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Environmental Hazards Associated With Mining Activities in the Vicinity of Bolivian Poopó Lake

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Abstract
Hydrographically Bolivian Poopó Lake is located in the basin of Desaguadero River and it has over a dozen main tributary rivers and other smaller rivers with lower flow. The mine water discharge from the abandoned and current mining activities polluted these rivers by carrying heavy metals, dissolved and suspended solids which in turn polluted the Poopó Lake which is considered as an important Lake in this area. The present paper deals with the environmental hazards associated with the mining activities with an objective of determining the environmental quality of the Poopó Lake and its tributary rivers, based on physical-chemical analysis of superficial water and sediment samples. The results of the research show that the Poopó Lake water quality can be classified as highly saline, containing high concentration of dissolved or suspended solid, as well arsenic, lead, cadmium, zinc and other heavy metals exceeding the permissible limits of pollutants. Desaguadero River contributed to the Poopó Lake pollution by 70% arsenic, 64% lead, 4.27% zinc and 2.18% cadmium. Other important pollution contributors are Antequera River by 57 % zinc, 32.9 % cadmium and 0.66% lead, and Huanuni River by 61.2% cadmium, 2.23% lead and 34.3% zinc. Vinto foundry, Kori kollo mine and mainly San José mine polluted the Poopó Lake by arsenic and lead through Desaguadero River. Bolivar and Huanuni mines polluted the Poopó Lake by cadmium and zinc through Antequera and Huanuni Rivers. Additionally the mining activities continue to pollute the Poopó Lake by dissolved and suspended solids transporting through Desaguadero, Antequera and Huanuni rivers.

Keywords: *Lake; mining; environmental; pollution; heavy metal; dissolved and suspended solids*.

1. Introduction

Environmental hazards to natural systems by toxic metals are a global environmental phenomenon of increasing significance [1]. Chemical data related to environmental studies of mine water and water draining into mining areas typically show extremely high values of pollutants [2]. Environmental effects of past and current mining activities are potentially important source of toxic elements (e.g. As, Ba, Cd, Cu, Pb and Zn) and could have significant impacts on the surrounding environment. The mineralogical composition of the rocks and ores is the main factor in the development of environmental pollution [3,4]. The toxic elements originating from abandoned mines can be dispersed due to mechanical and chemical weathering of mining wastes. Resolution of background concentration is especially important in highly mineralized areas, because natural weathering of metallic-ore deposits and weathering of metal-rich rocks are the primary sources of surface and groundwater contamination [5].

2. Environmental problems in South America due to mining

Numerous studies have been undertaken on metal contamination of sediments, soils, waters and plants that have occurred as a result of mining activities in various regions. To date, few research workers have investigated the environmental heritage associated with industrialization in the South American Andes. Examples are the historic environmental pollution by mining activities of de Chipian Lake (Figure 1), located near the Cerro de Pasco metallurgical region and Pirhuacocha Lake (Figure 2) and located near the Morococha mining region and the La Oroya smelting complex.

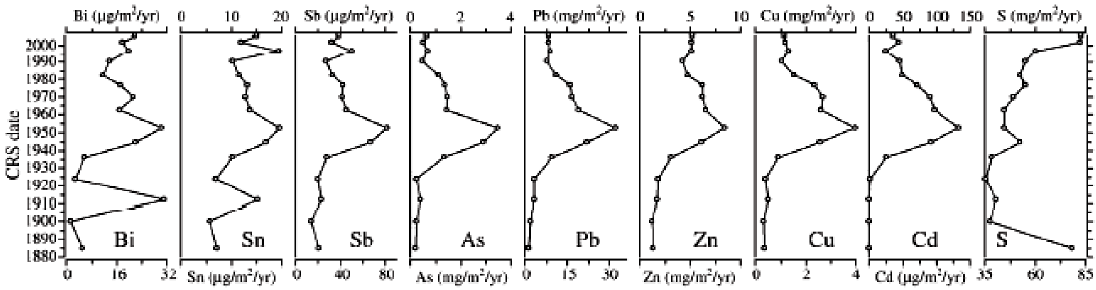

Figure 1. Historical environmental pollution by mining activities of Peruvian Chipian Lake [6]

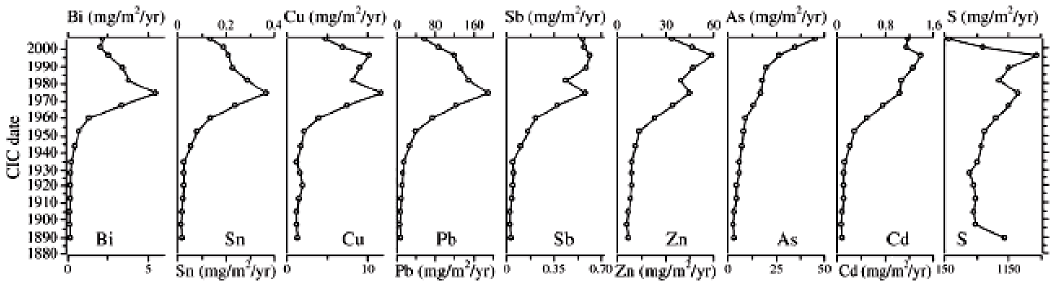

Figure 2. Historical environmental pollution by mining activities of Peruvian Piruacocha Lake [6]

The historical environmental pollution by mining activities of Pruvian Chipain Lake between 1880 and 2000 shows significant increase of Sn, Sb, As, Pb, Zn, Cu and Cd concentration and consequently environmental pollution in 1950s and 1960s (Figure 1); but in Peruvian Piruacocha Lake in the same period, increase of Bi, Cu, Pb, Sb, Zn, As, Cd and S concentration and consequently environmental pollution occurred between 1970 and 2000 (Figure 2).

Another example is the environmental impact of surrounding mining operations on Titicaca Peruvian Lake, near Poopó Bolivian Lake (Figure 3). According to a scientific study carried out by Peru's Ocean Institute Imarpe, proteins and mercury have been detected in the lake's fish. Although the quantities have yet to exceed the 0.3 mg/kg limit set by the Environmental Protection Agency (EPA), mercury even in small quantities affects people's health. Besides receiving sewage and industrial waste from the city of Puno, Lake Titicaca receives agricultural run-offs from the surrounding areas and tailings from mineral processing plants and the region's more than 30,000 informal miners. During the dry season, the Katari, Ramis, Seco, Seque, Pallina and Jalaqueri rivers deposit solids and metal contaminants [7] in the Poopó Lake.

2.1 Location of Poopó Lake

Poopó Lake, subject of the present paper, located on the Bolivian Altiplano and in the Oruro mining region, has 18º48´27"S latitude, 67º02´12"W longitude, 3686m of altitude and an area of 2378 km^2 of surface water. The Poopó Lake is part of the Titicaca Basin within the closed hydrological system of approximately 144000 Km^2 located between 3600 and 4500 m of altitude (Table 1). Within this hydrological system lie four major hydrological sub-basins: Lake Titicaca, Desaguadero River, Lake Poopó and Coipasa Salt Lake, collectively called TDPC system (Figure 3). Desaguadero River is Titicaca's only outlet that flows into Lake Poopó, creating Coipasa Salt Lake. Amongst these four sub-basins, Lake Titicaca, is the largest in South America, the highest navigable lake in the world, and, according to Inca cosmology, the origin of human life.

Table 1. Sub-basins within Titicaca Lake basin [8]

Basin		Lake	
Sub basin	Area (Km^2)	Average	Area (Km^2)
Titicaca lake (T)	56300	Altitude 3810m	8400
Desaguadero river (D)	29800	Flow 70 m^3/s	Length 398 Km
Popoo lake (P)	24800	Altitude 3686m	3191
Cipasa Salt Lake (C)	33000	Altitude 3657m	2225
TDPC system	143900		

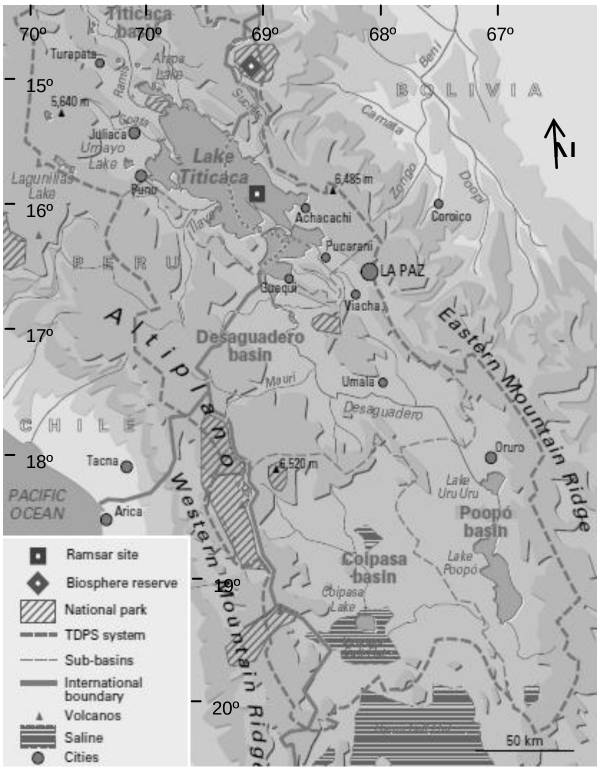

Figure 3. Poopó Lake basin within major Titicaca Lake basins [8]

3. Mathematical models

For the Lake the hydraulic balance can be described by using the following simple mathematic model:

$$Q + p = E\nu + Et + l \qquad (1)$$

where,

Q is the river contribution,

P is pluvial contribution in lake influenced area,

E_v is lake evaporation,

E_t is evapotranspiration and

L is water flow loses

For determination of heavy metal concentration in the river water, the following model is used:

where,

$$C_{mn} = \frac{C_p.Q_p + C_1.Q_1 + C_2.Q_2 + ...+ C_n.Q_n}{Q_p + Q_1 + Q_2 + ...+ Q_n} \qquad (2)$$

C_{mn} is heavy metal concentration after tributary river n,

C_p is concentration of heavy metal in principal receptor river,

C_1, C_2, ..., Cn are heavy metal concentration of 1, 2, …., n tributary rivers,

Q_p is water flow of principal river,

Q_1, Q_2, ..., Q_n are water flow are 1, 2, …, n tributary rivers.

In Equation (2) the heavy metal concentration was expressed in mg/l or ppm/l and the river's water flows in l/s. For total heavy metal or solids that contributed to Lake environmental pollution, M_c, expressed in kg/day, for each river was calculated using the Equation (3) based in heavy metal or solid concentration, C_r, expressed in mg/l and river water flow, Q_r, expressed in l/s, where r is number of each corresponding tributary river.

$$M_c = 0.0864\sum_{1}^{r} C_r.Q_r \qquad (3)$$

The chemistry of acid mine drainage, based on the oxidation of pyrites, the production of ferrous ions and subsequent conversion into ferric ions, is very complex, and this complexity has considerably inhibited the design of effective treatment options. Although a host of chemical processes contribute to acid mine drainage, pyrite oxidation is by far the greatest contributor [2, 9]. A general equation for this process is:

$$2FeS_2(s) + 7O_2(g) + 2H_2O(l) \rightarrow 2Fe^{2+}(aq) + 4SO_4^{2-}(aq) + 4H^+(aq) \quad (4)$$

The oxidation of the sulfide to sulfate solubilizes the ferrous iron (iron II), which is subsequently oxidized to ferric iron (iron III):

$$4Fe^{2+}(aq) + O_2(g) + 4H^+(aq) \rightarrow 4Fe^{3+}(aq) + 2H_2O(l) \quad (5)$$

Either of these reactions can occur spontaneously or can be catalyzed by microorganisms that derive energy from the oxidation reaction. The ferric irons produced can also oxidize additional pyrite and oxidize into ferrous ions:

$$FeS_2(s) + 14Fe^{3+}(aq) + 8H_2O(l) \rightarrow 15Fe^{2+}(aq) + 2SO_4^{2-}(aq) + 16H^+(aq) \quad (6)$$

The net effect of these reactions is to release H^+, which lowers the pH and maintains the solubility of the ferric ion [10].

4. Poopó Lake, river affluent and mining activities

4.1. General information

Historically Poopó Lake was a huge salt water Lake, geologically belonging to the superior Pleistocene age, when several glacial activities took place, which determined a progressive reduction of the Lake surface that at the beginnings of the Pleistocene Era was leveled about of 200m above the current level. The Poopó Lake, with a surface area of 3191 Km^2, is defined as the drainage area of the Desaguadero River (downstream Chuquiña). The Poopó river sub-basin is considered to be a closed basin because the Laca Hajuira river bed that takes the waters from the Poopó Lake to the Coipasa Salt Flat only flows seasonally. The annual average temperatures vary between 7.6ºC and 10.7°C and low values reach between -9ºC to -10º C and high values between 20ºC to 23ºC.

The average precipitations decrease progressively from 450mm in the northern lake and 200mm in the southern (December to March). The evaporations in the Titicaca Lake and in the southern TDPS system area are 1450mm and 1900mm respectively while the evapo-transpiration varies between 1000mm and 1500mm, respectively. The water depth of the Poopó Lake is not high, it descends towards the center of the lake, where the profundities are 2 meters.

4.2. Variation of surface of Poopo Lake

The variation of Poopó Lake area can be perceived by contrasting the satellite images which were taken on April 1990 and July 2001, See Figure 4.

The comparison of the satellite images shows the considerable decrease of the Poopó Lake area over the eleven-year period. The water surface area in 1990 was 2797.15 km^2 and that in 2001 was 2378.07 km^2 showing the reduction of Lake area of 419.08 km^2 at an average rate of 38.1 km^2/year. The summary of the hydraulic balance is presented in the Table 2.

By applying Equation (1), the hydraulic balance values, as shown in Table 2, indicate the water flow losses in Poopó Lake as 499.41×10^6 m^3.

4.3. Mining activities surrounding Poopó basin and tributary rivers

Mining activities surrounding Poopó Lake have been going on since pre-Colombian times. The mines are located along the north-eastern side of the Poopó basin, in the Eastern Cordillera.

The most important mines in Poopó basin are Bolivar and Huanuni. Bolivar underground mine is zinc, silver and lead producer and the ore deposits were discovered in the early 19th century. Huanuni mine production started in the early 20th century, with average production 6000 tons/year of tin concentrate. It is owned by a Swiss company called Sinchi Wayra and is situated in the Antequera basin, together with the Totoral and Avicaya mines. Another underground mine is San José mine, situated in north of the Poopó Lake, that has been extracting lead, silver, antimony, copper and tin minerals for many years. The San José mine has been inactive since 1992, though illegal extraction is still going on. In addition to mines, there is also a major group of foundries in the Poopó region, called Vinto foundry, situated in the north east of the basin. The main tributary rivers of Poopó Lake are Desaguadero, Márquez, Cortadera Tacagua, Juchusuma, Antequera (Pazña), Termas Pazña, Poopó, Huanuni and Tajarita (Figure 5).

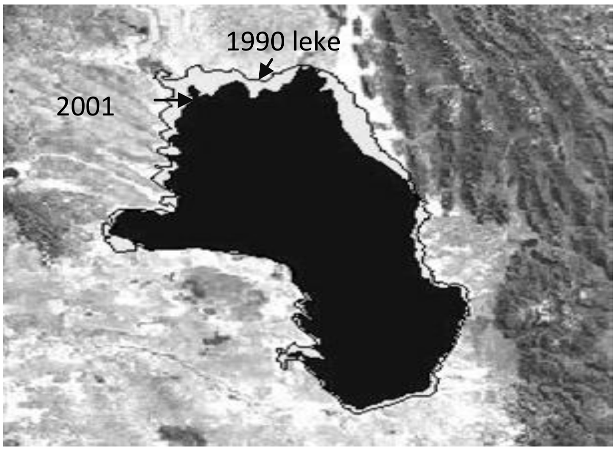

Figure 4. Variation of the Poopó Lake area over 11 years [11]

Table 2. Summary of hydraulic balance of Poopó basin

Hydric parameters	Period estimation 1990-2004	Aprox. area (km^2)	Average flow (10^6 m^3/year)
Precipitation	373.2 mm	22301.43	8322,89
Lake Evaporation	1793.71 mm	2587.61	4641.42
Evapotranspiration $Coef_{eiC}$=0.20	310 mm	19713.82	6111.28
Flow of the inflows	92.885 m^3/seg		2929.22

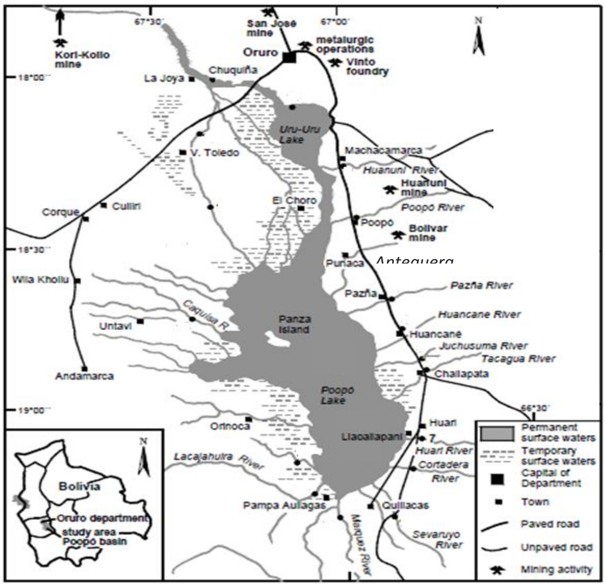

Figure 5. Poopó Lake, rivers and surrounding past and present mining activities [12]

4.4. Monitoring and assessment method

The monitoring of the Poopó Lake and its tributary rivers was made in four different climatic seasons: wet, semi wet, dry and semi dry. In each of the sampling points (Figure 6), water and sediment samples were taken.

5. Monitoring, physical and chemical analysis results

The following acronyms are used in figures and tables of this section: RMA-Márquez river; RSE-Sevaruyo river; RCO-Cortadera river; RTA-Tacagua river; RJU- Juchusuma river; RAN-Antequera (Pazña) river; TPA-Termas Pazña river; RPO-Poopó river; RHU-Huanuni (Machacamarca Bridge) river; RD1-Desaguadero (Karasilla Bridge) river; RD2-Desaguadero (Aroma Bridge) river; and TJ-Tajarita (Español Bridge) river.

5.1 Physical and chemical water quality of Poopó Lake

The physical and chemical water quality results of Poopó Lake, shown in Figure 7 and Figure 8, are based on four samples obtained in dry, wet, semi dry and wet seasons. These results show that the heavy metal, pH, conductivity, dissolved and suspended solids and other pollutants are approximately of similar values in LPO-AG-2-1, LPO-AG-2-2 and LPO-AG-2-3 sample points and slightly higher in LPO-AG-2-5 sample point. The Poopó Lake water is polluted by Na, Ni, Mg, dissolved solids, suspended solids, Chlorides Cl^- and Sulphate indicating highest pollution levels according to Bolivian permissible values. The Poopó Lake is also polluted to a lesser degree by Li, Sb, Ca and Cr only occasionally to the highest permissible values (Table 3), but the pH is high and lake water is not acidic.

Figure 6. Satellite location of sampling points in the Poopó Lake and its tributary rivers[13]

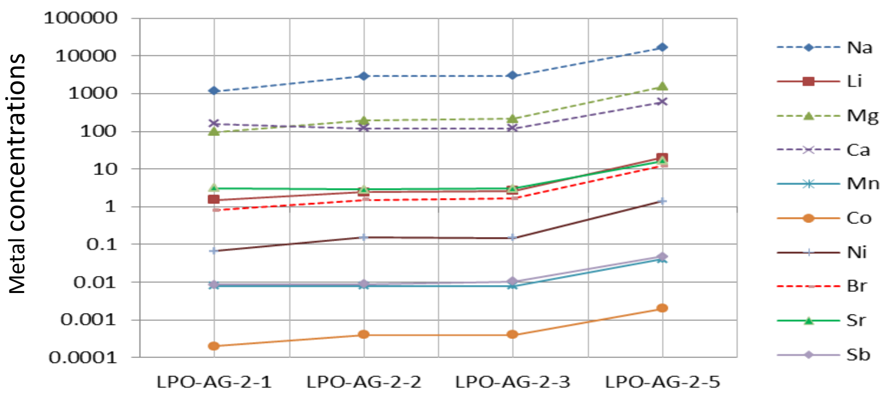

Figure 7. Analysis of the Poopo' Lake Water Samples

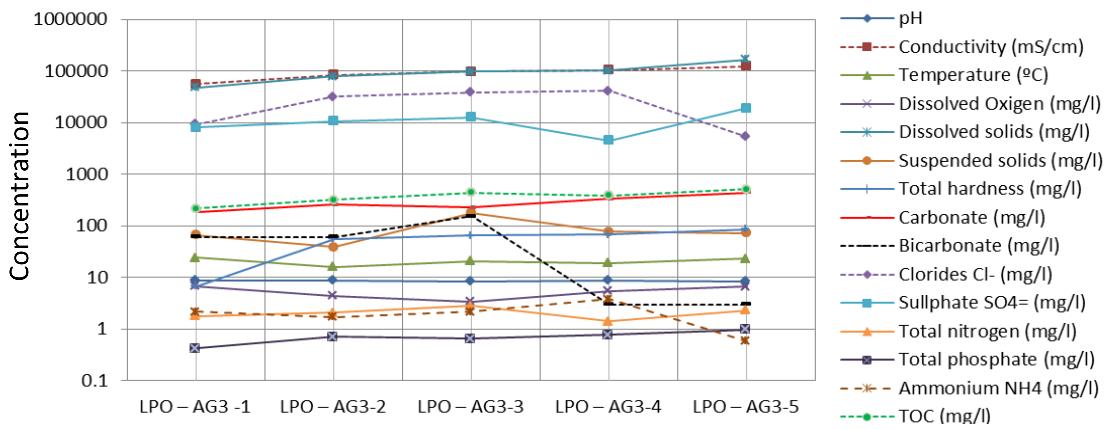

Figure 8. Complementary Analysis results of the Poopó Lake water samples

Table 3. Heavy metals highest Bolivian permissible value in Poopó Lake

Metals	Samples
Na, Ni	All
Li, Sb	LPO-AG-2-3 and LPO-AG-2-5
Mg	LPO-AG-2-2, LPO-AG-2-3 and LPO-AG-2-5
Ca, Cr	LPO-AG-2-5
Dissolved and suspended solids	All
Chlorides Cl^-, Sulphate $SO4^=$	All

5.2 Physical and chemical water quality of the tributary river of Poopo Lake

The heavy metals concentrations in the thirteen tributary rivers of Poopó Lake were measured in samples obtained in dry, wet, semi-dry and wet seasons. Results in Figures 9 and 10 show that the heavy metals concentration in Desaguadero and Tajarita rivers (RD1-AG-2-1, RD2-AD-2-1 and STJ-AG-2-1) are slightly lower compared to that in other rivers.

The pH, conductivity, dissolved and suspended solids and other concentrations were monitored in thirteen tributary rivers of Poopó Lake in dry, wet, semi-dry and wet seasons. The results in Figure 11 show the variation in pollutants concentrations of various samples.

Huanuni is the most polluted river because it contains six heavy metals in highest permissible concentration of aluminium, manganese, cadmium, nickel and copper. In the next place is Poopó river, that is polluted by five metals including sodium, lithium, zinc, sulphur and lead. Thereafter Antequera river is polluted by four heavy metals Aluminum, manganese, cadmium and zinc, and then Cortadera, Termas Pazña and Tajarita rivers are polluted by three metals each from the group of metals from (Na, Li, As, Zn or Pb). Finally, Tacagua river is polluted by two metals including sodium and zinc. Márquez, Sevaruyo and Desaguadero rivers are polluted by only one metal (Arsenic) and the Juchusuma river is not polluted (Table 4). All river water present high pH values except Antequera river where the water is acidic

By applying Equations (2) and (3), daily pollutants in thirteen tributary rivers contributing to the Poopó Lake have been calculated as follows:

- 3358307.52 kg of suspended solids,
- 2215448.69 kg of chlorides,
- 3969.49 kg of Zinc,
- 821.85 kg of Arsenic,
- 39.95 kg of Cadmium and
- 73.052 kg of Lead (Table 3).

The Desaguadero 1 River (Karasilla Bridge) contributes a 70% of arsenic, 64 % of lead, 4.27 % of zinc, and 2.18 % of cadmium; On the other hand, the Huanuni River contributes 61.23 % of cadmiun, 34.33 % of zinc and 2.23 % of lead. The Antequera River contributes 56.92 % of zinc, 32.92 % of cadmium, and 0.66 % of lead. The Desaguadero 2 River (Aroma Bridge) contributes a 17.7 % of arsenic, 17.97 % of lead, 1.90 % of cadmium, and 1.09 % of zinc (Table 5).

The results in Table 6 show that the heavy metals, suspended solid and chlorides are principal contributors of pollutants to the Poopó Lake through Desaguadero Rive.

5.3. Physical and chemical Analysis of sediment in Poopó Lake and tributary rivers

The heavy metals content in the sediments of Poopó Lake based on four samples are shown in Figure 12.

Arsenic, cadmium, lead, zinc are greatest metal pollutants in the lake sediments of Poopó Lake as permitted by the Bolovian Environmental Standards (Shown in Figure 13(a), Figure 13(b) and Table 7).

Chemical analysis results of sediment samples collected in tributary rivers compared with Bolivian standard show that Antequera, Huanuni and Tajarita rivers are polluted with five metals (Cu, Zn, As, Cd, Pb), Juchusuma, Poopó and Desaguadero with three metals (As, Cd, Pb), Márquez, Sevaruyo and Cortadera rivers with two metlas (As, Pb or Cd) and Tacagua and Kondo River (RKO) polluted for only with As (Table 8).

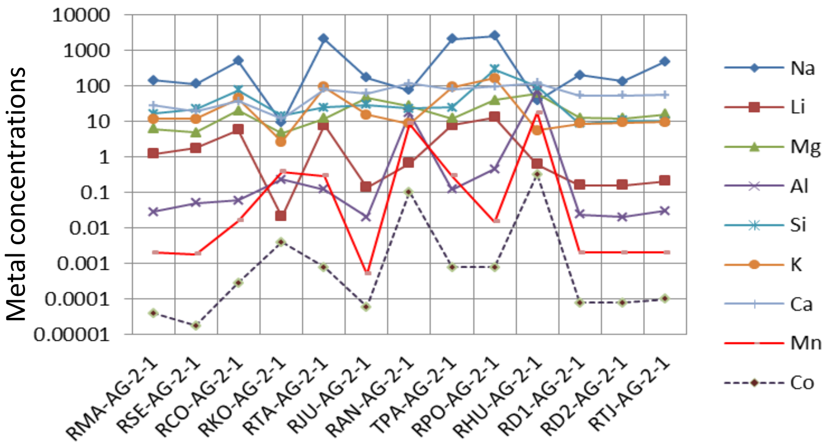

Figure 9. Heavy metals (Na, Li, Mg, Al, Si, K, Ca, Mn and Co) through ICP – MS of the waters of the Lake tributary rivers

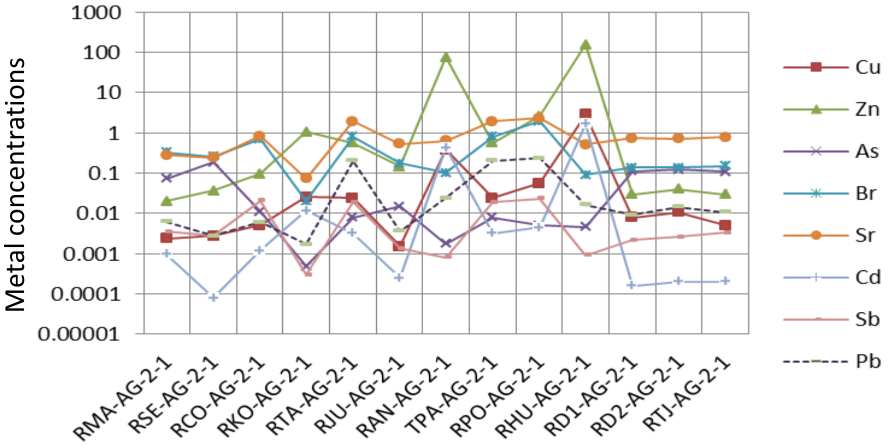

Figure 10. Heavy metals (Cu, Zn, As, Br, Sr, Cd, Sb and Pb) through ICP – MS of the waters of the Poopó Lake tributary rivers

Table 4. Heavy metals highest Bolivian permissible value in tributary rivers

Metals	Rivers											
	RMA	RSE	RCO	RTA	RJU	RAN	TPA	RPO	RHU	RD1	RD2	RTJ
Na			x	x			x	x				x
Li			x				x	x				
Al, Mn, Cd						x			x			
Ni, Cu									x			
Zn			x	x		x	x	x	x			
As	X	x								x	x	x
Sb								x				
Pb								x				x
pH						x						

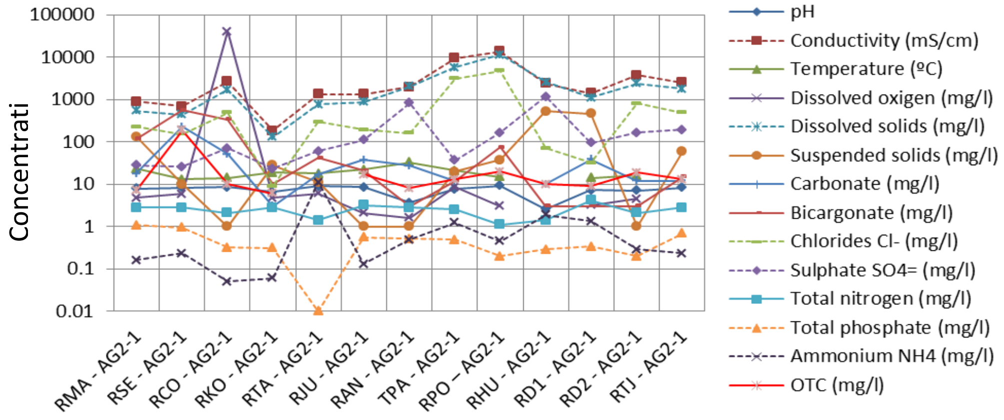

Figure 11. Physical and chemical Analysis of the tributary rivers of thePoopó Lake

Table 5. Tributary rivers contribution of heavy metals, suspended solid and chlorides to the Poopó Lake

Tributary rivers	Heavy metal, suspended solids and chlorides (kg/day)					
	Susp. solids	Chlorides	Zn	As	Cd	Pb
Marquez	2002.000	5824.000	3.300	1.910	0.020	0.270
Cortadera	55.820	4142.000	0.710	0.220	0.005	0.112
Pazña termal water	5.580	2307.000	0.240	0.003	0.001	0.070
Desaguadero 2	397225.000	196615.000	43.320	92.160	0.760	13.130
Desaguadero 1	2847548.000	1642863.000	169.450	578.140	0.870	47.070
Huanuni	15557.000	5390.000	1363.000	0.124	24.460	1.630
Poopó	214.000	17363.000	4.820	0.070	0.024	0.422
Tajarita	94463.000	326764.000	109.690	141.420	0.500	9.620
Antequera	161.800	8000.000	2260.000	0.045	13.150	0.480
Juchsumar	14.340	851.300	0.330	0.070	0.001	0.025
Tacagua	2.980	214.800	0.220	0.010	0.000	0.003
Kondo	356.000	114.590	13.370	0.006	0.150	0.020
Sevaruyo	702.000	5000.000	1.040	7.670	0.004	0.200
Total Poopó Lake	3358307.520	2215448.690	3969.490	821.848	39.945	73.052

Table 6. Percentage tributary rivers ccontributions to heavy metals pollutants, suspended solid and chlorides to the Poopó Lake

Tributary River	Susp. solids	Zn	As	Cd	Pb
Desaguadero 1	84.79	56.92	70.36	61.23	64.44
Desaguadero 2	11.83	34.33	17.21	32.92	17.97
Tajarita	2.81	4.27	11.22	2.18	13.17
Huanuni	0.46	2.76	0.23	1.90	2.23
Others	0.11	1.09	0.03	1.77	0.66
Total	100.00	100.00	100.00	100.00	100.00

Table 7. Heavy metals highest Bolivian permissible value in Poopó Lake sediments

Metals	Samples				
	LPO-SD-2-1	LPO-SD-2-2	LPO-SD-2-3	LPO-SD-2-4	LPO-SD-2-5
Mn	x				
Cu, Zn	x	x	x	x	
As, Cd, Pb	x	x	x	x	x

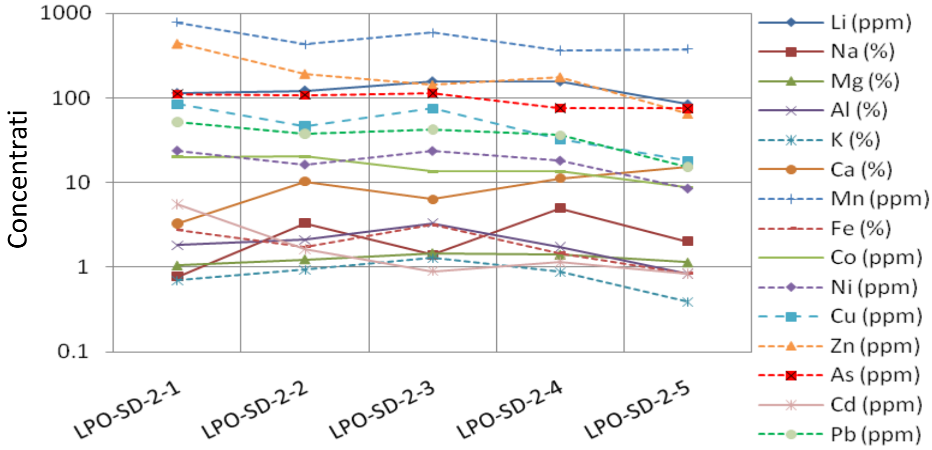

Figure 12. Heavy metals in Poopó Lake sediments

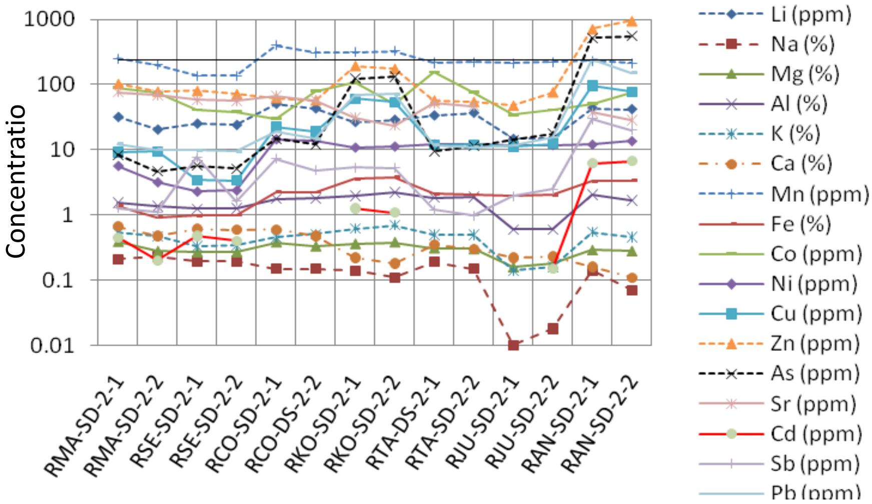

Figure 13(a). Heavy Metals in tributary rivers sediments

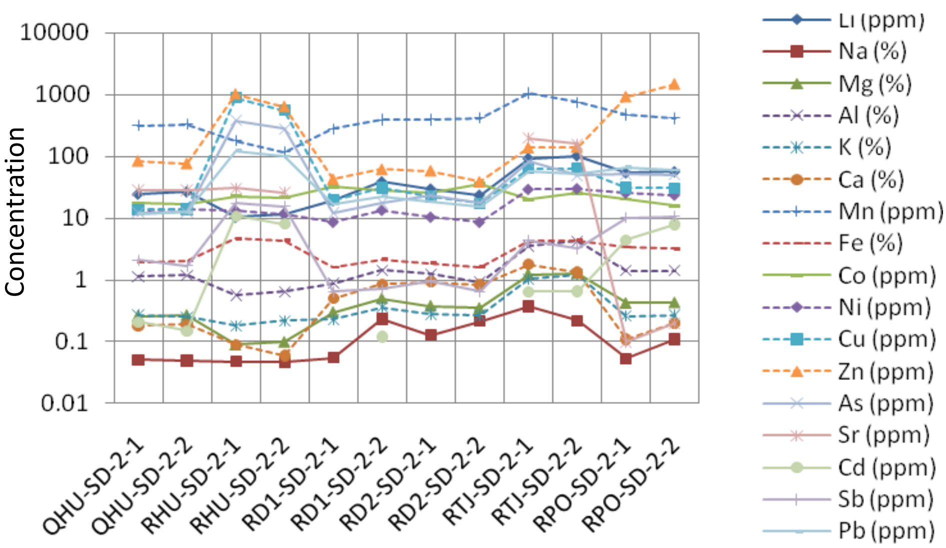

Figure 13(b). Heavy metal in the tributary rivers sediments

Table 8. Heavy metals highest Bolivian permissible value in tributary rivers

	Rivers											
	RMA	RSE	RCO	RTA	RJU	RAN	RKO	RPO	RHU	RD1	RD2	RTJ
Cu, Zn						x		x	x			x
As	X	x	x	x	x	x	x	x	x	x	x	x
Cd	X	x			x	x		x	x	x	x	
Pb			x		x	x			x	x	x	x
Mn												x

6. Discussion

Poopó Lake pollution due to mining activities therefore characterized by correlating the principal metals in mining production and secondary heavy metals formation in the surrounding mining area: somewhat than, river pollution by mine effluent composed of heavy metal and solids flow to the Poopó Lake and cause environmental pollution. Trough Desaguadero river, Poopó Lake is polluted with 64% of its lead, 70% of its arsenic, 4.27% of its zinc and 2.18% of its cadmium. Correlated with principal metals production of adjacent mines, San José mine is the highest polluter by lead, and Vinto foundry and Kori Kollo mines contribute pollution by heavy metals like arsenic, zinc and cadmium (Figure 14).

Through Antequera river, Poopó Lake is polluted with 57% of its zinc, 32.9% of its cadmium, 0.66% lead and Hununi river by 34.3% of its zinc, 61.2% of its cadmium, 2.23% of its lead. Associated with principal metals production in these mines, they are more highly polluted by zinc and cadmium and lead (Figure 14). The Totoral and Avicaya mines are located near Huanuni mine.

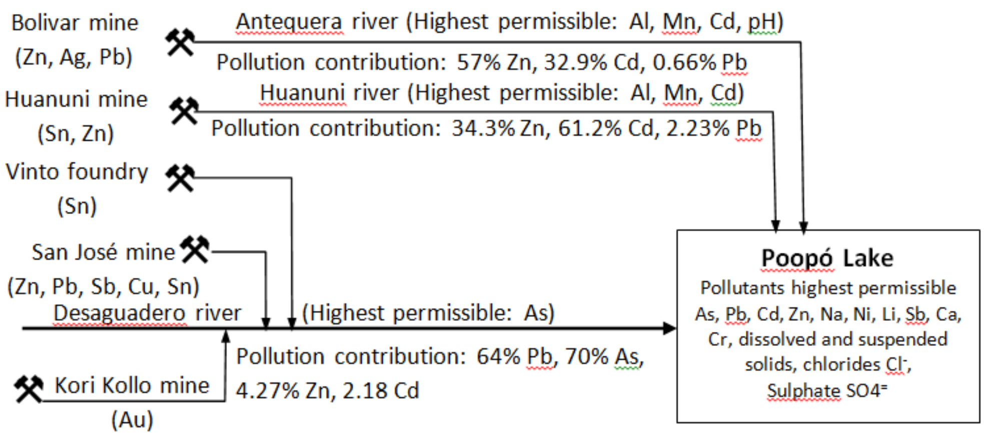

Figure 14. Mining activities and main tributary rivers contributions for Poopó Lake pollution

Compared to mining activities, the tributary river pollution contribution with metals is highest for Poopó Lake pollution (Figure 14) and this contamination mainly is by arsenic, lead, cadmium and zinc. Additionally, mining activities contributed to Poopó Lake pollution by dissolved and suspended solids.

Others heavy metals pollutants are associated with the geological and hydrological characteristics of diverse river basins, such as: sodium pollutant, which is associated with Cortadera, Tacagua, Termas Pazña, Poopó and Tajarita rivers; nickel pollutant which comes trough Huanuni river, but has no relation to mining activities; lithium pollutant, which is linked to Termas Pazña and Poopó rivers; antimony pollutant is related to only Poopó river.

Chemical analysis results and mathematical analysis results using Equations (4), (5) and (6) show that the acidity of the Poopó Lake water is represented by pH 8.5 to 8.8. In the tributary rivers the pH varies mostly from 6.6 to 8.9 and only Antequera river has a low pH of 3.6. This indicates that mining activities in Bolivar Mine provide acidic environment only to Antequera river, but contributes no acidity to the Lake-Poopó.

7. Conclusions

The following conclusions can be drawn from this study:

- Poopó Lake water is highly saline having As, Pb, Cd and Zn concentrations well above the permissible limits with suspended and dissolved solids concentrations also above the permissible limits.

- Daily charge of the suspended solids and dissolved heavy metals by tributary rivers are 3358307.87 Kg suspended solids, 2215448.99 kg chlorides, 3970.49 kg zinc 821.62 kg arsenic, 30.95 kg cadmium and 73.05 kg lead.
- In the pollution process of Poopó Lake, Desaguadero river contributes with 70% of its arsenic, 64% of its lead, 4.27% of its zinc and 2.18% of its cadmium, then Antequera river contributes 57 % of its zinc, 32.9 % of its cadmium and 0.66% of its lead and finally Huanuni river contributes with 61.2% of its cadmium, of its 2.23% lead and of its 34.3% zinc.
- Mining activities polluted the Poopó Lake by arsenic, lead, cadmium and zinc. Additionally, mining activities also contributed dissolved and suspended solids to the mining effluent.

Vinto foundry, Kori Kollo and San José mines mainly polluted the Poopó Lake by arsenic and lead trough Desaguadero river.

- Bolivar and Huanuni mines polluted the Poopó Lake by cadmium and zinc through Antequera and Huanuni rivers.
- Acid mine drainage has no environmental impact on all rivers and Poopó Lake, except Bolivar mine pollutes the Poopó Lake through acidic Atequera river.

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