposure.

The above is an approximation of the risk to which the population may be exposed, however for the analysis to be more accurate, it would be necessary to know the true exposure time of the population to the tailings of the dam under study, although there is evidence that people are in prolonged contact with the tailings of the Cerro de Mercado mine.

It is difficult to know how much of the tailings from the Boleo Estrella tailings dam are actually exposed, since the tailings of this dam were characterized, however, there is more tail dams which were not characterized however would be expected to have a similar composition since the processes of iron extraction in the mine (flotation and magnetic refining) have not changed in a long time according to the engineer in charge.

Taking into account that the extraction process has not changed and the composition of the tailings of the other dams are the same as those of the Boleo Estrella tailings dam, the risk calculation with SADA was made for a different scenario, in this case a residential scenario, in this case; long-term daily exposure is taken into account and generally result in the highest exposures and potential risks.

The exposition is calculated for a lifetime. For the calculations in the software the same parameters were used as in the recreational scenario, likewise the same parameters were used as in figure 9, and in figure 7 the parameters considered by the residential scenario are observed. The results obtained by SADA for the residential scenario are shown in table 4.

Table 4. Results for a recreational scenario

	PRG				TRC (mg/kg)
	Ingest. (mg/kg)	Dermal (mg/kg)	Inhalation (mg/kg)	THI (mg/kg)	
Name	Adult	Adult	Adult	Adult	Adult
Antimony	0.038	0.01	8.1E-6	0.048	31
Arsenic	0.31	0.039	-	0.349	22
Barium	0.013	0.0098	0.00096	0.024	67000
Chromium III	0.00011	0.0011	-	0.00121	1.8E+06
Strontium	0.00034	9.1E-5	-	0.43E-4	47000
Manganese	0.029	0.0044	0.014	0.0474	1800
Nickel	0.0097	0.0019	0.0011	0.0127	1600
Vanadium	0.049	0.26	0.00023	0.309	78
Zinc	0.00028	7.4E-5	-	0.35E-4	23000

In a different scenario such as the residential one, where the exposure time is all of life, it is observed that indeed the concentrations of each metal in each route of exposure is greater than those reported in table 1 and it is precisely due to the longer exposure time managed in this scenario that is 350 days, compared to the recreational that is 40 days.

However, as in table 1 well as in table 5, when comparing the values of THI and CRT (values obtained from 147-SEMARNAT / SSA1-2004 and EPA, 2016), it should be noted that all concentrations of the THI column they are less than the CRT, there for it is unlikely that the adult population surrounding the study site will experience adverse health effects, even if they are exposed for life to the tailings. In the case of children, the results are shown in table 6.

Table 6. Results for children in a recreational scenario.

	PRG (THQ=1)	TRC (mg/kg)
Name	Ingestion (mg/kg)	
Antimony	0.36	32
Arsenic	2.8	39
Barium	0.12	16000
Chromium III	0.00099	1.2E+05
Strontium	0.0032	47000
Manganese	0.27	1900
Nickel	0.091	1600
Vanadium	0.46	390
Zinc	0.0026	23000

The above table shows that for a prolonged exposure time, such as the residential scenario, it is not expected to observe adverse health effects due to the fact that the values of ingestion concentrations are lower than the values of CRT concentrations. Based on the above, it can be asserted that the risk of children to suffer health problems can be considered negligible.

In the case of the carcinogenic effects of arsenic the results are shown in the following table

Table 7. Results for arsenic in a recreational scenario

	PRG (TR=1E-6)				CTR (mg/kg)
Name	Ingest. (mg/kg)	Der. (mg/kg)	Inh. (mg/kg)	TI (mg/kg)	
Arsenic	1.5E-4	7.2E-6	8.5E-8	**1.6E-4**	**0.68**

As well a table 3, in table 7 the value of the TI concentration is lower than the CRT, based on this the risk that the population will develop some type of cancer due to the arsenic present in the tailings can be neglected, even when the exposure time is longer.

The use of computational software for risk analysis of health and the environment has been used by authors such as:

- Wcislo, Dlugosz, & Korcz (2005) used the NORISC software to determine the health risk due to the presence of agrochemicals in an area of Tuscany in Italy.

- Wang & Yi Hu (2012) used the GeoDetector software to investigate areas with potential health risks.

- Li et al, in 2014 with the help of Crystal ball software, determined the risk to which the population in China was exposed due to 72 mining areas.

- Miri et al. (2017) to determine the impact to health due to PM10 particles in Iran used the AirQ software.

In the previous works mentioned the importance of software in risk analysis, either to health or to the environment because they allow one to obtain an overview of the state of the contaminated site as well as the possible effects on health and the environment. These packages have multiple tools such as geographic information systems, statistical tools and, above all, they are based on the equations and parameters established by the EPA, and in some cases they are freely available.

Conclusions

The Spatial Analysis of Decision Assistance (SADA) software was used in the risk analysis of the Boleo Estrella dam. 5.0 finding that the tailings of the aforementioned dam contain potentially toxic elements such as various heavy metals, the only metals that exceeded the PML established in NOM-157 SEMARNAT-2009 were chromium and antimony. The determination of the oxidation state of chromium shows that it is less toxic state (Cr^{3+}).

According to the software calculations, the EPTs present the tailings are below the concentrations on which it would be expected to observe adverse effects to health, the aforementioned was carried out for two scenarios with different exposure times and in both it was found that the tailings do not represent a danger for the population surrounding the Cerro de Mercado mine.

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