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Heavy metals in water and stream sediments from the Auriferous District of Ginebra, Colombian Andes

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Resumen

Se determinaron concentraciones de metales pesados tóxicos en aguas, sedimentos de corriente y sedimentos en suspensión del Distrito Aurífero de Ginebra, un área minera de pequeña escala en el Departamento de Valle del Cauca (Colombia), mediante técnicas de espectrometría de absorción atómica. Los datos mostraron anomalías positivas relacionadas con las colas de mina, cuyas concentraciones decayeron hasta por debajo de los límites máximos permitidos para agua potable, como resultado de un efecto buffer del agua natural del área de estudio. Sin embargo, se debe considerar el riesgo potencial de polución severa aguas abajo, así como la introducción de metales pesados tóxicos en la cadena alimenticia, por contaminación de aguas y productos agrícolas. También se presentan algunas recomendaciones.

Palabras clave: metales pesados, riesgo de contaminación, distritos auríferos, Colombia, Andes.

Abstract

Toxic heavy metal concentrations were determined for water, stream sediment and sediment in suspension samples from the Auriferous District of Ginebra, a small-scale gold mining area in Valle del Cauca Department (Colombia), by using atomic absorption spectrometry techniques. Data showed positive anomalies related to sewage sludge effluents from the mines that decay to concentrations till about under maximum permitted for drinking waters, as result of a buffer effect of the natural water from the study area. Severe pollution of downstream areas, as well as the introduction of toxic heavy metals into the food chain by contamination of the drinking waters and agricultural products, is a current potential risk that may be taken ever into consideration. Some recommendations were also presented.

Key words: heavy metals, contamination risk, auriferous districts, Colombia, Andes.

Introduction

Most of the gold mining programs generate tailings with high concentrations of heavy metals toxic to the human health. However, those tailings are released to the environment.

About a century ago, the Auriferous District of Ginebra (ADG) has greatly contributed to the gold production in the Valle del Cauca Department, Southwest of Colombia (De Armas 1986). But the source of drinking water for the municipalities of Ginebra and Guacarí receives the ADG's mine tailings and it may constitute a severe contamination factor for the human being if gold bearing developments have no attention with tailing disposals.

In order to determine the toxic heavy metals behavior in the ADG's mine tailings and the contamination risk for the inhabitants of Ginebra and Guacarí, a sampling of water and stream sediments was programmed. Results of chemical analysis are discussed along this study.

General setting

The ADG is located approximately 60 *km* NE of Santiago de Cali, the capital city of Valle del Cauca Departament (Figure 1). Because of the altitudes ranging between 1200 and 3000 meters above sea level, climate variations from wet temperate (in the lowlands) to wet cold (in the highlands) are found.

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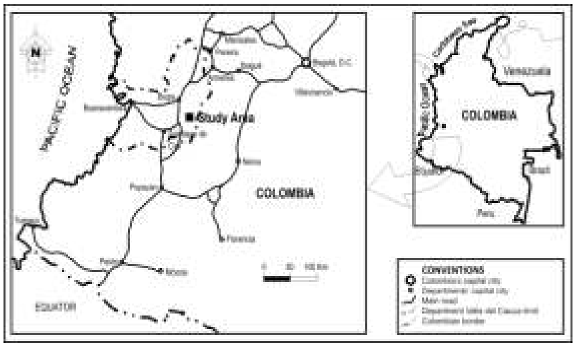

Figure 1. Location of he study area.

The Auriferous District is regionally affected by some NNE-SSW high-angle reverse faults from the Cauca-Romeral faults system. As a consequence of the movements in this system, a series of E-W transcurrent faults have been formed, configuring a great shear zone (McCourt *et al.* 1984a). This fact causes an abrupt topography and structural control of the affluent creeks of Guabas River, such as La Esperanza, La Magdalena, Aguas Blancas, Cocuyos and Lulo.

Two main geological units dominate the regional geology of the ADG: the Ophiolitic Massif of Ginebra and the Buga Batholith. The first one is a Jurassic-Cretaceous sequence which presents, from the base upward, peridotites, stratified gabbros, gabbros, dolerite dikes, metabasalts, plagiogranites, microbreccias and tuffs (Espinosa 1985). The second one is an acidic to intermediate intrusive rock (quartz diorite–tonalite until hornblende–diorite) which intruded the Ophiolitic Massif of Ginebra. A K / Ar datation showed a radiometric age of 113 ± 10 *Ma* (Toussaint *et al.* 1978), while a Rb / Sr isochrone showed an age of 99 ± 4 *Ma* (Brook 1984).

The Jurassic–Cretaceous basic pillow-lavas of the Amaime Formation are cropping eastward. They were also intruded by the Buga Batholith, and present locally komatiitic basalts (McCourt *et al.* 1984b).

The relationship between the massif of Ginebra and the Amaime Formation is considered as a thoroughly developed ophiolite, where the basalts of the Amaime Formation could be the roof (McCourt 1984).

The intrusion of the Buga Batholith in the Ophiolitic Massif of Ginebra produced a hydrothermal mineralizing fluid which ascended through the cracks and formed two types of deposits: vein type and stockwork (disseminated gold) type (Buenaventura & González 1994).

Thirteen gold mines had been recorded in the ADG (Figure 2), almost all of them developing vein type deposits, except for El Retiro mine, where a disseminated gold type deposit is mined (Muñoz-Ramos 1995, González & Buenaventura 1996).

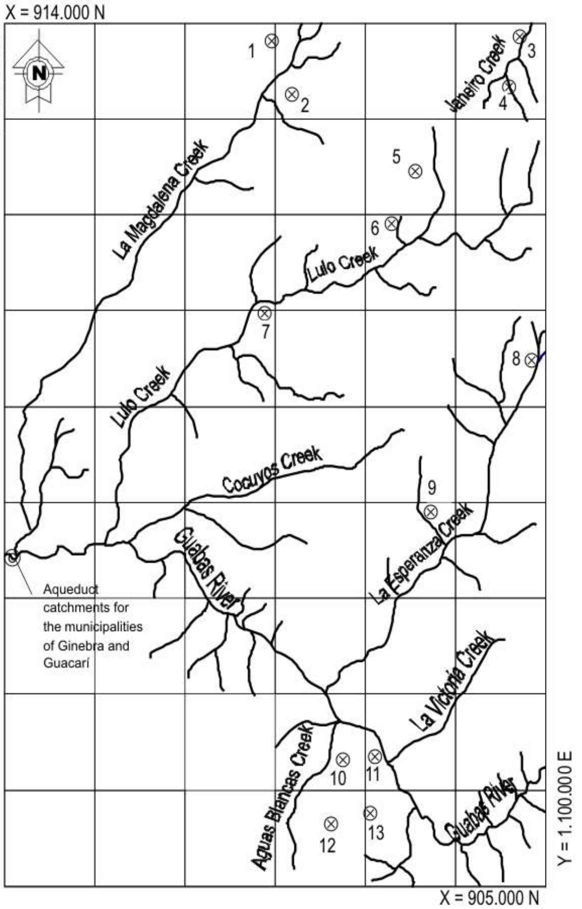

Figure 2. Generalized Map of the Auriferous District of Ginebra. Origin of plane coordinates in Bogota's Observatory datum. (1: La Magdalena; 2: Santa María de la Magdalena; 3: Santelina; 4: Cueva Loca; 5: El Retiro; 6: El Peñón; 7: Los Lulos; 8: La Montecristo; 9: La Esperanza; 10: San Expedito; 11: La Victoria; 12: Cascabel; 13: La Emilia).

The mineralogy is mainly composed by quartz and sulfides, such as arsenopyrite, pyrite and chalcopyrite. The vein deposits have high concentration of base metals, such as copper, lead and zinc. Because of this, malachite, azurite, covellite, limonite, hematite, etc., are present as oxidation product of the sulfides. (Muñoz-Ramos 1995). An intimate association gold-iron sulfides was found by Prieto *et al.* (1994).

While minor alteration is observed in the vein type deposits, argillic and propylitic alterations, with intensive chloritization and silicification, are there in the stockwork deposit (Muñoz-Ramos 1995).

Technical framework

The handcrushed run-of-mine ore from the ADG is grinded in Californian-type stampmills, before passing over a mercury coated copper plate, a blanket table or sluice and a hydraulic trap (Muñoz-Ramos 1995, González & Buenaventura 1996). As a result of this procedure, the gold-ore mineral is mixed with Hg to form an Au-Hg amalgam, which is thermically separated into gold and mercury (Figure 3).

This process generates mine tailings which are mixed again with mercury in closed amalgamating barrels, before going to tailing piles for about one year of natural oxidation. Thereafter, the amalgamation tailings are re-treated in cyanidation plants for precipitating gold on zinc, and the new resultant tailings are then released into the rivers (Muñoz-Ramos 1995).

Materials and methods

The sampling was concentrated in Lulo Creek, the most affected by the mining of the sector, and Guabas River, the main river in the area and where the catchments for the aqueducts of Ginebra and Guacarí municipalities were built.

Twenty seven water and stream sediment samples were collected just up and downstream the effluents of the mines and in the intermediate sectors between effluents (Figures 4 and 5).

In order to assess the immediate risk for the inhabitants from the Ginebra and Guacarí municipalities, samples of water and stream sediments were collected nearby their aqueduct catchments.

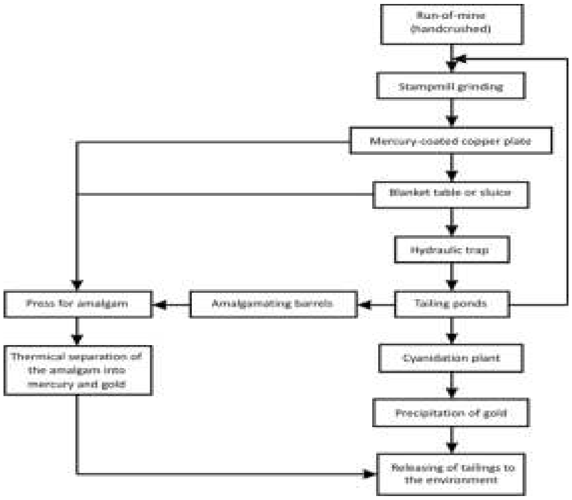

Figure 3. Flow diagram of the activities in a gold-ore-processing plant in the Auriferous District of Ginebra, including amalgamation and cyanidation.

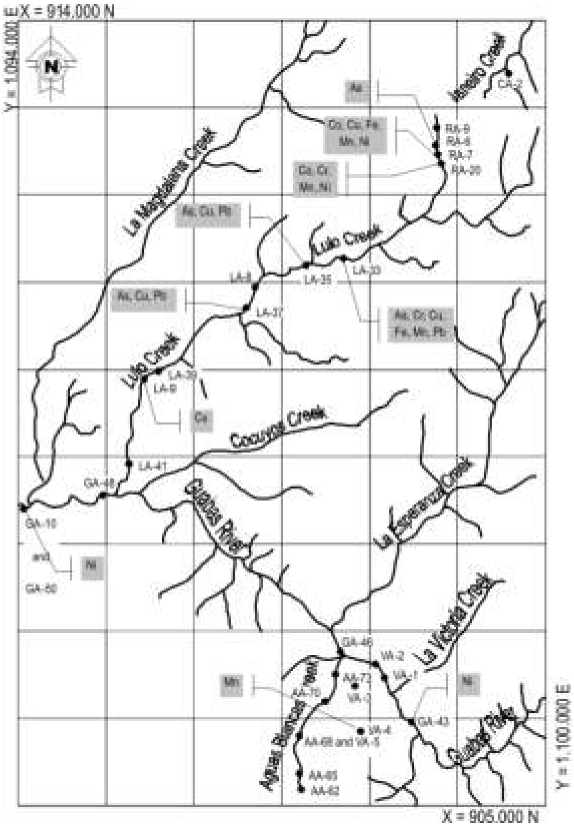

Figure 4. Sampling and positive geochemical anomalies location map for the water samples from the Auriferous District of Ginebra. Origin of plane coordinates in Bogota's Observatory datum. (•: sampling point; As: >1,3 ppb; Au: >0,18 ppb; Co: >7,7 ppb; Cr: >16,8 ppb; Cu: >24,7 ppb; Fe: >1,9 ppm; Mn: >78,4 ppb; Ni: >22,6 ppb; Pb: >39,6 ppb).

One sample of sediments in suspension was obtained by filtering through 45 μm Millipore filters a water sample collected nearby to one of the mine effluents into Lulo Creek.

Anthropogen unpolluted water and stream sediment samples were collected from about seepage of Lulo Creek, before El Retiro Mine, and Aguas Blancas Creek. The concentrations of the analyzed chemical elements in those samples were considered as geogene background values for this area.

Data compiled by different authors (Turekian & Wedepohl 1961; Gibbs 1977; Förstner & Witmann 1983; and Salomon & Förstner 1984) were used as world background mean concentration values of heavy metals in the environment.

Previously to be taken to the laboratory, the water samples pH was read *in situ*, and enough nitric acid was added to each sample after its filtration, to assure a pH about 2, trying to keep all chemical elements in solution until they were

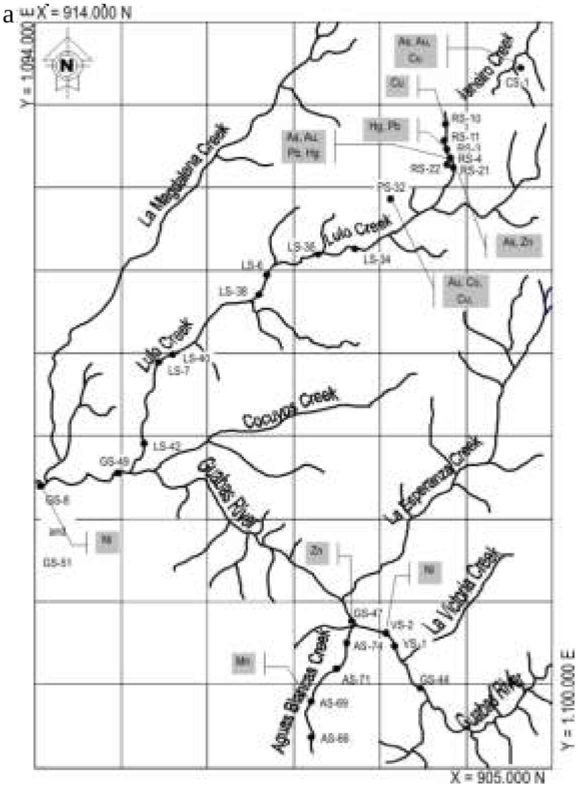

Figure 5. Sampling and positive geochemical anomalies location map for the stream sediment samples from the Auriferous District of Ginebra. Origin of plane coordinates in Bogota's Observatory datum. (•: sampling point; As: >19,8 ppm; Au: >4,1 ppm; Co: >35,3 ppm; Cu: >109,9 ppm; Hg: >1343,1 ppb; Mn: >748,7 ppm; Ni: >83,6 ppm; Pb: >137,2 ppm; Zn: >53,7 ppm).

Each of the stream sediment samples was hand collected and placed in transparent plastic bags until completing about 1 *kg*.

Thereinafter, all the water and stream sediments samples were duly packed for transportation and carried out to the INGEOMINAS (Colombian institute of geoscientific, mining, environmental and nuclear research and information) laboratories in Bogotá, D.C., to be analyzed.

Concentrations of Au, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn in water samples were determined using graphite furnace coupled to an atomic absorption spectrometer (GF-AAS) techniques while hydride generator coupled to an AAS (HG-AAS) was used to determine concentrations of As and Hg.

For almost all the chemical analysis of the stream sediments, a mixture of HNO_3–HCl was added to the samples before to be heated in water bath. In the case of the gold analysis, the samples were calcined before adding a mixture of HNO_3–HCl and $KBrO_4$ to destroy the sulfides and release the gold. Analysis of Ag, As, Au, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn were carried out as for the water samples.

Following the methodology of Garret (1984), the results from the chemical analysis were grouped inside frequency histograms where the number of class intervals was calculated using the Burgess' formulation:

$$\text{Number of class intervals} = 1 + 3{,}3\log(n)$$

where n: number of total samples.

All data values were normalized and logarithmic transformations were carried out where needed, as well as the elimination of outlier values.

The positive or negative geochemical anomalies for each one of the analyzed elements was determined using the Hawkes & Webb (1962) math formulation, as follows:

$$t = \bar{x} \pm 2s$$

where t: threshold (limit value), $\bar{x}$: mean, s: standard deviation.

Data values above higher threshold are considered positive geochemical anomalies, while data values below minor threshold are negative geochemical anomalies.

In order to evaluate possible inter-dependence among chemical elements, the Pearson's correlation coefficients matrix was calculated over the results from the chemical analysis for both water and stream sediment samples.

Results

The pH of the natural water from the ADG ranged between 6,71 and 8,09, but the input of mine effluents into the creeks produced pH decay till about 4,0.

Except for As, geogene background measured for each one of the analyzed metals in the water samples was higher than the world background. However, some of the collected water samples showed also local positive geochemical anomalies (Table 1) for As (>1,3 *ppb*), Au (>0,18 *ppb*), Co (>7,7 *ppb*), Cr (>16,8 *ppb*), Cu (>24,7 *ppb*), Fe (>1,9 *ppm*), Mn (>78,4 *ppb*), Ni (>22,6 *ppb*), and Pb (>39,6 *ppb*).

On the other hand, positive geochemical anomalies in stream sediment samples were found (Table 2) for As (>19,8 *ppm*), Au (>4,1 *ppm*), Co (>35,3 *ppm*), Cu (>109,9 *ppm*), Hg (>1 343,1 *ppb*), Mn (>748,7 *ppm*),Ni (>83,6 *ppm*), Pb (>137,2 *ppm*) and Zn (>53,7 *ppm*).

Data values from Hg and Zn contents in the water samples, as well as the Ag in the stream sediment samples, were not statistically treated because the results were close or below the detection limit of the

Table 1. Heavy metal contents in water samples from the Auriferous District of Ginebra.

Sample	Cu (*ppb*)	Pb (*ppb*)	Ni (*ppb*)	Co (*ppb*)	Mn (*ppb*)	Cr (*ppb*)	As (*ppb*)	Fe (*ppm*)	Hg (*ppb*)	Au (*ppb*)	pH
AA-62 *	22,47	9,80	7,57	<5	52,79	<5	<0,5	<0,1	<0,5	0,140	6,76
AA-65 *	13,70	5,65	<5	<5	20,87	<5	0,51	<0,1	<0,5	0,090	7,12
AA-68 *	11,95	3,22	8,43	<5	11,34	<5	0,61	<0,1	<0,5	0,040	7,33
AA-70 *	16,45	<3	<5	<5	3,88	<5	0,74	<0,1	<0,5	0,180	7,6
AA-73 *	12,20	<3	<5	<5	17,77	<5	<0,5	<0,1	<0,5	0,040	7,78
CA-02	12,95	3,58	5,18	<5	13,66	<5	<0,5	<0,1	<0,5	0,080	7,3
GA-10	10,45	5,65	<5	<5	23,44	<5	0,56	0,1	<0,5	0,002	7,86
GA-43	11,20	4,61	<5	<5	22,41	<5	0,79	0,2	<0,5	0,260	7,09
GA-46	11,20	3,58	<5	5,54	18,29	<5	0,56	0,1	<0,5	0,040	7,15
GA-48	10,69	4,27	<5	<5	24,47	<5	n,d,	0,2	<0,5	0,070	7,23
GA-50	12,45	3,58	<5	<5	16,75	<5	0,56	0,1	<0,5	0,060	7,22
LA-08	21,46	7,03	18,10	<5	43,52	<5	0,65	0,3	<0,5	n,d,	7,7
LA-09	25,22	11,19	<5	<5	20,87	<5	0,88	0,6	<0,5	n,d,	7,53
LA-33	50	119,4	19,05	7,42	100	17,68	4,23	2,6	<0,5	0,012	6,71
LA-35	42	114,04	22,4	<5	50	5,48	3,21	1,9	<0,5	0,024	6,72
LA-37	25,22	43,01	5,18	<5	50	7,77	1,54	1,6	<0,5	0,040	6,75
LA-39	13,95	19,49	<5	<5	46,09	<5	0,98	0,6	<0,5	0,002	6,81
LA-41	11,45	8,76	5,18	<5	37,86	<5	1,12	0,3	<0,5	n,d,	6,85
RA-06	19,46	7,03	<5	<5	5,42	<5	2,28	<0,1	<0,5	0,062	7,0
RA-07	34,23	29,87	59,32	41,24	260	13,10	1,19	2,0	1,09	n,d,	5,16
RA-09 *	9,45	<3	<5	<5	30,6	<5	<0,5	<0,1	<0,5	0,040	7,2
RA-20	16,70	34,71	57,32	29,73	1370	62,92	<0,5	0,2	<0,5	0,002	4,0
VA-01	11,95	<3	18,57	<5	27,56	<5	<0,5	<0,1	<0,5	0,160	8,09
VA-02	10,95	<3	<5	<5	32,97	<5	<0,5	<0,1	<0,5	0,020	7,5
VA-03	13,70	9,46	12,36	7,18	25,50	<5	<0,5	0,1	<0,5	n,d,	6,78
VA-04	11,95	22,26	6,62	<5	87,80	<5	<0,5	0,2	<0,5	n,d,	7,21
VA-05	9,69	3	6,62	<5	5,16	<5	<0,5	<0,1	<0,5	0,044	7,5
World Mean	1,8 [a,b]	0,2 [c]	0,3 [a]	0,05[d]	< 5 [e]	0,5 [c]	2 [f]	0,03 [e]	0,01 [g]	0,04 [h]	---

*: sample used to determine the geogene background. n.d.: non determined. [a]: Gibbs (1977). [b]: Boyle (1978). [c]: Trefry & Presley (1976). [d]: Turekian *et al.* (1967). [e]: Kennedy *et al.* (1974). [f]: Kanamori & Sugawara (1965). [g]: Förstner & Witmann (1983). [h]: Crocket (1974).

analytical method (0,5 ppb, 5 ppb and 1 ppm, respectively).

The Pearson's correlation matrix for the water samples showed highly positive correlation between Cu-Pb (r^2 = 0,952), Cu-As (r^2 = 0,928), Cu-Fe (r^2 = 0,921), Fe-Pb (r^2 = 0,946) and Fe-As (r^2 = 0,880), as well as highly negative correlation between pH-Co (r^2 = -0,888), pH-Cr (r^2 = -0,896), pH-Mn (r^2 = -0,895) and pH-Ni (r^2 = -0,815).

For the stream sediment samples, higher positive Pearson's correlation were found between Co-Mn (r^2 = 0,713), Cr-Mn (r^2 = 0,795), Cr-Ni (r^2 = 0,625), Au-Cu (r^2 = 0,648), Au-As (r^2 = 0,675), and the main negative correlations were between Mn-Pb (r^2 = -0,691), Au-Ni (r^2 = -0,611), As-Ni (r^2 = -0,590), As-Mn (r^2 = -0,622) and Cr-Pb (r^2 = -0,608).

Discussion and conclusions

Positive geochemical anomalies were observed related to sewage sludge effluents from the mines, as shown in the plotted maps (Figures 4 and 5).

Despite some positive geochemical anomalies for several toxic trace elements had been found along the Lulo Creek and the Guabas River, the samples collected close to the aqueduct catchments showed only a positive anomaly for Ni in the stream sediments.

The cause of this low dispersion of analyzed chemical elements in the District could be explained as follows.

The grinding of the ore mineral increases the mineral surface and accelerates the oxidation process. Then, as a product of the oxidation of sulfides, minor quantities of sulfuric acid are formed and the pH of the water is locally decreased close to sewage sludge effluents from the mine into the creeks, increasing the local concentration of several toxic heavy metals.

Furthermore, the influence of the pH could also be verified from the Pearson's correlation matrix, where negative correlation between the pH of the water and the toxic chemical element concentrations were found.

But because of the presence of basic rocks, the pH of the ADG's natural waters ranges from mildly acid to mildly basic, and the water alkalinity lets the elements in solution quickly reach its hydrolysis point and precipitate. Rather, the stream water of the ADG is behaving as a great

Table 2. Heavy metal contents in stream sediment samples and one sample of sediments in suspension from the Auriferous District of Ginebra.

Sample	Cu (*ppm*)	Pb (*ppm*)	Zn (*ppm*)	Ni (*ppm*)	Co (*ppm*)	Ag (*ppm*)	Mn (*ppm*)	Fe (%)	Au (*ppm*)	Hg (*ppm*)	As (*ppm*)	Cr (*ppm*)	Cd (*ppm*)
AS-66 *	52	14	40	50	30	<1	660	4,6	<0,05	113	1,0	174	1,0
AS-69 *	36	16	40	63	30	1	780	4,2	<0,05	95	1,0	235	1,0
AS-71 *	37	17	31	62	30	1	630	3,7	<0,05	89	1,0	311	1,0
AS-74 *	41	18	33	61	30	1	670	3,8	<0,05	124	2,0	306	1,0
CS-01	226	100	16	35	30	1	290	2,6	5,0	280	26,0	13	1,0
GS-08	68	25	46	86	24	<1	430	3,8	<0,05	156	3,0	145	1,0
GS-44	58	25	45	72	25	<1	410	4,2	0,10	60	1,0	136	0,9
GS-47	79	87	55	77	25	<1	413	4,0	0,18	366	1,0	146	1,1
GS-49	62	90	48	79	22	<1	380	4,2	0,06	142	1,0	138	1,0
GS-51	68	79	50	85	23	<1	410	3,9	0,06	240	1,0	142	1,0
LS-07	82	80	40	39	18	<1	220	3,5	0,60	190	5,5	97	1,0
LS-34	80	100	37	35	20	<1	n,d,	n,d,	0,70	540	11,0	74	0,8
LS-36	72	113	34	36	19	<1	170	3,2	0,60	620	6,6	73	0,7
LS-38	80	127	42	43	20	<1	200	3,3	0,40	414	13,0	96	1,0
LS-40	93	133	44	45	21	<1	260	4,0	0,52	650	13,0	103	1,0
LS-42	100	132	46	42	22	<1	330	4,4	0,50	1150	13,0	112	1,0
LS-6-1	77	85	40	35	18	<1	220	4,1	0,46	865	9,9	86	1,0
LS-6-2	71	67	35	35	17	<1	190	3,4	1,26	780	5,0	80	1,0
PS-32	265	73	45	30	40	1	310	4,6	4,72	<50	6,6	21	1,0
RS-03	44	254	44	22	17	2	240	4,0	3,28	8170	5,0	39	1,1
RS-04	81	152	36	30	14	5	90	4,7	5,06	17516	39,0	72	1,0
RS-10 *	121	17	32	55	32	<1	720	4,5	0,23	349	3,0	146	0,9
RS-11	36	43	38	26	24	<1	260	4,0	1,6	343	5,0	45	0,8
RS-21	74	110	369	27	18	<1	90	3,8	1,6	1100	22,0	60	1,0
RS-22	79	176	30	25	16	<1	90	3,0	1,12	405	21,0	61	1,0
VS-01	56	14	43	70	21	<1	360	3,5	<0,05	<50	2,0	139	0,8
VS-02	61	20	42	84	22	<1	400	4,0	<0,05	50	2,0	157	1,0
World Mean	31 [a]	20 [b]	95 [b]	32 [a]	13 [a]	0,07 [b]	600 [b]	4,72 [b]	0,0X [c]	0,2 [b]	13 [b]	60 [a]	0,3 [b]
LC-SS**	201	618	99	114	25	3	390	5,2	1,5	1,2	27	380	1

*: sample used to determine the geogene background. **: sediments in suspension sample. n.d.: non determined. [a]: Salomon & Förstner (1984). [b]: Turekian & Wedepohl (1961). [c]: According to Turekian & Wedepohl (1961), the world background is about of tenth of *ppb*, or rather 0,0X *ppm*, though they do not establish a numerical value.

buffer solution, already capable of controlling the pollution by sewage sludge of the mines.The distance between the sewage sludge effluents into the creek and the positive geochemical anomalies for some metals as a function of their pH of hydrolysis, the presence of Fe^{3+} and Mn^{2+} as colloids and their mobilization capability in the secondary geochemical environment was also reported by Muñoz-Ramos (1995).

This conclusion could also be verified in the results for the stream sediments samples, where greater toxic elements concentrations may be associated with the acidic effluents from the mines of the Auriferous District.

High concentration of As and Pb could not be explained as oxidation product from the ophiolitic massif of Ginebra minerals but from the arsenopyrite (FeAsS) and galena (PbS) in the acidic rocks, because of the negative Pearson's correlation between Mn-Pb, As-Ni, As-Mn and Cr-Pb.

Then the positive Pearson's correlation for Au-Cu, Au-Pb, Au-As, may supports the possibility of a magmatic origin for the Au, from the intrusion of the Buga Batholit.

Co, Cu, Fe, Mn and Ni could not be strongly hazardous to human health if ingested in the drinking water (Rodier 1981, ATSDR 2000, 2001, 2002, 2003), but As, Cr, Hg and Pb top the priority list of hazardous substances (ATSDR 1999).

Because of the negative correlations Hg-Ni, Hg-Co, Hg-Mn and Hg-Cr, as well as the positive correlation Hg-Au, presence of the Hg is explained by an anthropogenic input, as result of its non-technical use and recuperation.

The volume of Hg emissions to the environment is the main pollutant problem in the ADG. High concentrations of this toxic metal are observed in sewage sludges and downstream from de inputs of the mine effluents into the creeks. Aerial transportation of Hg was also deduced from a vertical variation of the Hg concentrations in the soils around the gold-ore-processing plants (Buenaventura & González 1994, Muñoz-Ramos 1995).

The chip type rock samples from the Cueva Loca mine showed concentrations of Au about 16,2 g / t, while the tenor for El Retiro mine ranged between 1,14 and 5,54 g / t (Buenaventura & González 1994).

Comparing these results against concentrations in downstream sediments collected for this study nearby their sewage sludge effluents into the creeks, it could be possible calculate gold losses of about 30 % at Cueva Loca mine and about 20 % at El Retiro mine. The losses are product of non-technical processing of the ore mineral.

These results open a possibility of investment for updating the gold-ore-process to improve the gold production in the ADG. Consequently, a change from non-technical small-scale mining to industrialized-mining could also increase the volume of acidic effluents from the mines to the stream water of the sector. It would may become available the toxic heavy metals, because of the increasing of the potential risk of variations of the pH and redox conditions for the auriferous district, if there is not quite attention for disposal of tailings.

On the other hand, rests of large flows or avalanches in the recent history can be observed along the Lulo creek basin. This fact increases the potential risk of a mechanical transport of sediments that could carry them close to the aqueduct catchments or downstream, where the pH and redox conditions are favorable for releasing their toxic metals content.

During this study, it was determined that Lulo Creek, downstream El Retiro mine, has a mean flow of about 11,6 l / s and loads approximately 34,3 g / l of sediments in suspension, with about 80 % of its particles lesser than 80 mesh. The concentration of the chemical elements analyzed in this type of sediments is quite high when compared against the concentrations in the other stream sediment samples (LC-SS sample in Table 2). Moreover, concentrations above the local background were also found for As, Au, Cu, Fe, Hg, Ni and Pb.

Lulo Creek has a mean flow of about 50 l / s in its outlet, while the mean flow of Guabas River is about 7 m^3 / s. This fact, added to the buffer effect of the natural water from the study area, lets a good dilution of the chemical elements before they arrive to the aqueduct catchments. The concentrations of chemical elements in the water samples from the aqueduct catchments for Ginebra and Guacarí municipalities are less than the ruled by Ministerio de Salud (1998) for drinking waters in Colombia.

In order to avoid environmental pollution, technical advice is necessary for the gold miners to design and construct stream sediment traps, as well as for training and implementation of easy and cheap methods for recovering the mercury used in the amalgams, such as the use of distillation retorts.

A program of continuous water and sediments monitoring in the ADG, as well as periodic analytical determination of heavy metals concentrations in human tissues from the inhabitants of Ginebra and Guacarí municipalities should be designed. Those data will let the municipal authorities to get corrective actions on time before a high contamination occurs.

Due to the intensive use of wood for building small tunnels, galleries and camps at the vein type minings, a forestation program of the Guabas river and affluents' basin in the ADG is needed for avoiding landslides, land slumps and soil erosion. These phenomena could cause avalanches and undesired non-controlled remobilization of sediments.

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