Pollution Associated to artisanal Gold mining in Ayacucho Department , PERÚ

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ABSTRACT
In Huanca region (Ayacucho Department) soils and surface watercourses in the catchment of the Acari River are affected by the artisanal gold mining. Tailing ponds storing Hg-rich wastes from operations related to amalgamation processes represent potential pollution sources for environmental and human health. According to the geochemical data corresponding to a preliminary study made at the site of the artisanal gold mining, mercury anomalies are evidenced in Huanca settlement.

INTRODUCCIÓN
In Peru, the artisanal mining is abundant and geographically limited to the zones of Nazca and Ocoña (Ica and Arequipa Departments), Huanca (Ayacucho Department), Altiplane (Puno Department), the mountains of La Libertad Department, Madre de Dios Department and the Amazonic forest where alluvial deposits are exploited. In these areas mining is the main economical activity that has taken the place of other economical activities as agriculture and grazing. However, on the last years there is a decreasing in the production of the artisanal mining with respect to the medium and great mining: artisanal mining production has reached a 12% of total mining in 2002 and a 7% of total mining in 2003.

Gold production (kg)	1990	1994	1998	2001	2002	2003
Total	20,179	47,799	94,214	141,458	160,103	175,302
Artisanal	11,800	24,480	22,560	16,620	18,720	12,849
Artisanal mining (%)	58%	51%	24%	12%	12%	7%

Table 1. Evolution of total and artisanal gold production in Peru (data from the Energy and Mining Ministry of Peru)

The area of study corresponds to the settlement of Huanca (Ayacucho Department), which is located 590 km south-eastern of Lima. In Huanca settlement exists small agricultural fields for production of potatoes, corn and apples, which are commercialised in the Acarí village, but the main economical activity of the area is the artisanal gold mining. Another important economical activity is the ore treatment plant managed by Minera Dynacor, which is a Canadian mining company; this treatment plant allows a higher recovery of gold from ore than the artisanal recuperation by amalgamation. The artisanal gold mining activities in this area involves mercury amalgamation for gold recovery from the exploited ore. The population living in the village of Huanca is estimated in 1,200 inhabitants, which participate in the artisanal extractive operations for gold recovery without any type of health protection in the manipulation of mercury. The artisanal mining generates an important socio-economical impact in the employment creation (as well direct as indirect). Estimation about the number of miners working in artisanal mining in Ica, Ayacucho and Arequipa is in the order of 10,000 workers.

In this area, gold veins with lengths from 1 to 10 cm and gold grade from 1 to 80 oz/ton, are exploited by artisanal mining. These veins have low interest for medium to big scale mine companies but they have enough interest for artisanal mining because of the easy and low cost of operations. At the site of Huanca settlement two important tailing dams are located. The first one is associated to the old Cu exploitations of the Hochschild Company, and the second one to the gold exploitations of the Metalex Company, which is located in the installations of the current treatment plant of Minera Dinacor mining company (fig.1), in the left margin of the Acarí River, which is the main source of water for the area. Main operations associated to artisanal mining are the manual selection of the high-grade ore, grinding, the amalgamation of ore with mercury, the collecting of ore for treatment in the cianuration plants of the mining companies, and the burn of the amalgama in conventional furnaces at home.

Some studies estimate that the yearly losses of native mercury to the environment reach the 85 tonnes in the mining zones of Ica-Arequipa-Ayacucho and Puno. Furthermore, it is estimated that the burn of the amalgama process produces a Hg release to the atmosphere of 20 tonnes by year (Mosquera et al., 1999).

Fig.1. Current tailing pond of Minera Dynacord

CHARACTERISTICS OF THE SITE

Climatic conditions

The area of study is located at a height of 750/800 metres above sea level, in a typical coastal sub-tropical climate. According to the meteorological conditions registered at COPARA station, 15 km from Nazca village in Ica Department, the average temperature fluctuates between 22 º C and 24 º C in summer and between 15 º C and 20 º C in winter. The relative humidity ranges from 50 to 70 %. The zone is characterized by scarce precipitations along the year. 1mm/month is the maximum precipitation registered in the pluviometric station of Otapara, located in the Acarí river catchment, at 400 metres above sea level. Table 2 represents the total monthly precipitations in mm registered in the pluviometric station of Lucanas, at 3,375 metres above sea level, for some years of the period 1975-2002.

Year	1975	1980	1985	1990	1995	2000	2002
January	272.55	108.46	69.98	120.02	69.62	166.66	163.95
February	247.73	112.96	133.18	113.64	91.88	205.94	167.40
March	192.45	19.18	127.00	116.92	134.58	107.88	208.75
April	40.10	12.96	23.74	12.44	27.14	68.58	66.05
May	6.18	3.68	4.90	1.00	1.78	8.58	17.30
June	1.07	0.02	4.58	1.50	0.00	1.08	1.60
July	0.35	3.28	0.00	0.65	0.02	1.68	27.30
August	3.78	5.02	4.00	0.30	0.00	24.94	8.40
September	9.63	16.12	5.22	0.00	2.60	14.30	10.30
October	6.65	19.14	20.54	2.38	5.58	38.20	6.45
November	8.30	16.54	25.38	1.60	23.45	22.88	19.05
December	30.07	26.52	61.48	36.70	27.05	100.98	30.10

Table 2. Total monthly precipitations in mm for some years of the period 1975-2002 (data from the National Service of Meteorology and Hydrology of Peru - SENAMHI)

Geologic and hydrologic conditions

Regionally, the area of study corresponds to the geomorphologic unit of the Subandine Flat Area, which constitutes an erosion surface dissected by numerous gorges and rivers draining towards the Pacific. In this geomorphologic unit it can be differentiated the bed of the Acarí river, developing a flat area with slope towards the Southwest, with an average wide of 300 m, developing agricultural areas in some zones.

In the area of study materials correspond to igneous intrusive rocks of La Costa Batholite belong to the Tiabaya unit of Medium Cretaceous. Intrusive rocks differ in composition from tonalites, to diorites and granodiorites, with granular texture, and zoned plagioclases with alteration rings and solids inclusions of hornblende. In the area recent alluvial, elluvial and colluvial deposits are abundant (fig. 2). Main structures are related to the tectonic movements of the andine cycle, and the fault systems N-10º-E (65º NE dip) and N-80º-E (40º SE dip) are the most abundant.

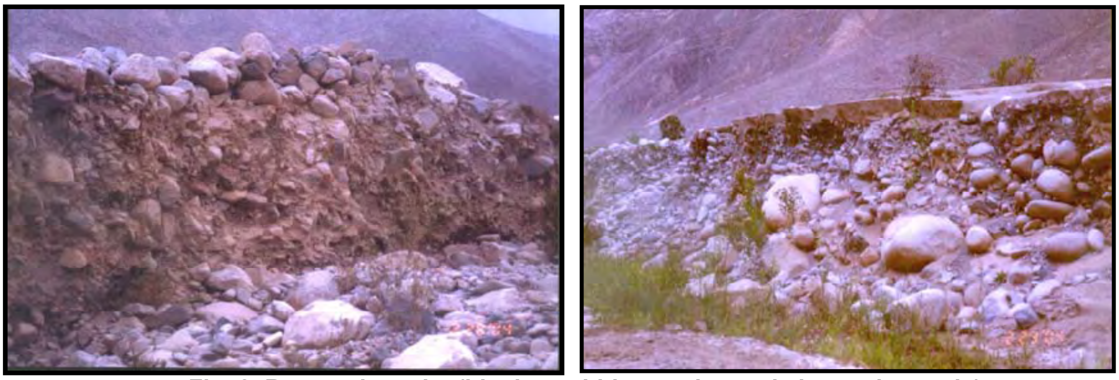

Fig. 2. Recent deposits (blocks, pebbles, and gravels in sandy matrix).

Soils are affected by the geomorphologic and climatic conditions of the area, with scarce of water and absence of vegetation. The physical weathering is dominant and it is affected by temperature changes. The desegregation products are mobilised by the wind and transported and deposited in function of weight and size. In a great part of the area of study related to the aridity it can be considered that soils are not appropriate for agricultural activities, excepted the areas in proximity to the Acarí river, where small crops are developed. Soils composition consists of a mixture of blocks, pebbles, and gravels included in a sandy matrix with small percentage of fine particles, with lenticular intercalations of slime sandy soils with contents of gravels (typical soil composition is in the order of 20% blocks of different size, 15% pebbles, 25% gravels, and 40% slimy sands).
Mineralization is banded or brecciated and it presents in veins, lenticular bodies and disseminations of pyrite. Veins are of regular length with auriferous pyrite in milky quartz. Paragenesis is constituted by auriferous pyrite, chalcopyrite, galene, sphalerite and malachite, in a gangue of quartz and calcite. The mineralization has a tectonic control related to the fracture systems of N 20-25 W and N 50-60 W trend in La Costa Batholite, with well-developed hydrothermal alteration.
The Acarí River is the main superficial watercourse in the area. The flow ranges from 500 l/s in dry months to 20,000/40,000 l/s in rainy periods. Water is used for domestic and agricultural applications. The piezometric level in the area is 10 m and Dynacor mining company uses groundwater for industrial operations.

SAMPLING LOCATION AND METHODOLOGY

Sampling

A preliminary soil sampling has been made at the site of the Huanca village, and in agricultural lands in proximity to the village (Soto, 2005). In Huanca settlement, it has been made a random soil sampling constituted by 9 surface soils (C1 to C9). Representative samples have been collected in the area where the manual metallurgical operations are located. For sampling design it has been taking in consideration several incidences occurred in the area such as mercury spills during the commercialisation operations, mercury dispersions associated to the tailing ponds, the burn of the amalgama in conventional furnaces, and others. Samples have been collected at depths of 5 cm. and their localisation is represented in figure 3.

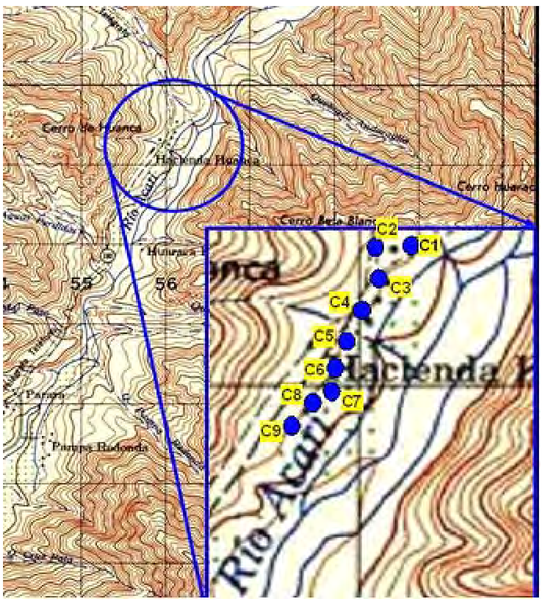

Fig.3. Localisation of samples in soils in Huanca settlement.

In the agricultural lands used by Huanca community, a random soil sampling constituted by 4 agricultural surface soils (TR1 to TR4) has been made. Representative samples have been collected in the main agricultural area, in the right margin of the Acarí River, at 500 m of Huanca settlement. Samples have been collected at depths of 10 cm with manual tools and their localisation is represented in figure 4.

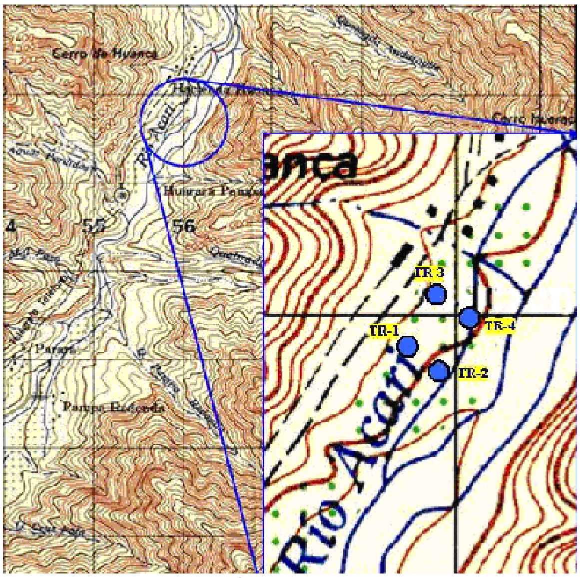

Fig.4. Localisation of samples in agricultural soils.

Furthermore, representative samples of materials stored in tailing ponds have been collected for chemical analysis. Water samples of the Acarí River have been collected too in order to have representative values of the quality of surface water upstream and downstream mine operations. In tailing ponds two representative samples (RA1 and RA2) have been collected at depth of 60 cm. They were located inside the old tailing pond that is located in the site of the metallurgical treatment plant of the Metalex Co, at a distance of 200 m of the course of Acarí River. This tailing pond has been abandoned in 1995, when the new mining company operating at the site constructed a new one for the new ore treatment plant. Also have been sampled three informal current tailing ponds used by the artisanal work of miners. These tailing ponds are located in Huanca settlement. Figure 5 shows the localisation of the samples on the tailing ponds.

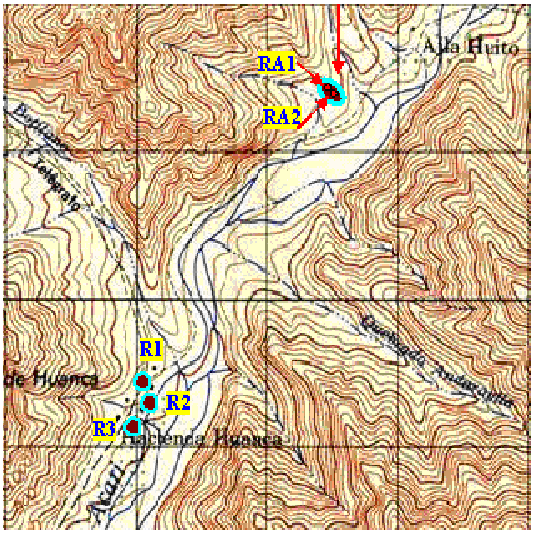

Fig.5. Localisation of tailing samples.

In Acarí River six sampling points have been selected for monitoring: W1 (Upstream Dynacor Plant), W2 (Water Dynacor Plant), W3 (Downstream Dynacor Plant), W4 (Downstream Huanca village), W5 (Upstream Otapara plant) and W6 (Downstream Otapara plant). Localisation is represented in figure 6.

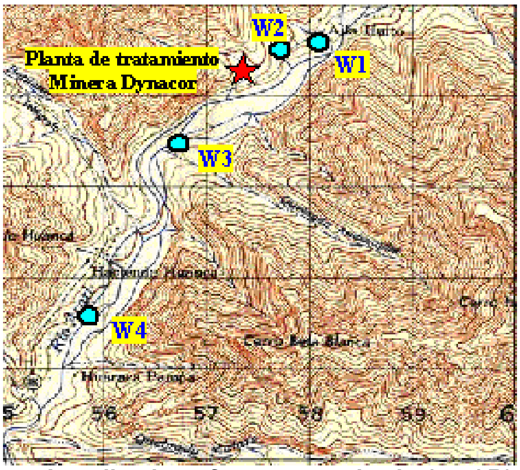

Fig. 7. Localisation of water samples in Acarí River.

Preparation and Analysis

Given that one of the most important factors controlling the mobility and the concentration of chemical elements in soils is pH, as it affects all adsorption mechanisms and the speciation of metals in the soil solution, measurements of pH of soils were made "in situ" in the field by use of specially adapted portable soil pH-meter HANNA HI-9025.

Representative samples of soils and tailings were dried in laboratory for 48 h. in an oven at temperature of 35ºC to minimise loss of mercury due to volatility. After drying, stones and other large particles of the samples were removed, and desegregated in an agate mortar the components of the samples. Samples were ground to a size finer than 147 µm and then homogenised and quartered by means of an aluminium rifler (which was cleaned between samples using a jet of compressed air), to provide a representative samples for analysis. A portable X-ray fluorescence analyser equipped with three different radioisotope sources (^{109}Cd, ^{241}Am, and ^{55}Fe) has been used for geochemical characterisation of soils and tailing ponds. These equipments constitute, in general, a powerful and efficient technology, capable to identify priority metallic pollutants and other elements as arsenic and selenium in soils and sediments, and to delimit the polluted area (Loredo *et al*., 2003). The equipment was put in contact with materials from soil and/or tailing ponds, then it provides analysis of up to 35 elements (depending of the radioisotope sources applied), in minutes. Little sample preparation was undertaken; any non representative debris, such as rocks, pebbles, leaves, vegetation, roots, and others, was removed from the soil surface to be smooth so that the probe window makes good contact with the soil surface..

For water analysis, multielemental chemical analyses (Mo, Cu, Pb, Zn, Ag, Ni, Co, Mn, Fe, As, U, Au, Th, Sr, Cd, Sb, Bi, V, Ca, P, La, Cr, Mg, Ba, Ti, B, Al, Na, K, W, Tl) by Inductively Coupled Plasma have been made at ACME Analytical Laboratories Ltd. in Vancouver (Canada). FAA (Flameless Atomic Absorption) has been used to analyse Hg in concentrates. Quality control was achieved by routine analyses of standards and field and analytical duplicates.

RESULTS AND DISCUSIÓN

Soils in the area affected by mining and smelting operations have pH values ranging from 6.67 to 8.01 units. Chemical analysis of soils collected in the area where the manual metallurgical operations are located show mercury concentrations between 15.3 mg/kg and 44.2 mg/kg. Arsenic reaches concentrations of 48.4 mg/kg at the site of an old manual metallurgical operation, coinciding with maximum concentration of mercury. Table 3 summarises the results corresponding to total elemental concentration for mercury and arsenic in surface soils and tailing samples of the area of Huanca settlement.

The soils around the old manual metallurgical operations are strongly enriched in mercury. These geochemical anomalies are clearly associated to manual operations related to the amalgamation processes, which distribute metallic mercury in soils and mercury vapour in the atmosphere, constituting an important source of pollution for the inhabitants of the area and for the environment. It must be emphasised that at sites close to the old manual metallurgical operations and the informal current tailing ponds produced by the miners work, the concentrations of total mercury are distinctly high (up to 44.2 mg/kg,). Mercury concentrations in soils decrease as a function of distance from the before mentioned sources.

	Sample	pH	Hg	As
Soils in Huanca village	C1	7.03	24	33.4
	C2	7.10	<1	<1
	C3	6.74	44.2	48.4
	C4	6.67	28.9	45.2
	C5	8.01	15.3	<1
	C6	7.70	<1	<1
	C7	7.90	<1	<1
	C8	6.81	<1	<1
	C9	6.99	<1	19.1
Agricultural soils	TR1	7.23	2	15
	TR2	7.41	<1	19
	TR3	6.93	1	19
	TR4	7.08	<1	23
Old tailing pond	RA1	6.93	58	776
	RA2	3.26	104	314
Current tailing ponds	R1	6.83	139	51
	R2	6.97	189	134
	R3	7.28	186	67

Table 3. Analytical data of soils and tailings in the area of Huanca settlement

Analytical data corresponding to water samples collected in different monitoring points of the Acarí River are represented in Table 4. These values do not represent important changes in water quality as results of the mining and processing operations.

Sample	As ($\mu g.l^{-1}$)	Au ($\mu g.l^{-1}$)	Ca ($mg.l^{-1}$)	Cl ($mg.l^{-1}$)	Hg ($\mu g.l^{-1}$)	K ($mg.l^{-1}$)	Mg ($mg.l^{-1}$)	Na ($mg.l^{-1}$)
W1	16.5	0.63	86.27	85	<0.1	6.93	16.48	96.66
W2	17.1	0.42	96.66	72	<0.1	6.13	14.08	70.93
W3	7.1	0.37	122.19	88	<0.1	6.39	16.14	92.84
W4	16.2	0.26	119.11	95	<0.1	6.78	18.39	93.09
W5	21.4	0.23	113.05	106	<0.1	6.47	18.35	110.94
W6	6.9	0.15	122.10	143	<0.1	8.02	21.16	144.81

Table 4. Analytical data of water in the Acarí River (Huanca district).

Furthermore, average characteristic values for water quality in the Acarí River, upstream and downstream mine operations, are indicated in table 5. Differences in water quality for samples collected upstream and downstream artisanal mining operations are not observed. Important dilution effects take place and as consequence changes in water quality are not significant.

Sample	M2 (upstream of mine site)	M3 (downstream of mine site)
Conductivity (mS/l)	1.04	1.04
pH	6.8	7.2
TSS (mg/l)	12	8
Sulphates (mg/l)	403.2	361.1
Nitrates (mg/l)	0.73	0.18
Total Cu (mg/l)	<0.01	<0.01
Total Iron (mg/l)	0.02	0.04
Total Cyanide (mg/l)	<0.01	<0.01

Table 5. Average values of water quality of Acarí River, upstream and downstream mine operations.

CONCLUSIONS

The studies accomplished in the Huanca district reveals high mercury concentrations in soils and tailings reaching up to 44.2 $mg.kg^{-1}$ and 189 $mg.kg^{-1}$ respectively. Soils around ore processing operations are strongly enriched in mercury. In relation to the amalgama process, important losses of native mercury to the environment are produced. Water quality of Acarí River that flows through the area do not present changes important as consequence of the mining and processing operations.

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