Centro de Tecnologia Mineral
(Mineral Technology Center)
Ministério da Ciência, Tecnologia e Inovação
(Ministry of Science, Technology and Innovation)

Coordenação de Processos Minerais – COPM
(Mineral Processes Coordination)

Funcate – Fundação de Ciência, Aplicações e Tecnologias Espaciais
(Space Science, Application and Technology Foundation)

FINAL REPORT
"ASSESSMENT OF ENVIRONMENTAL CONTAMINATION BY ARSENIC AND EPIDEMIOLOGICAL STUDY OF THE ASSOCIATED ENVIRONMENTAL EXPOSURE IN HUMAN POPULATION OF PARACATU-MG"

December 09, 2013

VERSION 1

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- Ricardo Sierpe - Geographer
  - Organization of primary and secondary data in Georeferenced Information Systems;
- Vanessa Godoy - Geographer

- Organization of primary data of arsenic contents in human biological samples in Georeferenced Information Systems ;

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EXECUTIVE SUMMARY

The primary purpose of this project was to answer to the Paracatu City Public Authorities on the levels of human exposure to arsenic (As) and its associated risks to the local population's health.

An Action Plan was developed based on the As toxicology and the activities were carried out in two stages. Inorganic As is considered the most toxic form of the element; a wide variety of health adverse effects including skin and internal organs cancer and cardiovascular and neurological effects have been assigned to chronic exposure to As, mainly by oral ways by water intake. Inhalation contributes with less than 1% of the total dose; As half life time in human body is only a few hours and its excretion is primarily made through the urine but it also binds to keratin. Therefore the analysis of total As in urine and blood matrixes indicates acute exposure levels (days) while the analysis of As in the hair indicates chronic exposure (6 months to 1 year). The characteristic pattern of change of the skin caused by arsenic (hyperkeratinization, hyperpigmentation) is most likely the most sensitive clinic indicator and diagnostics of As chronic exposure (many years).

Thus, Stage 1 included the characterization of As levels in environmental compartments (public supply water, surface water, ground water, bottom sediment, soil and particulate material in the atmosphere), as input to the epidemiological study and assessment of human exposure. Additionally a survey was carried out of cancer mortality data in Paracatu population as well as an analysis of the city database on out-of-home treatment, emphasis on cancer cases and a review of social media as grounds for communication of results. Stage 2 is related to the epidemiological study and the assessment of exposure biomarkers (As in urine, blood and hair) and effects by investigation of dermatoses and dermatology cases referred to in the Paracatu PSFs.

The chemical analyses of arsenic in environmental and biological matrixes were conducted in CETEM/MCTI specialized labs of the Evandro Chagas Institute/MS, the UFF/MEC Graduate Course and in commercial labs; intercalibration exercises came up satisfactory.

Results revealed low arsenic contents in household supply waters and in particulate material in the atmosphere within the expected ranges for urban areas but with higher contents in areas near the gold mining.

Considering the potential low chronic environmental exposure, the possible effects would be expected after a long period of environmental exposure. Thus the epidemiological strategy followed the sectional methodology with convenience sampling and inclusion criteria considered the Paracatu resident more than 20 years with more or less 40 years of age, living in districts located near the gold mining activities (served by PSF Amoreiras and selected for this study: Amoreiras II, Esplanada, Nossa Senhora Aparecida and Alto da Colina) or in a district far from the gold mining, the Paracatuzinho district served by PSF Paracatuzinho, considered as reference area.

The As contents in urine, hair and blood of the sampled population indicate current low exposure of human population to As in line with the environmental data obtained .

Results in surface waters, soils and sediments are discussed within the text; analyses of social media as strategy of communication of results of this research project are also presented herein as well as complementary activities.

The recommendations to the City Authorities are offered at the end of this Report.

1. INTRODUCTION

In answer to the request by Paracatu – MG City Hall (PMP), CETEM/MCTI coordinated actions to form a team of researchers with high recognition in the scientific community and presented in 2010 a work proposal for "Assessment of Environmental Contamination by Arsenic and Epidemiological Study of the Associated Environmental Exposure in Paracatu-MG Human Populations". The researchers were invited according to their specialization in environmental toxicology, epidemiology, clinical toxicology, environmental medicine, environmental chemistry, environmental geochemistry, assessment of human health and environment risks, to name a few, as shown in the Technical Team. The studies commenced in March 2011 (with the release of the first portion of resources) and conclusion in December 2013. Five (5) Partial Reports were delivered to Paracatu City Hall (September 2011, July 2012, December 2012, March 2013 – Project Progress Report – and June 2013).

The main purpose of this project was to conduct an assessment of environmental contamination by arsenic and an epidemiological study of the associated environmental exposure in human populations in the municipality.

For that, the activities based on the Action Plan (described below) were carried out basically in two stages. Stage 1 included the characterization of arsenic levels in environmental compartments (public supply water, surface water, ground water, bottom sediment, soil and particulate material in the atmosphere), a survey of cancer mortality data in Paracatu population emphasizing the cases having proven association with arsenic environmental / occupational exposure (and comparison with rates observed in other townships, regions and in the Country) and analysis of the city database on out-of-home treatment, emphasizing cancer cases. The results were inputs to the strategic planning of the epidemiological study and assessment of human exposure. Furthermore a study of review of social media was carried out as a basis for communication of results. Stage 2 concerns the epidemiological study and assessment of human exposure to arsenic including investigation of skin disease cases referred to in Paracatu PSFs.

This Final Report presents the main works of assessment of levels of human exposure to arsenic carried out by measurement of arsenic contents in biological indicators (urine, blood and hair) and the consolidated data of all previous steps conducted during Stage 1 and ends with the conclusions and recommendations of future actions to Paracatu City Hall.

2. ACTION PLAN

The arsenic (As) toxicology was considered as primary grounds for the proposed Action Plan. Inorganic As is considered the most toxic form of this element and is found virtually in all environmental compartments being of particular interest in surface, ground waters and in certain foods. A wide variety of health adverse effects including skin and internal organs cancer and cardiovascular and neurological effects have been assigned to chronic exposure to As, mainly by oral ways by water intake. Most As environmental exposure assessment studies were carried out in human populations exposed to variable contents of As by oral ways, ingestion of contaminated water. Most studies on As human exposure by inhalation is from occupational exposure, that is, in exposure situations in work environment. We can say that, in most situations, the oral exposure is the most important way of exposure, while inhalation contributes with less than 1% of total dose; drinking water is the most important way of oral exposure of human populations to inorganic As (ASTDR, 2007). Considering that the arsenic half life time in the human body is only a few hours and its excretion is mainly by urine, the analysis of total arsenic in urine and blood matrixes indicate acute exposure levels (days) while analyses of arsenic in hair indicate chronic exposure (6 months to 1 year). The characteristic pattern of change in skin color caused by arsenic (hyperkeratinization, hyperpigmentation) is probably the most sensitive indicator and clinical diagnostic of chronic exposure to arsenic (many years) .

3. ACTIVITIES CARRIED OUT

The Action Plan was designed after holding the I Technical Workshop of Paracatu Project with the presence of the coordinators of the project sub-areas and invitees. During the execution of the project other five (5) Technical Workshops were

held at CETEM for discussion of strategies, methodologies and results. Several other technical meetings were held in specific sub-areas, on site and/or by video-conferences .

Considering the Action Plan established by the technical team the action strategies were designed and the consequent activities were carried out briefly described herein divided in the two stages already referred to above:

a) Definition of sampling sites considering the technical registry of the urban population consumption water supply; collection and analysis of As in supply waters of urban network and in some points of the rural network managed by PMP;

b) Obtainment of authorization of major owner companies for collection of well water in different locations of the municipality; collection and analysis of As;

c) Definition of sampling sites considering the Paracatu River sub-basins in Paracatu Municipality, collection of surface waters, sediments and soils and analysis of As in such matrixes aiming at the characterization of environmental distribution of the element;

d) Obtainment of filters with particulate material in the atmosphere sampled in Paracatu and analysis of As in the filters;

e) Assessment of As contents in particulate material in the atmosphere and its potential implications to human health;

f) Application of methodology of review of social media in the districts served by Paracatuzinho and Amoreiras PSFs and their major results;

g) Obtainment of project approval by the Ethics Committee;

h) Analysis of cancer mortality rates in Paracatu and comparisons with the rates of other townships, regions and in the Country using DATASUS data and assessment of potential use of information from the Paracatu population cancer cases database;

i) Definition of the epidemiological study pillars based on the Action Plan premises and environmental results obtained, including criteria of inclusion in the study, methodologies for collection of the population biological material, system of records and documentation, logistics of the epidemiological study field works, packing and transport of biological samples to specialized labs;

j) Training of technical teams in Paracatu;

k) Analyses of the city database of out-of-home treatment focusing on oncology cases;

l) Assessment of daily attendance records at the PSFs aiming to identify cases of chronic skin diseases with potential causal relationship to environmental exposure to arsenic;

m) Publication of results already presented to Paracatu City Hall in specialized scientific forums.

4. MATERIALS AND METHODS

4.1 Sampling Plan

a) Environmental Samples

a.1 Sampling of Human Consumption Water

The sampling of human consumption water was conducted in May 2011 and totaled 41 samples referenced to COPASA technical registry covering impounding, treated water, storage and distribution. Water in households was also collected especially those located at the “line end” of the distribution system, as well as water from wells used for supply in rural areas. The line-end households are important as they can be vulnerable points to post-treatment contamination in the event of rupture or breakage of piping and negative pressure to lack of supply. Table 1 shows the location of sampled points.

Table 1 – Location of collection points and inventory of sampling carried out in Paracatu (MG).

Point	Location	Description	Characteristic
1	S 17.26550 W46.95534	Impounding of Santa Izabel Brook	Raw river water
2	S 17.25891 W46.94344	Sta Izabel Brook ETA (Water Treatment Plant)	Raw river water
3	S 17.25891 W46.94344	Sta Izabel Brook ETA	Treated water
4	S 17.23577 W46.89739	Paracatuzinho Reservoir receiving treated water from Sta Izabel ETA	Treated water
5	S 17.23069 W 46.87097	ETA Santana C 10	Raw water from artesian wells
6	S 17.23069 W 46.87097	ETA Santana E 02	Raw water from artesian wells
7	S 17.23069 W 46.87097	ETA Santana C 06	Raw water from artesian wells
8	S 17.23069 W 46.87097	ETA Santana C 08	Raw water from artesian wells
9	S 17.23069 W 46.87097	ETA Santana E 07	Raw water from artesian wells
10	S 17.23069 W 46.87097	ETA Santana E 06	Raw water from artesian wells
11	S 17.23069 W 46.87097	ETA Santana E 04	Raw water from artesian wells
12	S 17.23069 W 46.87097	ETA Santana C 12	Raw water from artesian wells
13	S 17.23069 W 46.87097	ETA Santana C 02	Raw water from artesian wells
14	S 17.23069 W 46.87097	ETA Santana	Raw water from artesian wells
15	S 17.23435 W 46.86286	RAP Vila Mariana	Treated water solely from the Santana ETA
16	S 17.22257 W 46.85784	REL JK	Treated water mainly from Santa Izabel ETA
21	S 17.20552 W 46.87423	RAP Amoreira 2	Treated water mainly from Santa Izabel ETA

Table 1 – Continued

17	Avenida Eduardo Ferreira de Araujo	Vista Alegre District
18	Rua Antonia Neto Siqueira	Vista Alegre
19	Rua Severiano Silva Neiva	Alto do Açude District
20	Rua Vicente Lopes Costa	Alto do Açude
22	Rua Cristal	Esplanada District
23	Rua Amélia da Silva Neiva	Esplanada
24	Rua Prata	Amoreiras 2
25	Rua Esmeralda	Amoreiras 2
26	Rua 6	Bela Vista 2
27	Rua Elisabeth	Alta Colina
28	Rua João Macedo	Bela Vista
29	Rua Francisco Melo	Bela Vista
30	Rua Pedro Araújo Caldas	Cidade Nova
31	Rua João Paulo II	Bom Pastor
32	Rua Perimetro	Paracatuzinho
33	Rua Ricardo Adjoto	Paracatuzinho
34	Rua Benedito Oliveira Melo	Paracatuzinho
35	Rua Jacaranda	Primavera
36	Rua Belmiro Araujo Neves	Novo Horizonte
44	Avenida Olegario Maciel	Downtown
46	Rua Bento Pereira Mundim	Downtown

Table 1 – Continued

38	Untreated raw water from the Marinho Farm well	
39	Reservoir of water from the Santo Antônio Lake Well	Lagoa de Santo Antonio Village
41	Well raw water with no chlorination collected in nearby house	Sao Sebastião Well
42	Well water with chlorination each 8 days: Rua da Igreja	São Domingos Village

a.1.1 Sampling of Ground Waters

Samples of ground water were collected in November and December 2011 totaling 25 samples located in different points in the Municipality including those in Dow, Monsanto and Coopervap industries, in addition to Copasa wells which were collected in two occasions. The Kinross and Votorantim mining companies monitoring wells were also sampled; Table 2 shows the location of sampled wells.

Table 2 – Location of Ground Water Collection Points (consumption and monitoring wells) conducted in (MG).

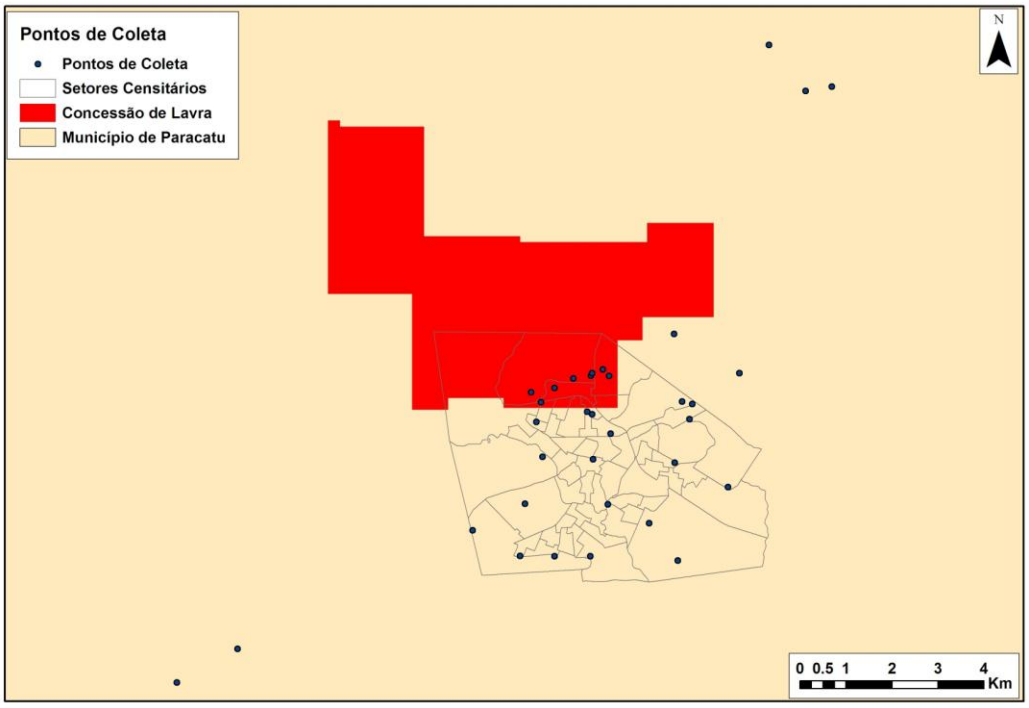
	SAMPLE	DATE	LOCATION	COORDINATES	
HUMAN CONSUMPTION WATER	1	29/11/2011	DOW	S17°12'00,3"	W46°50'41,4"
	2	29/11/2011	DOW	S17°12'07,0"	W46°50'36,8"
	3	29/11/2011	MONSANTO	S17°11'55,5"	W46°50,41,0"
	4	29/11/2011	COOPERVAP/SEDE	S17°12'55,7"	W46°52'16,0"
	5	29/11/2011	COOPERVAP/GRÃOS	S17°14'15,3"	W46°50'56,0"
	6	29/11/2011	COOPERVAP/USINA	S17°14'26,6"	W46°50'49,0"
	9	30/11/2011	COPASA		
	10	30/11/2011	COPASA		
	11	30/11/2011	COPASA		
	12	30/11/2011	COPASA		
	13	30/11/2011	COPASA		
	14	30/11/2011	COPASA		
	15	30/11/2011	COPASA		
	16	30/11/2011	COPASA		
	17	30/11/2011	COPASA		
MONITORING WELLS	7	12/01/2011	KINROSS	S17°08' 6,0"	W46°50'59,7"
	8	12/01/2011	KINROSS	S17°11'34,2"	W46°53'40,7"
	18	13/12/2011	VOTORANTIM	S17°30'526"	W046°49'725
	19	13/12/2011	VOTORANTIM	S17°30'827"	W046°49'586
	20	13/12/2011	VOTORANTIM	S17°30'871"	W046°49'873
	21	13/12/2011	VOTORANTIM	S17°31'048"	W046°49'305
	22	14/12/2011	VOTORANTIM	S17°29'400"	W046°48'726
	23	14/12/2011	VOTORANTIM	S17°29'720"	W046°49'183
	24	15/12/2011	VOTORANTIM	S17°29'588"	W046°49'669
	25	15/12/2011	VOTORANTIM	S17°30'210"	W046°49'509

- COPASA wells have no coordinates because they were collected at the inlet of ground waters at the Treatment Plant.

The quantification of As concentrations in samples of water, soils and sediments was carried out in ICP-MS, with detection limit of 0,5 µg/L for water and 0,5 mg/Kg for soils and sediments. The minimum precision of As analyses is 90% and the minimum accuracy using certified samples is 95%.

Figure 1 shows a map with location of points of sampling of human consumption water carried out in this study.

Figure 1. Map with location of human consumption water sampling points carried out in this study



a.2. Surface Waters, Sediments and Soils

Two sampling campaigns were conducted for surface waters, sediments and soils; the sampling conducted in October 2010 included collection of surface water (n=23), soils (n=17) and river sediments (n=17) in 23 collection points located in three Paracatu River sub-basins: Rico Creek, Entre-Ribeiros Brook and Escuro River. The collection comprised Paracatu River sub-basins under direct and/or indirect influence of anthropogenic activities (mining, impact of household sewage wastes or both) with little or no activity (sub-basins considered as control). The sampling carried out in September 2011 included sampling of surface water (n=18), soils (n=10) and river sediments (n=15) in 17 collection points in the same Paracatu River three sub-basins, aiming to complement the first campaign and consolidating the environmental sampling,

Table 3 shows the geographic location of all collection points; the maps of Figure 2 and 3 show the cartographic location of collection points and Figure 4, 5 and 6 present in schematic form the position of sampling points along the three sub-basins focused herein.

Table 3 –Geographic location, description of collection points and inventory of sampling of surface water (A), sediments (SD) and soils (SL) .

Sample	Sub-basin	Creek	Coordinates		Collection			Description
			Latitude	Longitude	A	SD	SL	
X	Rico	Espalha	-17.22079	46.95077	X	X		Area with no mining impact near the creek head
X1			-17.22586	-46.90711	X			Area with no mining impact near the city
2		Rico	-17,21047000	-46,89061000	X	X	X	Immediately downstream the gold mining area /Kinross
1			-17,22494000	-46,88066000	X	X	X	Under the bridge near SESC/Paracatu.
14			-17,23167000	-46,87236000	X			Rico Creek upstream the Pobre Creek contribution
15			-17,22972000	-46,87576000	X		X	Under bridge, Rico Creek
13			-17,23181000	-46,87110000	X	X	X	Rico Creek downstream the Pobre Creek contribution
9			-17,30433000	-46,77095000	X	X	X	Under bridge on BR – 040 – to Belo Horizonte
8			-17,40291000	-46,53893000	X	X	X	Rico Creek under bridge
5			-17,41436000	-46,52701000	X	X	X	Mouth of Rico Creek in Paracatu River
10		Pobre	-17,21516000	-46,85888000	X	X	X	Near Pobre Creek heads
12			-17,22646000	-46,87221000	X			Channeled Pobre Creek in urban perimeter
06	Rio Paracatu		-17,41250000	-46,52928000	X	X	-	Upstream the Rico Creek contribution
07			17,41543000	46,52518000	X	X	-	Downstream the Rico Creek contribution
Y1	Ribeirão entre Ribeiros	Neto	-17,19850	-46,8243	X	X	X	Upstream the mouth with Santo Antônio River; former gold prospecting area
Y			-17,14397	-46,82473	X	X	X	Near mouth with Santo Antônio
3		Sto. Antônio	-17,14098000	-46,83941000	X	X	X	Downstream the gold mining tailings dam/ Kinross
20			-17,13772000	-46,82555000	X	X		Downstream Neto River /S. Domingos and upstream Sta Rita River
16		São Pedro	-17,11487000	-46,77425000	X	X	X	São Pedro River upstream Santa Rita River
17			-17,11679000	-46,77204000	X	X	X	São Pedro River downstream Santa Rita River
18		Sta. Rita	-17,11738000	-46,77230000	X	X		Santa Rita River
Y2			-17,11264	-46,84853	X	X	X	Santa Rita upstream Santo Antônio entrance
19			-17,13603000	-46,82159000	X	X	X	Santa Rita River downstream Santo Antonio river
21			-17,13618000	-46,82388000	X			Santa Rita River Dam
Y3			-17,12000	-46,76575	X	X	X	Votorantim Hydrological Station
22	Escuro	Sta. Isabel	-17,36456000	-46,85425000	X		X	Upstream Escurinho River; water impounding area for the city.
24		Traíra	-17,49077000	-46,81638000	X	X	X	Downstream zinc and lead mining / Votorantim (Morro Agudo).
23		Escurinho	-17,42770000	-46,82976000	X		X	Downstream Santa Isabel River
25			-17,47742000	-46,79919000	X		X	Downstream Sta Isabel River and downstream Traíra River (Votorantim water impounding area)

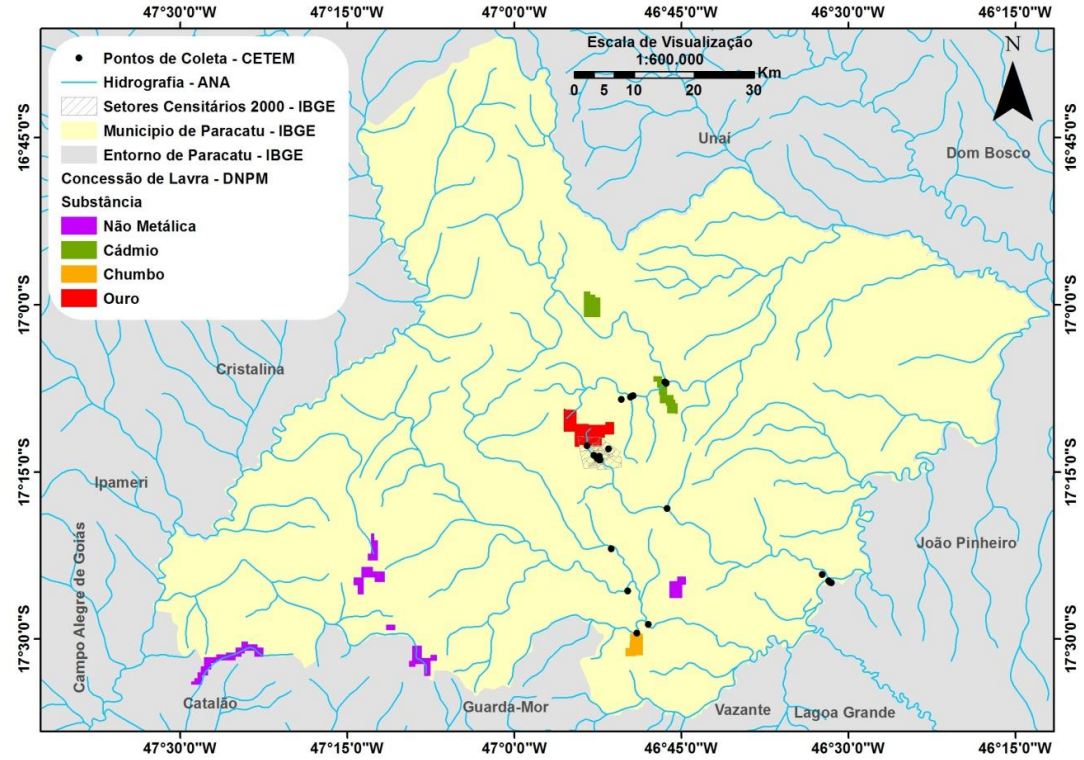


Figure 2: Cartographic Location of Points of Collection of Water, Current Sediments and Soils in Paracatu (MG): Overview.

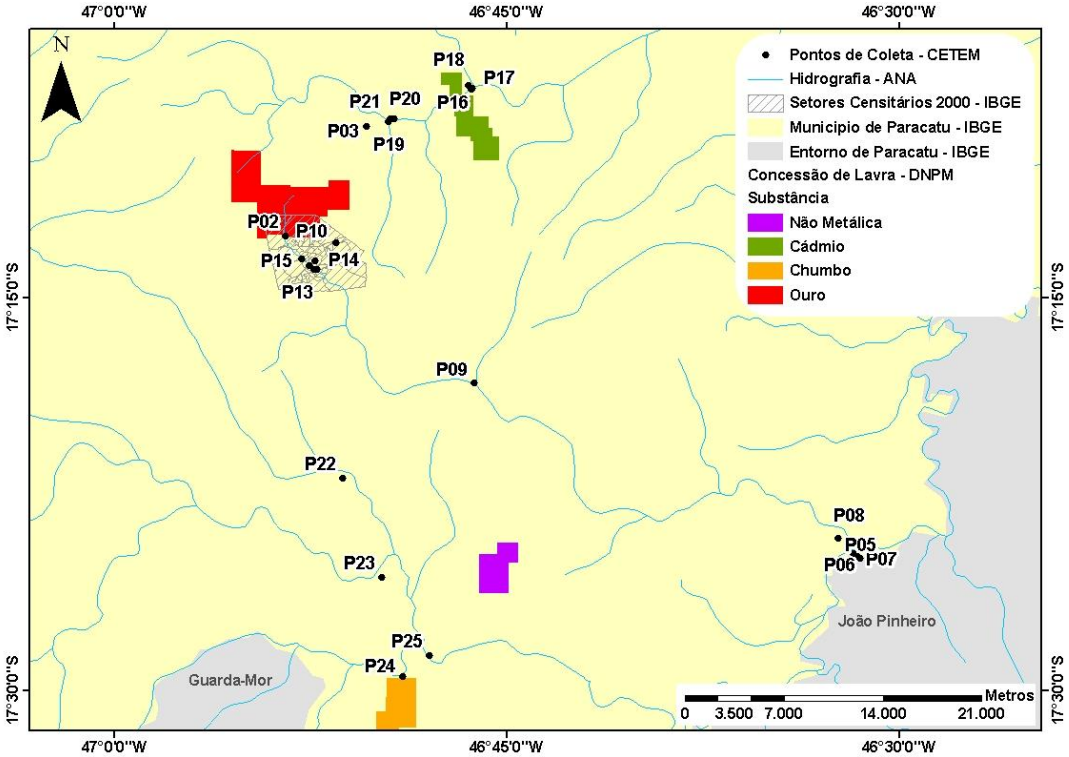


Figure 3: Detailing of Spatial Distribution of Collection Points in Paracatu (MG).

Figure 4. Schematic Positioning of Sampling Stations of Sub-Basins considered as Control in this Study

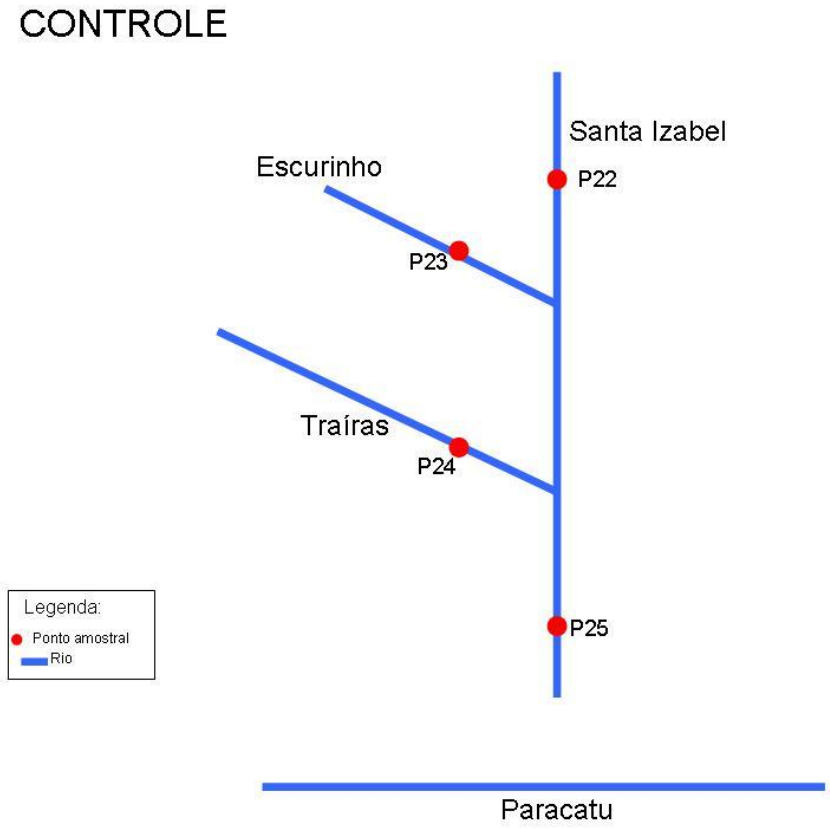


Figure 5. Schematic Positioning of Sampling Points along the Rico River basin within the gold mining hydrographic axle and urban area of City of Paracatu .

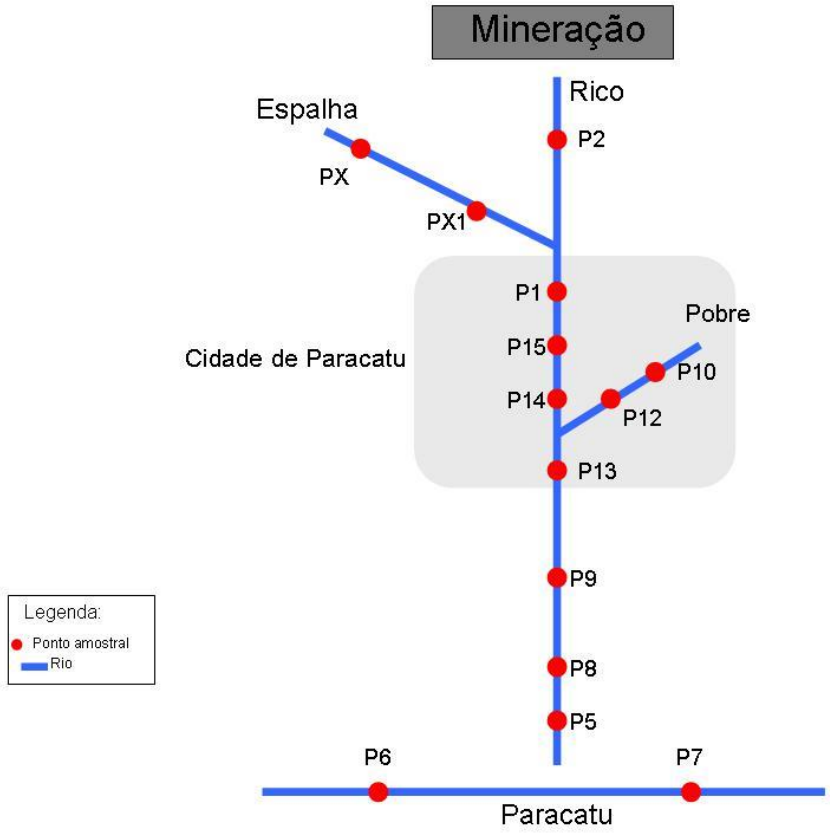
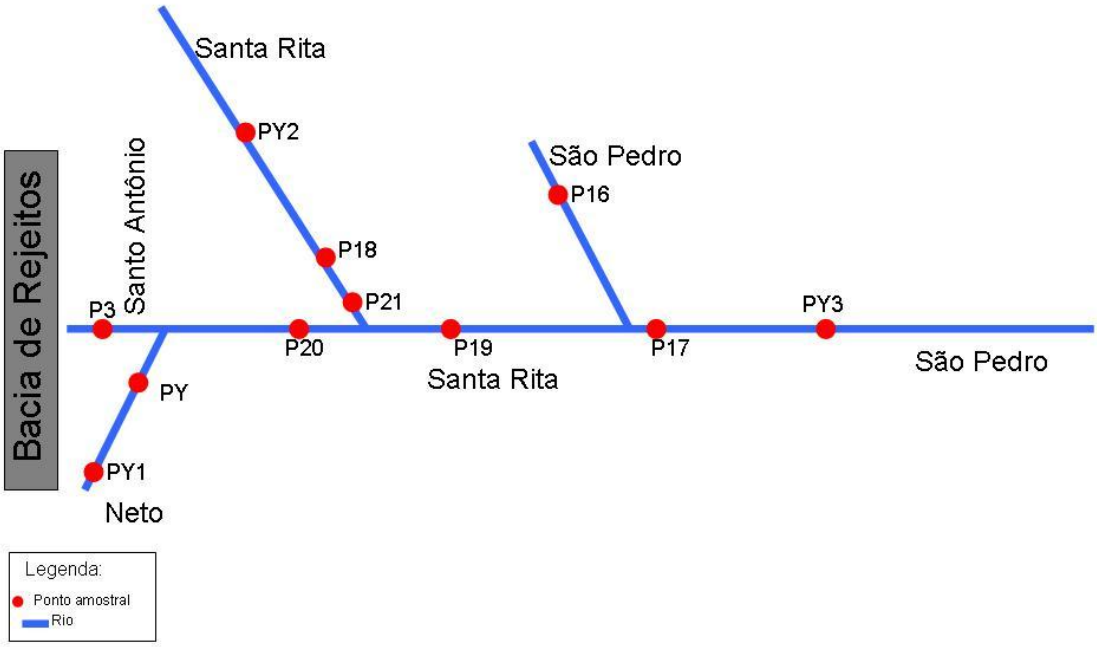


Figure 6. Schematic Positioning of Sampling Points along the Sub-Basins of the Tailings Basin Outlet Hydrographic Axle


Santa Rita
PY2
São Pedro
P16
Bacia de Rejeitos
Santo Antônio
P18
P3
P21
PY3
P20
P19
P17
São Pedro
Santa Rita
PY
PY1
Neto
Legenda:
Ponto amostral
Rio

a.3. Ecotoxicological Tests in Surface Water and Soils

Surface water and soils samples were subject of ecotoxicological tests aiming to estimate the bioavailable fraction of As as well as its toxic effects to the water and land biota. The test with *Daphnia similis* was selected for assessment of ecotoxicity of surface water as indicated by the Brazilian legislation; the acute testing was used for assessment of ecotoxicity of soils with invertebrate *Eisenia andrei,* having observed parameters of lethality, loss of mass and bioaccumulation of arsenic .

a.4. Sampling of Particulate Material (MP) Filters in the Atmosphere

The samples of filters containing total suspended particles (PTS) collected from the atmosphere refer to the 8 collection points existing in the Municipality and one of them – Arena Station – has two collectors: one of PTS and another of MP10 (inhalable particles). PTS is formed by suspended particles in the atmosphere of diameter below 100 μm (micrometers) and MP10 is formed by particles of diameter below 10 μm. Arsenic (As) concentrations were analyzed in filters from continuous 24-hour collection. Analyses were made in filters representing a collection of 24 hours per month covering the period between May 2011 and June 2012 of each of the 8 sampling points. Table 4 provides the name of the sampling points (stations) used for determination of As in the atmospheric MP, the type of MP samplers installed therein and the geographic coordinates of their locations. Amoreiras Stations has automatic samplers whose filters are inadequate to the determination of As in the collected MP. Figure 7 shows the spatial distribution of monitoring stations in the Municipality.

Table 4 – Type of Sampler and Location of Sampling Points for Determination of As in the Atmospheric Particulate Material in Paracatu (MG).

LOCATION	SAMPLER	Coordinates	
		E	N
1- ALTO DA COLINA	PTS	299332,000	8096560
2- COPASA	PTS	300650,313	8096702,615
3- DER	PTS	301309,338	8095542,753
4- UNIÃO	PTS	299558,869	8095548,609
5- SÃO DOMINGOS	PTS	302391,054	8097558,705
6- ARENA	PTS	298553,000	8096404,000
	MP10		
7- BARRAGEM	PTS	300317,000	8103144
8- LAGOA SANTO ANTÔNIO	PTS	305096,000	8102926
AMOREIRAS (Automatic Station)*	PM10 e PM 2,5	300719,000	8096800,000

PTS: Total Suspended Particles; MP10: Inhalable Particles; *Station with automatic sampler and type of filter improper to the determination of As in the particulate material by the methodology used in this work.

The filters used are in fiberglass and collected in equipment already available in Paracatu. As was analyzed in atmospheric MP at the CETEM Mineral Analyses Lab according to the US Environmental Agency methodology (United States Environmental Protection Agency – USEPA) based on "Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air" – Compendium Method IO-3.1.

First the method was validated and confirmed for the analysis of As present in the atmosphere MP sampled with fiberglass filters through addition tests and recovery with standard As solution and addition of certified reference material (MRC), adapted from the US Environmental Protection Agency method (US EPA).

Figure 7. Location of Sampling Stations whose PTS and MP10 sampler filters were used for the determination of As in the atmosphere particulate material in Paracatu (MG).

a.5. Assessment of Risks to Human Health

Arsenic data in surface water, soils and sediments of the three sub-basins under study (Rico Creek, Entre-Ribeiros Brook and Escuro Creek) were integrated into the arsenic data in the atmospheric material in the assessment of environmental exposure.

The arsenic concentrations in drinking water are not only below the quality limited set forth by the Brazilian Legislation and other countries, according to the WHO recommendations (10µg/L), but are also below the detection limit (<0.5 µg/L), except for one sample (1.6µg/L). Thus the ingestion of human consumption water was not considered a major exposure way to Paracatu population and in the present model the expression “water intake” or “water ingestion” is related to accidental ingestion during water recreation activities, swimming for example.

The assessment of risk to human health was conducted according to the methodology proposed by USEPA (1989) and suggested by CONAMA 420 (2009). Such methodology comprises 4 stages: 1) Preparation of a qualitative design model on the transfer of arsenic between environmental compartments (multi-means), ways of

exposure and potential receptors: adults and children; 2) Assessment of chronic exposure (magnitude, frequency and duration of exposure) to the receptors and previously selected ways of exposure. This stage was conducted in two steps: first the concentration of exposure was estimated for certain matrixes while for others the contents were quantified (soils, surface water, human consumption water and atmosphere particulate material) and the daily doses of potential exposure were calculated; 3) Assessment toxicity: there is sufficient evidence for arsenic carcinogenic effects (Group A) and therefore a risk unit is provided (which depends on the way of exposure and is related to the probability of cancer development as a result of such specific exposure) and the reference dose (RfD) for the arsenic non-carcinogenic effects; and 4) Characterization of risks which enables the integration of the results from the assessment of exposure and assessment of toxicity in qualitative and quantitative form .

b) Epídemiological Study

b.1. Analysis of Mortality Rates by certain Types of Cancer in Paracatu

The following were selected for this assessment: a) types of cancer with known connection with the history / background of environmental and/or occupational exposure to As; b) annual rates of these types of cancer in Brazil in Southeastern region (where Minas Gerais State is politically inserted) and Center-West region (for the geographic location of Paracatu, near the Planalto Central), the State of Minas Gerais and some Minas townships with and without mining activities including gold mining and standardization of rates for 100.000 inhabitants.

The analyzed data come from SUS - *Sistema Único de Saúde*, they are annual and refer to the period from 2000 to 2010. The rates referring to 2000 and 2010 will be shown and discussed as they cover periods with population census data .

b.2. Pilot Study of Dermatological Morbidity (Skin Diseases)

From the individual daily cards and records of Paracatu PSFs and information from *Hospital da Mulher*, data were organized on dermatologies referred to in the PSFs and part of the technical team in this project consolidated the 2011 and 2012 annual data, identifying patients with chronic dermatologic problems. The patients were contacted and invited to appear at the PSF on a scheduled date when they were examined by the medical team of this project solely aiming to identify skin diseases which would show relation to recognized dermatological problems caused by exposure to inorganic arsenic.

b.3 . Strategies for the Environmental Exposure Study

The study followed the sectional methodology with convenience sampling. In this methodology the sampling was conducted in the urban population as it would be more significant numerically, as more than 80% of the town population is urban. The arsenic analyses for assessment of exposure (exposure biomarkers) are made in the hair for assessment of long term exposure (6 to 12 months) and urine and blood for assessment of recent environmental exposure (few days).

The criterion of inclusion in this study was designed considering the results of the characterization of environmental contamination by arsenic which indicated potential low doses of As. Thus the possible effects would be expected after a long period of environmental exposure (more than 20 years of exposure; long exposure period associated with a long latency period);

a) Therefore the inclusion criteria adopted in the epidemiological study cover: being a Paracatu resident for more than 20 years, with 40 years or more of age (to meet the conditions of long exposure period associated with long latency period);
b) Also to meet the inclusion criteria for more or less proximity to the gold mining, districts located near the gold mining activities were selected as well as far away districts as control.
c) After the definition of districts of interest of the study according to more or less proximity to the gold mining areas and identification of Family Health Units

(PSF) serving them, the Amoreiras and Paracatuzinho PSFs were selected and the later will be acting as control or reference;

d) The districts closer to the gold mining served by Amoreiras PSF are: Amoreiras II, Esplanada, Nossa Senhora Aparecida and Alto da Colina. Paracatuzinho, far away from gold mining is served by PSF Paracatuzinho;

e) The earliest effects and of recognized connection to As exposure are skin troubles which have characteristics relatively different from other troubles. Thus the data on these problems were inventoried at the Family Health Units emphasizing Paracatuzinho and Amoreiras PSFs and the *Clínica da Mulher* (where there are dermatology specialists);

From the consolidation of A Records of PSFs it was known that the number of residents served by the 12 Paracatu PSFs is approximately 40.000 residents; out of these, 4.000 are served by Amoreiras and Paracatuzinho PSFs. Since the inclusion criteria in the study require age above 40 years it was calculated, from A Records, that the number of residents in such conditions would reach around 1.500 in each PSF.

The 12 health agents from the two PSFs prepared cards especially designed for the project with the data of residents older than 40 years in each of their micro-regions in a total of 12 micro-regions.

Several stages of the epidemiological study were planned from such information including:

a) Training of health agents and college students to present the project purposes to the population inviting the residents to participate in the study;

b) Training of health agents for collection of hair tissue, presentation and application of epidemiological questionnaire form;

c) Training of college students to guide the population in collecting urine samples for analysis of arsenic and creatinin;

d) Several meetings with health agents to clarify doubts;

e) Hiring of qualified personnel for follow-up and guidance in blood collection at the PSFs;

f) Instructions for proper decontamination of urine sample container cups for arsenic analysis;

g) Setting of field logistics and physical structure in the two PSFs for blood collection and packing of blood and urine samples;

h) Approval of the project at the Ethics Committee;

i) The collection of biological samples started in November 2012 and was completed in May 2013;

j) Proper transport of biological samples from Paracatu PSFs to analytical labs of Evandro Chagas Institute;

k) Typing of all information in the epidemiological questionnaire to a computerized database.

l) A qualification course was offered to the health agents in May 2012 (certificate issued by CETEM) and to the TECSOMA team students (certificate issued by TECSOMA). The course addressed mainly the toxicology of arsenic, environmental exposures and methodology of biological samples collection .

m) From a program of clarification on the project through a letter individually addressed to pre-selected residents, these residents were invited to participate in the project;

n) It was estimated that about 40 to 50% of the population meeting the inclusion criteria (over 40 years old and residing over 20 years in Paracatu) would participate actively in the project, which would result in 1.500 participating residents, ideally divided into the two PSFs. Each resident, ideally generating 3 biological samples (hair, blood and urine) and as the arsenic analyses are conducted in triplicates, it was estimated about 13.500 analytical results in biological matrixes.

The total arsenic contents in human biological matrixes were analyzed in the Evandro Chagas Institute Metal Analysis Lab. An optical ICP with Hydride Generation was used for quantification of arsenic in urine and the testing of arsenic in hair and blood were conducted by Atomic Absorption Spectrometer with Graphite Furnace and with Zeeman-effect background correction.

Figure 8 shows the map of location of districts served by PSF Amoreiras and PSF Paracatuzinho.

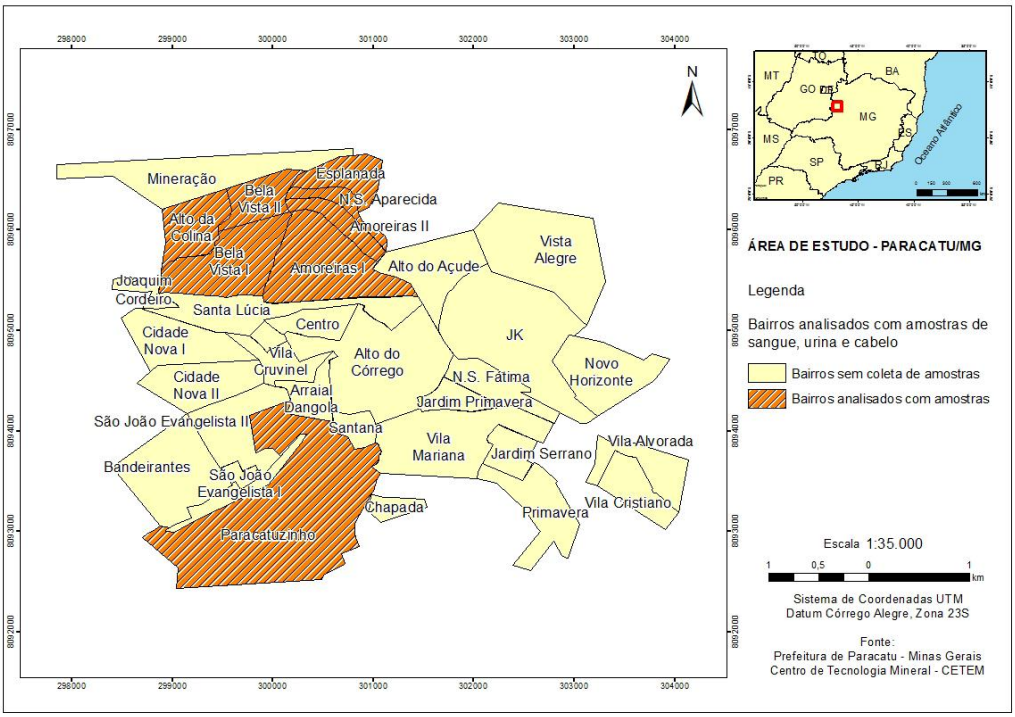


Figure 8. Map with location of districts served by PSF Amoreiras and PSF Paracatuzinho.

c) Analysis of Social Media as Strategy for Communication of Project Results

For an effective communication of results from research on the assessment of environmental contamination and the epidemiological study to the general public, it has been strongly recommended the development of a risk communication sub-project in parallel to the scientific activities. For that, it is important to obtain a diagnosis on which information are available to the population on the contaminants concerned and which publicizing channels are the most effective (George *et al.*, 2013). Thus in the case of this research in Paracatu, it is important to know which information on arsenic is available to the population and the best channels (George *et al.*, 2013) of the technical results obtained. Therefore the purpose of this item in the project was to review the level of knowledge and concern by the Paracatu population with the problem of arsenic as well as to identify the sources of information and the level of credibility of such sources towards the population. The results of these reviews will be used in the development of

strategies to promote the dissemination of the information (Mertens *et al.*, 2012) of technical results obtained from the assessment of environmental contamination by arsenic and the epidemiological study of human environmental exposure and implementation of interventions always aiming to reduce the human environmental exposure.

The data were personally collected in interviews based on a structured questionnaire on the districts focused in the epidemiological study already referred to above. The interviewees were 251 residents of districts served by PSF Amoreiras and 214 residents of Paracatuzinho, totaling 465 residents. A specifically developed questionnaire for this stage was used aiming to obtain information on: a) the residents' awareness of potential environmental sources of arsenic, its toxicity and health effects; b) the major sources of information through which the population has access to arsenic data; c) the population's confidence level in each of this information medium on the arsenic topic and d) the size and composition of the personal network of discussion on the arsenic topic.

RESULTS

The results shown are arranged in order to cover first the environmental data obtained in Stage 1 and then the epidemiological data obtained in the project Stage 2.

a) Assessment of Environmental Contamination by Arsenic

a.1 Supply Water

Supply water was collected according to the COPASA technical registry, the wells managed by PMP and households located mainly at the supply network end-zone. As informed by COPASA and PMP in Paracatu approximately 97% of the city population is served by COPASA supply system.

Table 6 shows the inventory of collected samples and contents of As (µg/L) in the water supplied.

Only two samples were above the detection limit of the analytical method used (0,5 µg/L), one with 0,6 µg/L and the other with 1,8 µg/L. All of them remained below the VMP (Maximum Allowable Value) of 10 µg/L for As defined by Ministry of Health Ordinance Number 518/2004.

Table 6 – As contents (µg/L) in samples of supply water in Paracatu.

Point	Location	Description*	Characteristic	As (µg/L)
1	S 17.26550 W46.95534	Impounding of Santa Izabel Brook	Raw river water	<0,5
2	S 17.25891 W46.94344	ETA Sta Izabel (Water Treatment Plant)	Raw river water	<0,5
3	S 17.25891 W46.94344	ETA Sta Izabel	Treated water	<0,5
4	S 17.23577 W46.89739	Paracatuzinho Reservoir receiving treated water from ETA Sta Izabel	Treated water	<0,5
5	S 17.23069 W 46.87097	ETA Santana C 10*	Raw water from artesian wells	<0,5/0,36/0,38
6	S 17.23069 W 46.87097	ETA Santana E 02*	Raw water from artesian wells	<0,5/0,15/0,16
7	S 17.23069 W 46.87097	ETA Santana C 06*	Raw water from artesian wells	<0,5/0,23/0,24
8	S 17.23069 W 46.87097	ETA Santana C 08*	Raw water from artesian wells	0,5/0,47/0,48
9	S 17.23069 W 46.87097	ETA Santana E 07*	Raw water from artesian wells	<0,5/0,34/0,35
10	S 17.23069 W 46.87097	ETA Santana E 06*	Raw water from artesian wells	1,8/1,55/1,63
11	S 17.23069 W 46.87097	ETA Santana E 04*	Raw water from artesian wells	<0,5/<0,1/<0,1
12	S 17.23069 W 46.87097	ETA Santana C 12*	Raw water from artesian wells	<0,5/<0,1/<0,1
13	S 17.23069 W 46.87097	ETA Santana C 02*	Raw water from artesian wells	<0,5/<0,1/<0,1
14	S 17.23069 W 46.87097	ETA Santana	Treated water from artesian wells	0,6
15	S 17.23435 W 46.86286	RAP Vila Mariana	Treated water solely from ETA Santana	0,5
16	S 17.22257 W 46.85784	REL JK	Treated water solely from ETA Santa Izabel	<0,5
21	S 17.20552 W 46.87423	RAP Amoreira 2	Treated water solely from ETA Santa Izabel	<0,5

*Analyses conducted in three different samples in two labs.

Table 6. Continued.

Residences				As (µg/L)
17		Avenida Eduardo Ferreira de Araujo	Vista Alegre District	<0,5
18		Rua Antonia Neto Siqueira	Vista Alegre	<0,5
19		Rua Severiano Silva Neiva	Alto do Açude District	<0,5
20		Rua Vicente Lopes Costa	Alto do Açude	<0,5
22		Rua Cristal	Esplanada District	<0,5
23		Rua Amélia da Silva Neiva	Esplanada	<0,5
24		Rua Prata	Amoreiras 2 District	<0,5
25		Rua Esmeralda	Amoreiras 2	<0,5
26		Rua 6	Bela Vista 2	<0,5
27		Rua Elisabeth	Alta Colina	<0,5
28		Rua João Macedo	Bela Vista	<0,5
29		Rua Francisco Melo	Bela Vista	<0,5
30		Rua Pedro Araújo Caldas	Cidade Nova	<0,5
31		Rua João Paulo II	Bom Pastor	<0,5
32		Rua Perimetro	Paracatuzinho	<0,5
33		Rua Ricardo Adjoto	Paracatuzinho	<0,5
34		Rua Benedito Oliveira Melo	Paracatuzinho	<0,5
35		Rua Jacaranda	Primavera	0,5
36		Rua Belmiro Araujo Neves	Novo Horizonte	<0,5
44		Avenida Olegario Maciel	Downtown	<0,5
46		Rua Bento Pereira Mundim	Downtown	<0,5

Water from Wells in Rural Area		As (µg/L)
38	Untreated raw water from Marinho Farm well	<0,5
39	Chlorinated water each 8 days – tablet system – Santo Antonio Lake Well Reservoir	<0,5
41	Non-chlorinated raw water collected in the house next to the reservoir	<0,5
42	Chlorinated well water each 8 days - Rua da Igreja	<0,5

a.1.1. Ground Water

Other samples of ground water, of human consumption and from monitoring wells were also analyzed for arsenic contents. Ground water was collected after authorization granted by owners and the results obtained for water from wells managed by COPASA are also shown in the previous item (human consumption water). Active wells were sampled at the tap outlets and/or reservoirs. Table 7 shows the As contents quantified in two samples of each well collected in two different occasions.

Monitoring wells in relation to those sampled in the area owned by Kinross and Votorantim were sampled with low flow collectors.

Table 7 – As contents (µg/L) in samples of ground water in Paracatu.

	SAMPLE	LOCATION	Arsenic Contents (µg/L)
HUMAN CONSUMPTION WATER	1	DOW	<0,1 / <0,1
	2	DOW	<0,1 / <0,1
	3	MONSANTO	<0,1 / <0,1
	4	COOPERVAP/SEDE	<0,1 / <0,1
	5	COOPERVAP/GRÃOS	<0,1 / <0,1
	6	COOPERVAP/USINA	<0,1 / <0,1
	C10	COPASA	0,36 / 0,38
	E02	COPASA	0,15 / 0,16
	C06	COPASA	0,24 / 0,24
	C08	COPASA	0,47 / 0,48
	E07	COPASA	0,34 / 0,38
	E06	COPASA	1,55 / 1,63
	E04	COPASA	<0,1 / <0,1
	C12	COPASA	<0,1 / <0,1
	C02	COPASA	<0,1 / <0,1
MONITORING WELLS	PM-B-03-35-30 /DOWNSTREAM DAM	KINROSS	<0,1 / <0,1
	PM-M-07-56-31/MINE	KINROSS	<0,1 / <0,1
	PM-MA-01	VOTORANTIM	<0,1
	PM-MA-10	VOTORANTIM	<0,1
	PM-MA-07	VOTORANTIM	<0,1
	PZ-INA-06	VOTORANTIM	0,29
	PZ-INA-08	VOTORANTIM	<0,1
	PZ-INA-04	VOTORANTIM	<0,1
	PZ-INA-09	VOTORANTIM	0,96
	PZ-INA-02	VOTORANTIM	0,35

The As contents observed are below the limit allowed by the Brazilian Legislation. In the case of PM-B-03-35-30 and PM-M-07-56-31 wells the As contents in this campaign are according to those observed in the company monitoring during an extended period of monitoring as per data from the reports sent to the Paracatu Secretariat of Environment which were made available for the acknowledgment by this project technical team.

a.2. **Status of Seasonal Sample**

The selection of dry season for sampling of surface water is due to the fact that, in such conditions, river waters directly reflect the quality of the water table and its

interaction with the soils as well as with pollutant loads with no interference by dilution processes and increase of particulate material caused by the runoff of rainwater (in this study, the composition in As of the suspended particulate material is assessed through the composition of river sediments). In September and October as indicated by Figure 9 (climatological normal for Paracatu) and Figure 10 (Water Balance in Paracatu) rainfall starts to increase but the water level in the rivers remains low as a consequence of the drought of the previous months .

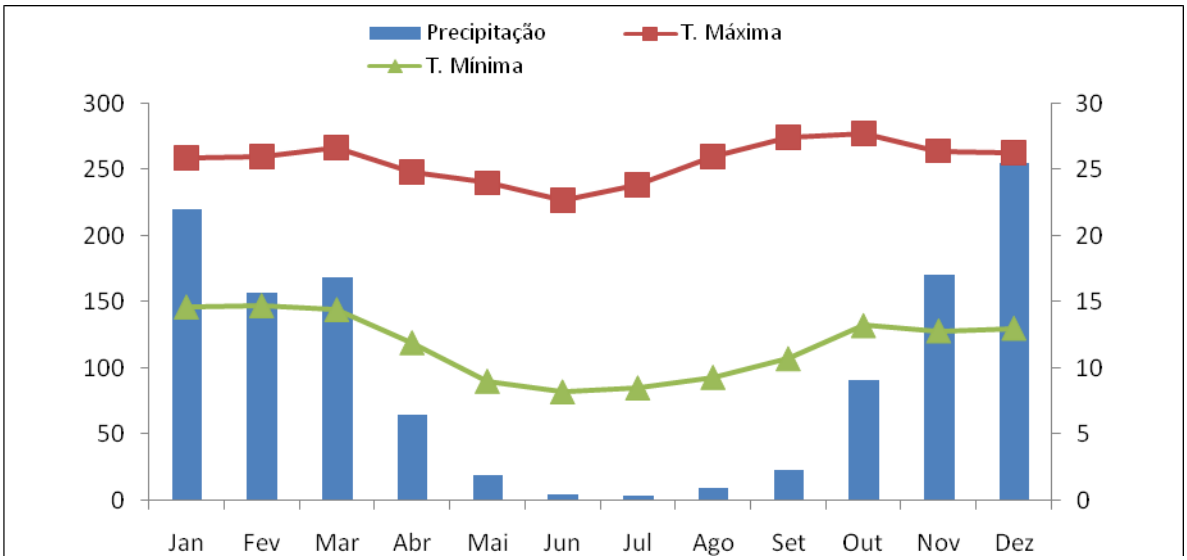


Figure 9: Climatological Normal for the city of Paracatu (MG). Data of 1973 to 2011 (INMET).

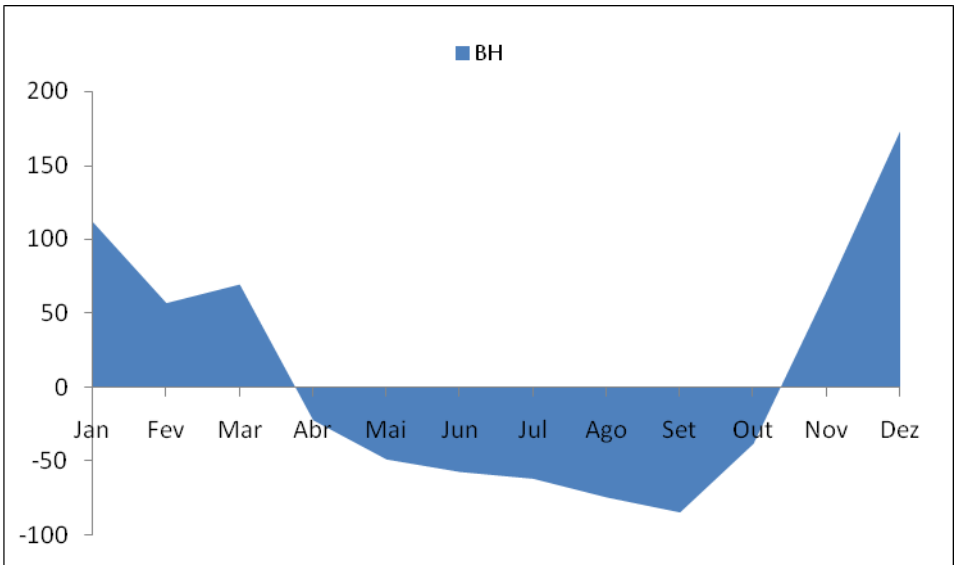


Figure 10. Water Balance in Paracatu (MG).

a.2. As Concentrations in River Water and Sediments and Soils

The determination of As in soils and river sediments was made in the total sample (considered as being the fraction < 1,7mm) as defined by the legislation, and in the silty-clayish fraction (< 0,075mm) as the latter presents a higher potential of retention of contaminants in a bioavailable form (that is, adsorbed on the particle surface).

The As contents obtained in the water correspond roughly to its dissolved fraction, filtered in 0,45 µm, that is, this is a fraction of higher potential of bioavailability. It should be mentioned that the legislation considers the analysis of unfiltered raw water; as a general rule, the suspended particulate material is the one presenting the highest concentrations of contaminants; in the case at hand, bearing in mind that the sampling was taken in dry season, the contents of suspended material were low (values below 10 mg/L); thus we observed that the As concentration in raw water was higher than approximately 15% than filtered water. This report considers the data of filtered water which represents higher risk.

The As contents in surface water, soils and sediments are shown in Table 5.

The levels of As contamination and the physical-chemical parameters measured in river waters were assessed through the comparison with guiding values proposed by CONAMA Resolution 357 (2005) for Class 2 waters and the ones recommended by Ministry of Health Ordinance 518, by CETESB (2005) and also by COPAM/MG which is 10 µg/L. Table 7 shows the contents above 10 µg/L colored in red and also indicates the maximum allowable contents for uses of water for irrigation and animal drinking.

For As in soils, CONAMA Resolution 420 (2009) sets forth a value of 15 mg/kg as “environmental prevention” and 35 mg/kg as “agricultural intervention”. The same Table shows contents above 35 mg/kg in red color.

For the quality of sediments the study used the provision for fresh water sediments in CONAMA Resolution 344 (2004) which sets forth general guidelines for assessment of sediments to be dredged; in the present case As contents of 17 mg/kg

were considered, that is, Level 2 or high probability of toxic effects to the biota in fresh waters; values above this level are shown in red in Table 7.

Table 7 – Total As contents in samples of river waters and sediments and surface soils; soils and sediments (<1,7mm).

Sample	Sub-basin	Creek	Total As		
			Water (µg/L)	Sediment (mg/kg)	Soil (mg/kg)
X	Rico	Espalha	<0,5	11,8	--
X1			<0,5	--	--
2		Rico	23,6	4297,2	1752,9
1			DI	2977,8	193,5
14			23,2	DI	DI
15			12,0	DI	631,7
13			19,1	2868,0	527,0
9			40,1	569,5	443,4
8			6,8	298,9	141,8
5			7,1	291,8	5,4
10		Pobre	<0,5	DI	5,6
12			11,9	DI	DI
06	Paracatu River		<0,5	DI	DI
07			<0,5	DI	DI
Y1	Entre Ribeiros Brook	Neto	29,1	1638,2	7,8
Y			22,1	31	1131,5
3		Sto. Antônio	5,0	159	81,5
20			18,9	3216,8	467,3
16		São Pedro	<0,5	3,0	12,7
17			0,6	832,3	98,7
18		Sta. Rita	19,1	1168,1	DI
Y2			1,5	1349,1	39,2
19			13,5	2874,0	13,0
21			5,2	DI	DI
Y3			2,7	203,5	86,6
22	Escuro	Sta. Isabel	<0,5	12,8	16,3
24		Traíra	0,7	105,7	19,3
23		Escurinho	<0,5	DI	3,6
25			0,8	3,8	7,5
CONAMA			**10 (human consumption)**	**17**	**35 (farming use)**
			33 (animal and irrigation)		**55 (household use)**
					150 (industrial use)

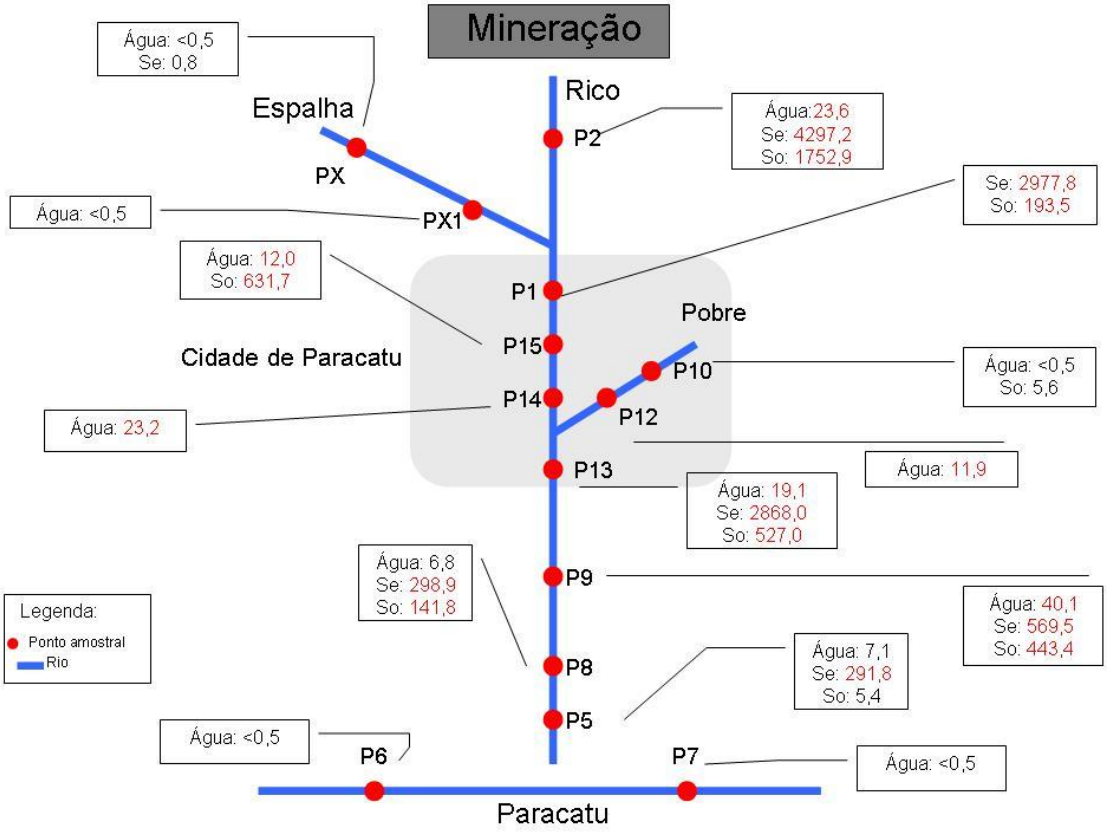
In red: Above 10 µg/L, guiding value for Waters Class 2 (CONAMA 357/2005) and MS Ordinance 518; 33 µg/L for Water Class 3 for animal drinking, irrigation of crops of trees, grains and pastures. Above 35 mg/kg, agricultural intervention value (CONAMA, 420/2009) and above 17mg/kg, guiding value by CONAMA 344/2004 representing high probability of toxic effects to the biota. DI – Unavailable data.

Limits referred to surface water Class 2: "to the levels of concentration for waters destined to supply for human consumption after conventional treatment, protection of water communities; primary contact recreational activities such as swimming, water ski and diving; irrigation of produce, fruit trees and parks, gardens, sport and leisure fields, with which the public may be in direct contact; water culture and fishing activity".

River Water

a) Rico Creek: Hydrographic axle of gold mining and urban area of the city of Paracatu.

Figure 11 – As concentrations in water, sediments (Se) and soils (So) along the hydrographic axle of gold mining and urban area of the city of Paracatu.



High values of As concentrations are observed in this sub-basin forming roughly a decreasing gradient from upstream to downstream. The Px and Px1 samples collected in the upstream sector of Espalha Creek, a control used in this sub-basin, present contents below the detection limit of 0,5 µg/L. The preservation of this Creek is essential for mitigation of the water quality of Rico Creek in Paracatu urban area; this aspect becomes increasingly important when we consider the advances in the city sanitation. The same occurs with Station P10 in the upstream sector of Pobre Creek; out of the peri-urban areas represented by Point 02 (just downstream the gold mining area / Kinross) up to Point 09 (downstream the Paracatu urban area) the contents increase

under influence of urban areas. The contents in the urban area are higher than the guiding value set forth by CONAMA 357/2005 (10 µg/L). From P9, the As gradient in the water decreases apparently showing attenuation with values below the guiding value up to Paracatu River where contents lower than the detection limit of 0,5 µg/L are observed. P9 (maximum value observed in this study) coincides with PT 005 of monitoring conducted by IGAM. Tables 1a and 1b show the results of historical series of As results in surface waters of Rico Creek in PT 005.

Table 1a- As contents (µg/L) in surface waters in PT 005- Rico Creek (coinciding with P9 of this study) under IGAM monitoring between 1997 and 2004.

Date of Collection	As
30/10/1997	0,30
03/02/1998	37,90
04/08/1998	11,50
13/07/1999	1,30
15/02/2000	45,70
22/08/2000	17,6
02/03/2001	26,9
27/08/2001	16,8
04/03/2002	34,8
20/08/2002	2,1
05/03/2003	<0,3*
26/08/2003	17,6
16/03/2004	22,0
31/08/2004	33,6
Average	20,6
Standard Deviation	14,7
N	13

*Data excluded for calculation of average and standard deviation

Table 1b- As contents (µg/L) in surface waters in PT 005-Rico Creek (coinciding with P9 of this study) under IGAM monitoring, average values from 2008 to 2011.

Year of Collection	As – Annual Average Value
2008	14,7
2009	18,6
2010	28,7
2011	25,8
Average (2008 to 2011)	21,9
Standard Deviation	6,4

The 1997 to 2004 sampling results are in average and standard deviation of 20,6 µg/L ±14,7. The average values of the period between 2008 and 2011 maintains the status observed in the previous period, that is, with average contents above the guiding value set forth by CONAMA 357/2005 (10 µg/L).

According to the Monitoring Report of Evolution of Quality of Water in Rico and Rapadura Creeks prepared by KINROSS: "Currently the average concentration of As in Rico Creek upstream BR-040 (Point 17B) is within the range of 30 µg/L". From the same Report we can see that the As analytical data from samples collected in the same sampling status of this Study (September-October in 2009 and 2010) are approximately between 10 and 30 µg/L.

Also according to a compilation of the Environmental Monitoring Reports in Morro do Ouro Mine sent to SEMEA in 2010, the As contents monitoring data in waters referring to Point 17 C, located downstream the Gold Mine in Rico Creek and described as "Rico Creek located within the Paracatu urban area; this point represents the quality of the creek water in a receiving point of the confluence of waters from Rico Creek, Macacos Creek and Espalha Creek. The point is located downstream the Morro do Ouro Mine towards the community; site affected by past and present prospecting activities" are shown in Table 2. The average of total As in the period was 8,94 µg/L with variation of 9,63 µg/L (n=16). The average of dissolved As contents resulted in 3,62µg/L ±2,44 µg/L (n=10).

Table 2 - As contents (µg/L) in surface waters of Rico Creek, Point 17C in monitoring by Kinross for the dates below related to 2010 and 2011 .

Date of Collection	Total	Dissolved
01/2010	8,0	3,4
02/2010	34,3	<0,1*
03/2010	13,0	8,8
07/2010	3,5	2,5
08/2010	28,0	2,6
09/2010	2,0	<0,1*
10/2010	1,4	1,0
11/2010	3,5	3,0
12/2010	9,0	2,0
01/2011	7,0	1,3
02/2011	3,9	6,0
03/2011	9,2	5,6
04/2011	2,6	<0,1*
05/2011	4,1	<0,1*
06/2011	4,6	<0,1*
Average	8,94	3,62
Standard Deviation	9,63	2,44
N	16	10

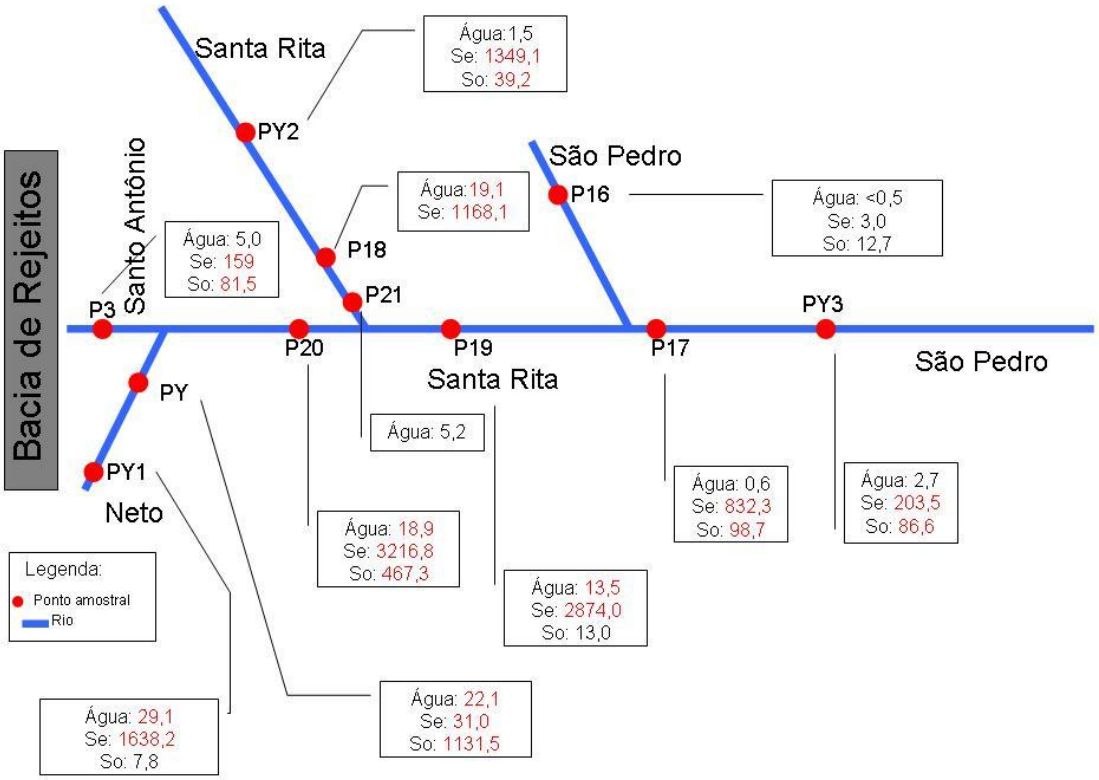
*Data excluded for calculation of the average and standard deviation

b) Entre Ribeiros Brook: Hydrographic axle of the Tailings Basin outlet

Santo Antônio, Santa Rita and São Pedro Creeks were sampled in this sub-basin as well as Neto / S. Domingos Creek. Point 03, in Santo Antônio Creek downstream the Kinross gold mining tailings dam presented concentration of 5 µg/L, below the guiding value set forth by CONAMA 357/2005 (10 µg/L). A higher value was observed in Point 20 (18,9 µg/L), downstream the confluence of Santo Antônio and Neto/S. Domingos

Creeks. Such increase is apparently due to As contaminated loads from the Neto/S. Domingos Creek PY1 and PY with 29,1 µg/L and 22,1 µg/L, respectively.

Figure 11 – As concentrations in waters, sediments (Se) and soils (So) along the Tailings Basin outlet hydrographic axle.



According to the above Kinross Report ("Evolution of Quality of Waters in Rico and Rapadura Creeks prepared by Kinross") the Neto / S. Domingos Creek has the Rapadura Creek as tributary which, together with Rico Creek, was directly affected in the past by gold prospecting activities and has been monitored (as well as the Rico Creek) as part of the Kinross activities environmental control program, as it is located in the Company influence area. The Report presents a graph where the average As contents in 2010 is within the range of 30 to 40µg/L (Note: Taken visually from the graph).

Points 18 and 19 of this study downstream Point 20 in Santa Rita Creek also present high contents (19,1 µg/L and 13,5 µg/L, respectively), well above their control PY2 (1,5 µg/L). It is suggested that P21 (5,6 µg/L) should be better investigated as it is an outlet of flooded area / bog or abandoned dam. The São Pedro River (P16, P17 and

PY3, respectively: < 0,5 µg/L, 0,6 µg/L and 2,7 µg/L) apparently dilutes the contamination from upstream before reaching the Paracatu River .

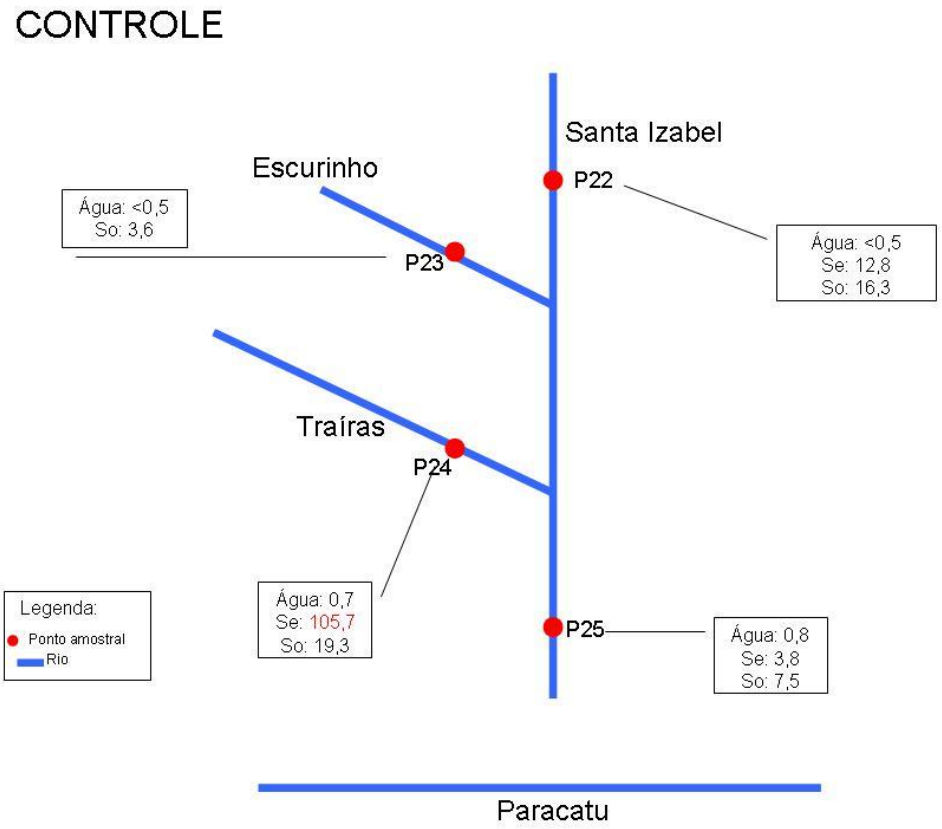
According to the compilation of Environmental Monitoring Reports in Morro do Ouro Mine sent to SEMEA in 2010, the data of monitoring of As contents in waters referring to Point COPAM 14, described as: "Santo Antônio Creek located in the RPM property border, receives the RPM final effluent from the drains of the tailings dam foundation after going through a passive treatment in wetlands. It is located at 800 m from the tailings dam embankment", are shown in Table 3. In most samples the total As contents are below the analytical method detection limit, that is, below 0,1 µg/L, having only one measurement of 4,7 µg/L. For dissolved As contents, all samples are below 0,1 µg/L.

Table 3 – As contents (µg/L) in surface waters of Santo Antonio Creek, Point COPAM 14, under Kinross monitoring for the dates below related to 2010 and 2011.

Date of Collection	Total	Dissolved
01/2010	<0,1	<0,1
02/2010	<0,1	<0,1
03/2010	4,7	<0,1
07/2010	<0,1	<0,1
08/2010	<0,1	<0,1
09/2010	<0,1	<0,1
10/2010	<0,1	<0,1
12/2010	<0,1	<0,1
02/2011	<0,1	<0,1
03/2011	<0,1	<0,1
05/2011	<0,1	<0,1
06/2011	<0,1	<0,1

c) Escuro River: Sub-basin used as control in this study .

Figure 12 – As concentrations in waters, sediments (Se) and soils (So) along the hydrographic axle of the sub-basin used as control in this study.



This sub-basin contains the main point of COPASA water impounding, the Santa Isabel Creek. Apparently it is a sub-basin which work as reference and/or control for As contamination studies, since all the collected points showed As concentrations lower or very close to the detection limit of the analytical method employed (0,5 µg/L), that is, at least 20 times below the quality standard set forth by the legislation (10 µg/L).

Parameters analyzed in the Water

Table 8 presents the other parameters analyzed in the water.

The pH determination in river water samples indicated values covering the neutrality range (6,0 – 8) and which are within the range recommended by CONAMA 357. These data are important because certain toxic metals may have their bioavailability increased to the water column under acid conditions.

Electric conductivity pointed out values between 7 and 432 µS/cm. The lower values are related to stations defined as control; the higher values observed in the Rico Creek sub-basin and in creeks sampled in Entre Ribeiros Brook sub-basin may be related respectively: (i) to the Paracatu urban area household effluents, and (ii) to the influence from the tailings dam added of the loads from the Neto/S.Domingo Creek axle (such influence should be analyzed in detail in the sequence of studies).

Sample	Sub-basin	Creek	pH	OD (mg/L)	Electric Cond. ($\mu S.cm^{-1}$)	TDS (mg/L)	ORP

Electric conductivity and TDS are closely associated parameters. Data in Table 8 show the same pattern of distribution.

The concentrations of total dissolved solids (TDS) are in conformity with the value set forth by CONAMA Resolution 357/2005 (500 mg/L).

The quantification of dissolved oxygen (OD) presented values between 0,5 and 9,86 mg/L. Little more than 20% of these values are not in conformity with the minimum concentration of 5 mg/L, established by CONAMA, indicating the occurrence of degraded environments, all of them located in the Rico Creek sub-basin due to influence of household effluents. The potential of oxy-reduction (ORP) shows point of reducing characteristics (negative or very low) associated with the OD, thus reinforcing the probable role of the untreated household effluents.

Table 8. Parameters analyzed in river waters.

X	Rico	Espalha	6	6	7	4	33,4
X1			6	6,39	11	25	31,9
2		Rico	6,5	6,52	79,5	39,5	21,79
1			6,67	5,22	63	32	3,00
14			6,90	0,97	116	58	-46,60
15			6,82	0,50	97	49	-1,90
13			7,0	4,13	129	64,5	-8
9			7,6	5,83	240	120	99,1
8			7,6	5,79	218	109	108,2
5			7,56	5,69	169	85	81,30
10		Pobre	7,79	4,40	301	151	145,00
12			7,56	4,41	330	165	50,20
06	Paracatu River		7,63	7,19	77	38	56,40
07			7,65	7,08	77	39	107,90
Y1	Entre Ribeiros Brook	Neto	7,7	5,72	246	123	71,2
Y			8,1	6,4	318	159	56,6
3		Sto. Antônio	7,9	6,16	432	216	104,9
20			8,0	5,66	357	179	104,95
16		São Pedro	7,83	6,44	251	126	64,70
17			7,82	6,56	252	126	47,60
18		Sta. Rita	7,77	6,77	340	170	99,90
Y2			7,8	4,94	167	83	60,9
19			7,71	6,11	253	127	-13,40
21			7,57	5,40	220	112	131,30
Y3			7,73	62,2	265	132	55,3
22	Escuro	Sta. Isabel	6,4	7,39	18,9	9	85,7
24		Traíra	6,8	6,96	29,5	14	70,75
23		Escurinho	6,9	8,12	14	7	93,25
25			7,36	7,38	48	24	83,00
CONAMA	**Guiding Value**		**6-9**	**5**	**-**	**500**	**-**

In red: Value off the standard according to CONAMA Resolution 357.

River Sediments and Soils

River Sediments

Table 7 shows that more than 85% of samples are above the values suggested for As in sediments - 17 mg/kg, guiding value given by CONAMA 344/2004. The higher

contents are spatially related in the points located: (i) in Rico Creek just downstream the Kinross mining activities; and (ii) in Santo Antônio Creek downstream its confluence with São Domingos Creek to further downstream in Santa Rita Creek .

The determination of pH indicated values between 5,4 and 6,9. Such values are mildly acid and yet they may contribute to the mobilization of As in the environment .

Soils

The determination of total As showed that virtually all samples presenting non-conformity in relation to the guiding values set forth by CONAMA Resolution 420/2009 - 35 mg/kg, agricultural intervention value – are in the Rico Creek sub-basin .

The determination of pH indicates values between 4,4 and 7,3. Most of the values occur within the neutrality range, little favorable to the As mobility in the environment. However it is important to observe that soils are slightly more acid than sediments, as the first suffered more intense selective processes than the latter.

Complementary Aspects

It is worth emphasizing two aspects related to the As concentrations observed in river sediments and soils:

(i) As a rule, sediments showed higher As contents than soils.

(ii) The results presented refer to analysis of total sample < 1,7mm (as determined by the Legislation). Both for sediments and for soils the As concentrations in this fraction are generally higher than those of the silty-clayish fraction (considered herein as < 0,075mm).

(iii) The fine fraction represents less than 10% of granulometry in approximately 65% of sediment samples and less than 20% of granulometry of all soil samples.

(iv) However despite the low participation in the granulometry of sediments and soils the fine fraction presents As concentrations generally similar or even lower than in the total sample in the case of soils; and in the case of similar sediments up to an order of magnitude lower than in the total sample.

(v) Such observations pointed out to the need to know better the distribution of As in the samples of soils and sediments through studies using selective extractors, mineralogical analysis of detail (DRX) and utilization of electronic scanning

microscope (MEV). These complementary analyses have already been started and are in progress being part of one of the doctor's degree dissertations .

(vi) Such additional effort is justified because fine particles have higher capacity of adsorption of contaminants on their surface (the smaller the particle the larger the specific surface and the higher quantity of contaminants which may adhere) in a form of higher availability (as they are more weakly attached / connected to the particle) for water and live organisms; additionally the composition of mineralogy of fine fraction may be different from coarser fractions of sediments and soils.

a.3 Ecotoxicological Tests in Waters and Soils

The results of the acute test with *D. Similis* showed no toxic effects with samples of tested surface waters, and the As contents varied from <0,5 to 40,1 µg//L (Table 9) .

Table 9. Result of acute test of immobility of *Daphia Similis* with surface waters.

Sampled Points (As Concentrations)	Replicates								Total of immovable females	% of immovable females	Toxicity
	24h				48h						
	1	2	3	4	1	2	3	4			
Control	0	0	0	0	0	0	0	0	0	0	Non toxic
Pt 02 (23,6µg//L)	0	0	0	0	0	0	0	0	0	0	Non toxic
Pt 03 (5,0µg/L)	0	0	0	0	0	0	0	1	1	5	Non toxic
Pt 09 (40,1 µg/L)	0	0	0	0	0	0	0	0	0	0	Non toxic
Pt 20 (18,9 µg/L)	0	0	0	0	0	0	0	0	0	0	Non toxic
Pt 22 (<0,5 µg/L)	0	0	0	0	0	0	0	0	0	0	Non toxic
Pt Y (22,1 µg/L)	1	0	0	1	1	1	0	2	4	20	Non toxic

The results of As contents in worms exposed to soil samples collected in PT 22, located on the margins of Santa Izabel River - Escuro River Basin, resulted in value near the one obtained in worms exposed to control soil, 1,6 and 2,1mg/kg, respectively. Now the As contents in worms exposed to soil of PT 02 from the Rico Creek basin,

reach about 35 times the control contents and PT 22 (Table 10). This indicates clearly that there is availability of As to the land biota and which probably the transport to the interior of tissues and/or external adsorption should be limited by the very organism. That is, FBC is not linear indicating that there is saturation in the absorption of As. Still, there is accumulation with the offer of As; on the other hand in acute testing it was not possible to verify adverse effects to invertebrates as shown in Table 11. Now the proposal is to test in chronic models (reproduction, etc.).

Table 10. As bio-concentration factor in worms exposed to Paracatu soils .

Sample	**As - Soil (mg/kg)**	**As - Worms (mg/kg)**	**Bio-concentration Factor**
Control	**0,8**	**1,6**	**2**
PT 22	**16**	**2,1**	**0,13**
PT 02	**1752,9**	**69**	**0,04**

Table 11. Ecotoxicological test with invertebrates exposed to Paracatu soils.

Amostras	No. Minhocas		Peso (mg)		% Perda de Peso
	Inicio	Final	Inicio	Final	
Controle	50	50	4,09 ± 0,31	3,42 ± 0,25	16,2 ± 1,64
Pt 02	50	50	4,11 ± 0,22	3,36 ± 0,18	18 ± 4,74
Pt 22	50	49	4,15 ± 0,31	3,38 ± 0,18	18,2 ± 6,22

a.4 Atmospheric Particulate Material

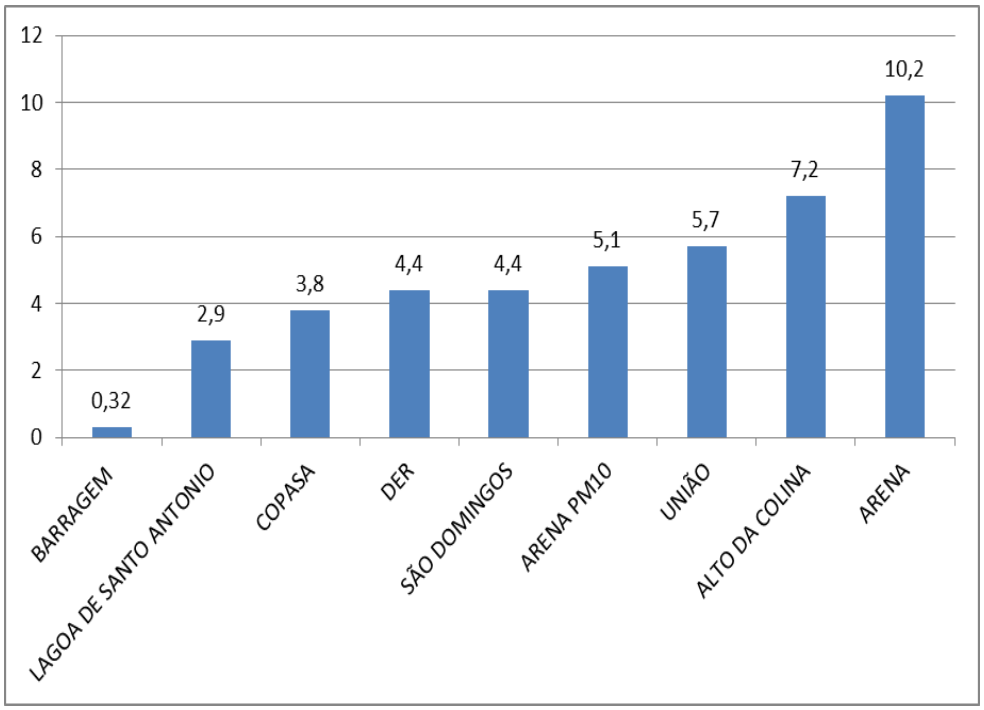
The filters containing total suspended particles (PTS) of the atmosphere originated from samplers available in Paracatu were quantitatively analyzed for arsenic (As). The geographic location of sampling stations is shown in Figure 12. The numbers indicated therein correspond to the following stations : 1- Alto da Colina; 2- COPASA, 3- DER, 4- União, 5- São Domingos, 6- Arena, 7- Dam and 8- Santo Antônio Lake.

Figure 12. Image with geographic location of samplers of atmosphere particulate material existing in Paracatu.

Arsenic Contents in Atmospheric Particulate Material

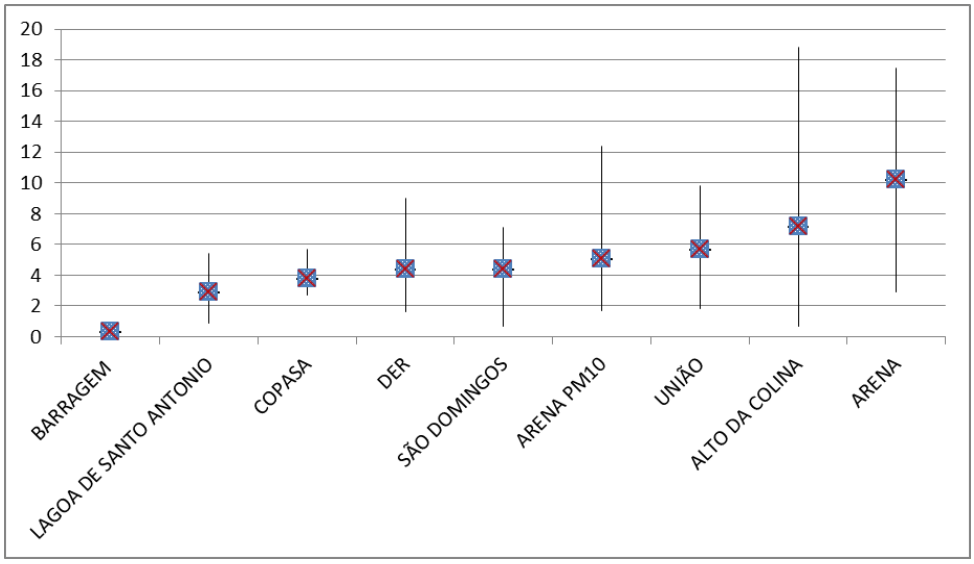
The results of analyses of As (ng/m^3; mass of As per volume of air) in PTS and MP10, expressed as annual arithmetic average from a sampling per month during 12 months are presented in Graph 1.

Graph 1. Average arsenic concentrations (ng/m^3) in atmospheric particulate material*, related to the period from May 2011 to June 2012 in the 8 sampling stations located in Paracatu.



*In total suspended particles (PTS) for the 8 stations and in inhalable particles (MP10) for Arena Station.

Graph 2. Minimum, medium and maximum concentrations of arsenic (ng/m^3) in atmospheric particulate material*, related to the period from May 2011 to June 2012 in the 8 sampling stations located in Paracatu.



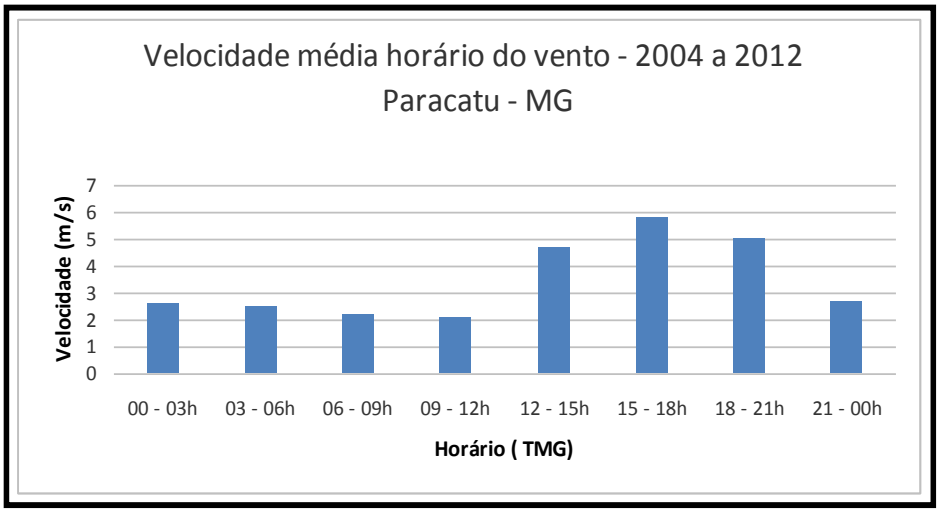
The results show the highest concentrations of As in the filters of Stations Arena (both in PTS and in MP10), Alto da Colina and União, indicating higher values in stations nearby and located southwest (SW) the gold mining area. If the origin of particles contributing to the higher As concentration in atmospheric MP of these 3 stations is the mining area, another factor in addition to the source, responsible for the higher values in these stations is the prevailing direction of winds in Paracatu which is

northeastern (NE). The monthly average speed of winds in Paracatu is low varying between 2,8 and 4,4 m/s. Occasional wind gusts occur and are responsible for intensifying the re-suspension of soil particles and dispersion of dust.

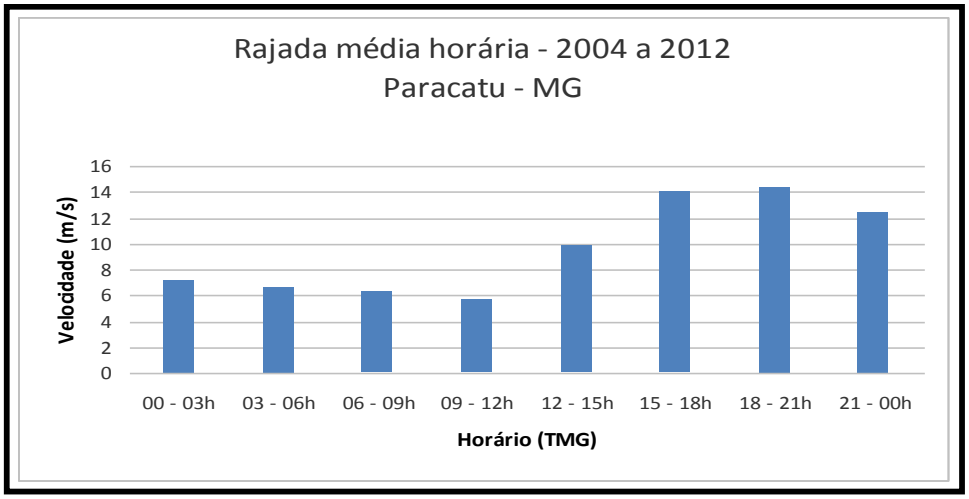
Thus the results indicate that the human population residing (or potentially) in areas close to Stations Arena, Alto da Colina and União are potentially subject to higher exposure than the population residing in the other sampled areas .

However it should be noted that the analyses of relationships between As concentrations and meteorological parameters should be and are being detailed in master's thesis to be presented in February 2014. The exposure of soils caused by deforestation and the mining activities represent the sources of mineral MP in suspension in the atmosphere. Weather and climate conditions such as wind direction and speed and seasonal distribution of rain are the major atmospheric factors of control of MP concentrations in the atmosphere. Winds act on the re-suspension and atmospheric dispersion of soil particles, the frequency and volume of rainfall is determinant in the control of moisture of soils, and the rain itself contributes to the transfer of MP from the atmosphere to the soil surface. For that, the meteorological parameters are being analyzed such as precipitation data, winds (speed and direction), temperature and relative humidity of the air obtained at the Data Collection Platform (PCD) Model Weather Station for the period corresponding to the study and its historical series. This station is located in Paracatu urban seat and is managed by the CPTEC – Weather Forecast and Climate Studies Center. It is interesting to observe (Graphs 3 and 4) that the highest average wind speeds happens between 15 and 18.00 hours, since the gusts also occur within this hourly range (extended up to 21.00 hours) reaching an average of 14m/s (as shown in the graphs below) which covers the time of detonations in the company mining front, possibly increasing the dispersion of dust from the detonations.

Graph 3. Average hourly wind speed in Paracatu between 2004 and 2012 .



Graph 3. Average wind speed in gusts in Paracatu between 2004 and 2012.



It is considered that in rural areas the average As concentrations vary between 1 and 4 ng/m^3 while in urban areas they vary between 5 and 7 ng/m^3 (measurements taken in the United Kingdom). In the United States it is estimated that As concentrations would vary between 1 and 5 ng/m^3 in remote / rural areas and between 20 and 100 ng/m^3 in urban areas (ATSDR, 2007).

However in methodologies of assessment of environmental risks to human health by As exposure in the atmosphere by inhalation, for carcinogenic purposes, the reference average contents of As concentrations for risks considered acceptable vary from 0,2 ng/m^3 (USEPA) and 0,6 ng/m^3 (European Union) to 2 ng/m^3 and 6 ng/m^3 for exposed risks of 1:1.000.000 (10^{-6}) or 1:100.000 (10^{-5}) respectively.

For non-carcinogenic purposes, the California Environmental Protection Agency - CalEPA) established as reference level for chronic inhalation 30 ng/m3 as the concentration of arsenic in the atmosphere. This limit is a concentration below which the appearance of non-carcinogenic toxic effects is not expected in the human population.

Also the As contents in MP10 are considered more hazardous, since the smallest particles may reach the deepest structures of the respiratory system and thus we should consider that the As contents in MP 10 of Arena Station show arsenic content which may be important. Such information indicates the need of MP 10 samplers in Alto da Colina and that the areas under the samplers' influence with the highest contents may be more exposed than the others in the municipality .

These results were considered in the development of the epidemiological strategy adopted in this study which considered as one of the inclusion criteria being a resident in an area more or less proximity to the gold mining .

The risk assessment should consider all major exposure ways integrating the environmental exposures for estimate of risks to human health and the results are shown in the item below.

a.5 Assessment of Risk to Human Health

Figure 13 shows the concept model developed for this study .

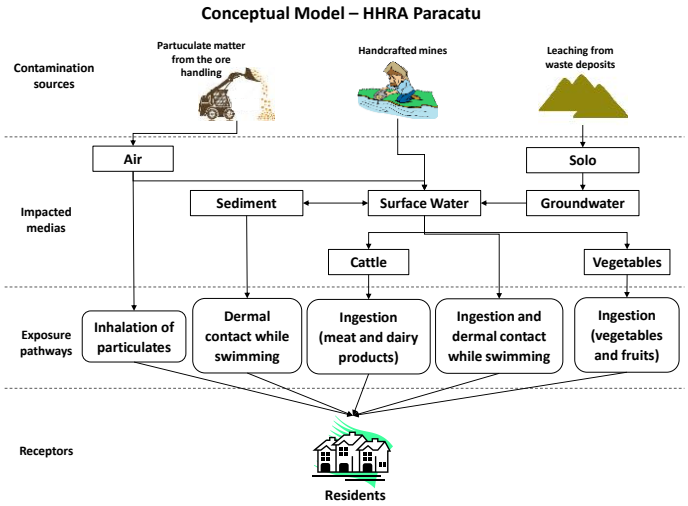
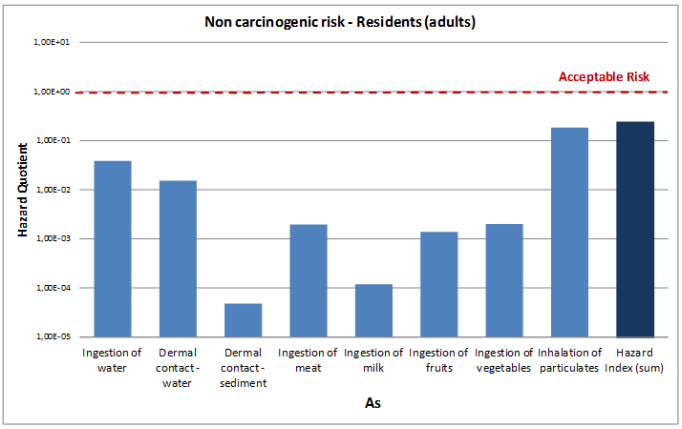
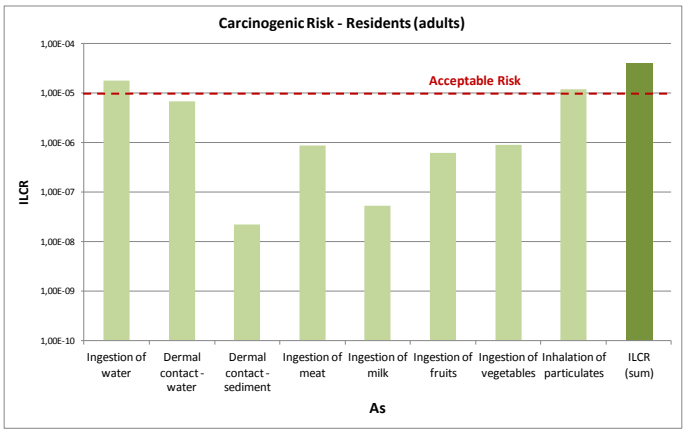


Figure 13. Concept model of human exposure to arsenic in Paracatu-MG

For adults, the hazard quotient which relates environmental exposure to non-carcinogenic effects of environmental contaminants considering all selected exposure ways and the reference oral dose for arsenic (RfD= 3E-4 mg/kg/day) resulted lower than the unit, meaning the non-presence of threat to public health (Graph 5). Considering the risks of carcinogenic effects in adults by environmental exposure to arsenic (relating the estimated doses to the potential of cancer by oral way, 1,5E0 per (mg/kg)/day), the results indicate risks above the acceptable level of 1E-5 (Graph 6).



Graph 5. Risk of non-carcinogenic effects in adults.

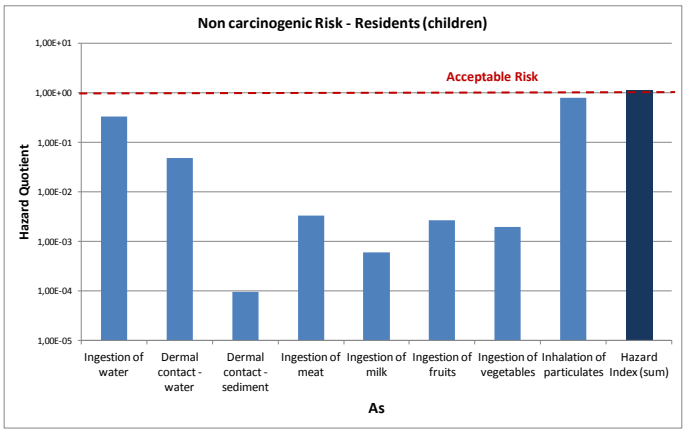


Graph 6. Risk of carcinogenic effects in adults.

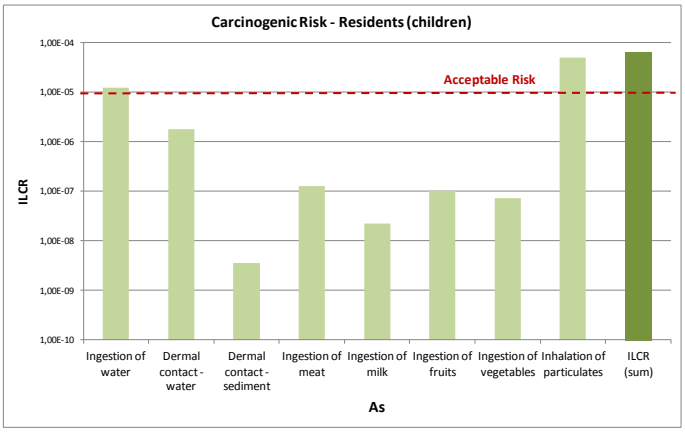
For children, the hazard quotient related to non-carcinogenic effects of arsenic, of each of the considered ways, also resulted lower than 1, but their integration resulted in value above 1, meaning potential problem to human health by environmental exposure (Graph 7). The estimate of risks for carcinogenic purposes resulted above 1x10-5 (for accidental intake of waters during swimming and inhalation of atmospheric particles) resulting in unacceptable risks (Graph 8).

The results showed that the environmental exposure to arsenic does not represent potential hazard of non-carcinogenic effects in adults, but children may be at risk. For carcinogenic purposes, children and adults are at risk. The ways most contributing to the risks are intake of water during recreational water activities and inhalation of particles.

However it should be emphasized that the risk assessment methodology uses extremely conservative approaches, following the principle of precaution and aiming to identify areas where there are no risks and areas where detailed environmental and epidemiological studies should be carried out. Thus the results indicate the need of conducting an epidemiological and human exposure study which will bring forth proper clarifications to the uncertainties associated with statistical models on which the assessment of risks to human health by environmental exposure is based. The results of the epidemiological study and assessment of environmental exposure are exhibited below.



Graph 7. Hazard Index of Non-Carcinogenic Effects in Children.



Graph 8. Risk of Carcinogenic Effects in Children

b) Epidemiological Study of Environmental Exposure to Arsenic of Paracatu Human Population

b.1 Analysis of Mortality Rates by certain Types of Cancer in Paracatu

This item required the selection of types of cancer with indication in the literature of association with environmental and occupational exposure to arsenic, especially by oral way, by intake of contaminated water and/or by inhalation, respectively being skin, lung, bladder and liver cancer. Table 12 shows the cancer mortality rates per 100.000 inhabitants in Paracatu as compared to Brazil, the Southeastern Region, Center-Western Region and Minas Gerais mining township of Nova Lima and non-mining of Três Corações and Itajubá.

Table 12. Cancer Mortality Rates per 100.000 inhabitants

Location		2000	2010
Minas Gerais	***Population***	*17.891.494*	*19.597.330*
	C22 – Liver	2,66	3,52
	C34 – Lung	6,47	9,52
	C44 - Skin	0,38	0,63
	C67-Bladder	0,98	1,58
Southeast	***Population***	*72.412.411*	*80.353.724*
	Lung	17,51	16,00
Center-West	***Population***	*11.636.728*	*14.05.340*
	Lung	7,05	12,50
Brazil	***Population***	*169.799.170*	*190.732.694*
	Liver	2,96	4,04
	Lung	12,40	14,06
	Skin	0,48	0,79
	Bladder	1,18	1,66
Paracatu	***Population***	*75.216*	*85.447*
	Liver	2,65	3,51
	Lung	3,98	10,50
	Skin	-	-
	Bladder	2,65	1,17
Nova Lima	***Population***	*64.387*	*81.162*
	Liver	6,21	6,16
	Lung	9,31	19,70
	Skin	-	-
	Bladder	3,10	-
Três Corações	***Population***	*65.291*	*72.765*
	Liver	3,06	1,37
	Lung	6,12	12,4
	Skin	-	-
	Bladder	-	1,37
Itajubá	***Population***	*84.135*	*90.658*
	Liver	8,31	6,60

	Lung	15,45	11,03
	Skin	3,56	1,10
	Bladder	2,37	1,10

Mortality rates of liver, lung, skin and bladder cancer in Paracatu residents in 2000 and 2010 (as well as in each year within such period) do not present any differences which would indicate higher number of cases in Paracatu.

b.2 Analysis of Out-of-Home Treatment Database

The out-of-home treatment database focusing on oncological data managed by the Paracatu Secretariat of Health lists information from 1992 to 2012 (October) and shows that the total number of cancer cases in that ten-year period is 488 cases resulting in an annual frequency of 48,8 cases.

The review of the database from 1992 to 2010 indicated that 52,7% of all cases recorded are head and neck (11,3%), cervix (11,5%), breast (18,9%) and prostate (11,0%), and that the others do not reach more than 10%of the frequency.

Analyzed under the age factor 70% of cancer cases occur as of 40 years of age; however the frequency of cancer among youth should not be disregarded but rather analyzed in further detail. Also from 1992 to 2010, there are records of 34 skin cancer case and 18 lung cancer cases.

Part of the municipal health records all over Brazil show inconsistencies including those observed in the present database. There are inconsistencies such as lack of confirmation of diagnosis, information of death and others, according to the SMS the 2007-2012 period is the one with higher systematic control of the database system and therefore the most credible and reliable. Thus, 399 oncology cases in out-of-home treatment are accounted for in such six (6)-year period, resulting in an average of 56 cases per year. The same analyses were carried out considering this period; however for comparison with another township with the same database structure of similar size and geographic location, in this case, Unaí, the initiative was not practical as the data available in Unaí do not cover all records (only 2012), has also many deficiencies which compromise the proposed comparison.

b.3. Pilot Study of Skin Diseases

The research on skin diseases was conducted by using organized data from the Paracatu Health Units of the Family Health Program (PSF) and the *Hospital da Mulher* (Women's Hospital), focusing on the residents of the districts served by PSF Amoreiras and PSF Paracatuzinho. Adult patients with any type of chronic skin diseases were invited to participate in the study and be assessed jointly by two doctors of the institutions forming the technical team of this research project. The diagnostic approach was based on the peculiar characteristic of possible skin troubles related to chronic exposure to arsenic described in the specialized literature (Guha Mazumder 2000), as appearing in Table 4.

Table 4. Dermatological Lesions associated with Chronic Exposure to Arsenic

Clinical Changes	Observations
1. Hyperkeratosis	Thickening of skin like "corns" or calluses or rough warts in palms of hands and soles of the feet
2. Melanoses	Dark lesions in spots of various sizes; special type of these lesions are pigmentation of raindrops in trunk and limbs.
3. Leuco Melanoses	Association of lesions or dark and bright spots side by side (pigmentation and de-pigmentation)
4. Carcinoma *in situ* (Bowen's Disease)	In general appearing as multiple lesions
5. Basal cell carcinoma	Multiple lesions in general
6. Spino cell carcinoma	Multiple lesions in general and in area not exposed to sunlight

Thirty (30) patients coming from the area served by PSF Amoreiras and 14 patients from PSF Paracatuzinho were thoroughly examined; no lesion suspicious of association

to arsenic chronic exposure was found; Table 13 exhibits the main dermatological diagnoses.

Table 13. Dermatological Diagnosis presented in Patients from PSFs Amoreiras and PSF Paracatuzinho.

Diagnosis	Amoreiras	Paracatuzinho
Allergic dermatitis	13 (43.3%)	2 (14.2%)
Fungal dermatitis	5 (16.6%)	4 (28.4%)
Verrucous lesion	1 (3.3%)	0
Dischromic lesion	10 (33.3%)	4 (28.4%)*
Hyperkeratosis	1 (3.3%)	1 (7.1%)
Carcinomas (probable diagnosis)	2 (6.6%)	0
Psoriasis	1 (3.3%)	1 (7.1%)
No dermatosis in the exam	6 (20.0%)	3 (21.4%)

* *p*= 0,51 (square chi test corrected by Fisher); n.s=not significant

The dischromic lesions which could be eventually related to the As chronic exposure showed no difference of prevalence statistically significant between the two study areas (*p*= 0,51), besides not presenting the clinical characteristics proper to the effect of As exposure. The two cases of hyperkeratosis diagnosed in the two areas were both related to excessive friction.

b.4 Results of Arsenic Contents in Blood, Urine and Hair of Paracatu Residents

The study followed the sectional methodology with convenience sampling using inclusion and exclusion criteria.

An open letter was distributed to the population in the districts included in the study. 2.274 Paracatu residents were personally contacted who met the inclusion criteria; 878 residents accepted the invitation to participate in the study, signed the informed consent and answered the epidemiological questionnaire (487 residents are served by PSF Amoreiras and 391 by PSF Paracatuzinho). Out of those, 797 gave out hair tissue for arsenic tests; 787 urine samples were collected for arsenic test and an equal number for creatinin tests and 851 blood samples .

According to the inclusion criterion the study population age group varies between 40 and 97 years; most of these residents have low educational level usually up to elementary school.

Most of the study population does not eat seafood which may be assumed for Paracatu general population; more than 90% of the study population are supplied by COPASA water system with one small portion (<10%) consuming well water. These results reinforce the strategy used for assessment of arsenic contents in public supply water for verification of exposure of the great majority of Paracatu population .

Most arsenic absorbed by the lungs or by the gastrointestinal system is excreted through the urine within 1 to 2 days; for this reason the urinary arsenic measurements are the best indicator of recent exposure to arsenic. Thus, arsenic tests in urine (few days) and in blood (hours are used for assessment of recent environmental exposure (few days), while arsenic tests in hair are used for assessment of long term exposure (6 to 12 months). Consequently the quantification of arsenic was made in the three biological matrixes.

Arsenic concentrations in blood, urine and hair in Paracatu sampled population and reference values are exhibited in Table 14.

Table 14 – Arsenic contents in blood (µg/L) and urine (*µg/gC* and µg/L) and hair (µg/g) in adult residents served by PSF Amoreiras and Paracatuzinho and reference values

Arsenic Levels	*Amoreiras*	*Paracatuzinho*	*p*	*Reference Values*	
UrinaryAs µg/gC	*N= 439*	*N= 339*			
Mean (DP)	3,55 (3,46)	2,15 (2,72)	*<0.0001*		
Median	2,46	1,40			
Min-Max	0,06-26,6	0,02-27,15			
Urinary As µg/L	*N= 439*	*N= 347*		*N= 1.339*	*N= 2605*
Mean (DP)	3,31 (2,14)	1,95 (2,05)	*<0.0001*	4.04 (2.01) *	-
Median	2,91	1,39		-	7,49 (6,9-8,12)**
Min-Max	0,10-9,89	0,05-14,4		0.7-30.3	-
Blood As µg/L	*N= 478*	*N=373*			
Mean (DP)	7,12 (2,98)	7,26 (2,53)	0.39	-	
Median	6,97	7,01		-	
Min-Max	0,57-14,9	1,1-22,03		-	
Hair As µg/g	*N= 423*	*N=374*			
Mean (DP)	0,14 (0,7)	0,14 (0,9)	n.s	-	
Median	0,12	0,11		-	
Min-Max	0,03-0,43	0,01-0,66		-	

*Reference Value from partial results of study carried out in São Paulo, SP in 2011 (unpublished data); ** CDC (National Health and Nutrition Examination Survey, 2007-2008; geometric mean)

Average contents (geometric mean) of total arsenic in urine in the US population in 2003 and 2004 were 7,70 µg/L (n=2.557) (Caldwell *et al.*, 2009); and, according to the National Health and Nutrition Examination Survey- NHANES, CDC , 2012, in the years of 2005-2006 it was 8,65 µg/L (n=2.576) and in 2007-2008, the average contents of arsenic in urine was 7,49 µg/L (n=2605).

A recent study defined that contents between 1 and 5 µg/L of arsenic in urine represent base contents (background) of exposure. Such contents were generated from epidemiological studies and values obtained at the National Health and Nutrition Examination Survey, which excluded populations consuming substantial amounts of fish (to eliminate the large contribution of arsenobetain and other arsenicals from seafood in the measurements of total urinary arsenic present in NHANES), even if not necessarily, they would not represent human health risks (NAS 2013).

Therefore we can say that the average arsenic contents in urine in the Paracatu sampled population are below the average contents obtained in the US population and that the maximum contents obtained in sampling in Paracatu are close to the median (14,9) obtained for 75% of the US population (CDC, 2012). Additionally considering the contents between 1 and 5 µg/L of urinary arsenic which representing base contents (background) of exposure, more adequate to the comparison, as the urinary arsenic contents in the Paracatu population under study probably have no contribution of arsenobetain (since such population has no habit of seafood consumption) the results indicate low environmental exposure to arsenic.

There is a trend towards larger arsenic contents in urine in the population served by PSF Amoreiras than in the population served by PSF Paracatuzinho, which is in line with the larger arsenic contents in the atmosphere measured in the regions closer to the gold mining area indicating higher environmental exposure by inhalation in area near the gold mining.

Typical contents of arsenic in blood of individuals not exposed are <1 µg/L (ATSDR, 2007), varying up to 5 µg/L (Santos, E., 2002). Arsenic concentrations in hair of non-exposed individuals are equal to or <1ppm (or 1 µg/g).

Average contents (median) of As in blood and hair of population of Eslobão, Santana-Amapá community in a study coordinated by Evandro Chagas Institute resulted in 5,5 µg/L (n=1.337) and 0,22 µg/g (n=512), respectively. Such study concludes that the

contents observed are within the normality ranges referred to in the literature (1 to 5 µg/L and 1 to 2 µg/g, for arsenic in blood and hair, respectively) (Santos, *et al.*, 2002).

Arsenic concentrations in the blood do not differ between the areas studied in Paracatu and are, in average, above the contents found in non-exposed population. This matrix, unlike urine, is not often used in monitoring due to logistical difficulties and for this reason it shows limitations in comparisons. However these results are worthy of more detailed studies and will be subject of different analyses during the execution of a doctor's degree dissertation still in progress.

The results of arsenic concentration in hair of the Paracatu sampled population do not show significant differences between the two studied areas; they are below 1 ppm and therefore are within the normality range referred to in the literature.

The results of arsenic concentration obtained in the three biological matrixes indicate low exposure level of the population sampled in Paracatu, in line with the estimates obtained by analytical results of environmental matrixes.

In answer to Office Letter–GAB.OF. 181/2012, where Paracatu City Hall requested "access to information on arsenic contents in urine and/or other matrixes as well as clinical or biological tests to work as monitoring of occupational exposure to arsenic in the Kinross company workers", Kinross sent in Office Letter DMA 139/2012 a chart with arsenic concentrations in urine (µg/g of creatinin) of employees assigned to areas with potential arsenic exposure. Although it is difficult to obtain an exact value of arsenic concentration in the chart containing the data, we can say that large part of workers show arsenic contents in the urine above 5 (µg/g of creatinin), and many of them are close to 10 (µg/g of creatinin); one close to 15 (µg/g of creatinin), one above 20 (µg/g of creatinin), two above 25 (µg/g of creatinin) and one above 30 (µg/g of creatinin). The arsenic occupational exposure limits set forth by Ordinance 3214 are arsenic contents in urine, in µg/g of creatinin: Maximum Allowable Biological Index (the maximum value of biological indicator for which it is assumed that most people occupationally exposed are not under risk of damage to their health; exceeding such value means excessive exposure) of 50 µg/gC and indicates the Normality Reference Values – VR (value likely to be found in populations not occupationally exposed) of 10µg/gC. Such arsenic concentrations in urine, including VR, are higher than the average obtained by environmental exposure in Paracatu residents. Thus, since the gold

mining workers are also Paracatu residents, we would recommend giving access to the Municipal Secretariat of Health to periodic monitoring of workers' exposure aiming to follow up the general health conditions of those showing arsenic concentrations in urine above the average of the general population. Such follow-up may mean the generation of knowledge on the arsenic toxicology, bringing inestimable contribution to the scientific knowledge and health management in the city.

c) Results of the Review of Social Media for Strategy of Communication of Results to Paracatu Population

In our sampling there was a large percentage of residents of districts served by PSF Amoreiras who were concerned with the potential effects to human health caused by arsenic exposure (67%), while in Paracatuzinho less than half of the interviewees showed such concern (49,3%). As to sources of information, 8,4%, 17,9%, 19,9% and 18,3% of the people interviewed in the districts served by PSF Amoreiras and 6,1%, 11,2%, 15,0%, 18,2% in Paracatuzinho are informed on the topic of As through the Internet, newspapers, television and radio, respectively. The source of information considered most reliable by the population was Internet (71,4%) in Amoreiras and television (87,5%) in Paracatuzinho.

Additionally, the mapping of personal discussion forums on the topic of arsenic in the environment and aspects associated with human exposure and health revealed that a significant percentage of individuals (38,6%) in Amoreiras and 17,3% in Paracatuzinho are used to talk over such topics with other people, including family members, friends, neighbors, coworkers, members of associations and health agents. Interpersonal relations were considered as the ones with highest credibility in the districts served by PSF Amoreiras (92,8%), where the residents showed higher concerns with the possible toxic effects to human health associated with arsenic environmental exposure.

Based on such results it is suggested to consolidate an Internet platform to present the purposes, methodologies and results of the research and design campaigns aired on TV to present the main results of the project. Analyses of social media will be used for the development of communication strategy of scientific results and should involve different sectors of the society. Seminars, lectures and guidance material should be prepared in interaction with the population, which will certainly bring better

perspectives in the approach of the topic. Increasing the dissemination of information is considered the first step to promote behavioral changes aiming to reduce the environmental exposure and risk (Valente & Davis, 1999). The strategies will be developed with City Hall, representatives of public authorities and Paracatu population .

Complementary Activities in Progress

Complementary activities are related to the individual delivery of results obtained for the Paracatu population who accepted the invitation and was part of this project and the enforcement of the communication strategy for the return of results of this research to the entire population of Paracatu. These activities will be carried out in the next 6 months and a report of activities, conclusions and recommendations will be delivered by August 2014.

A technical report will be consolidated and delivered to City Hall addressing the concentrations of other metals in addition to arsenic, quantified in samples of surface waters, soils and sediments sampled in Paracatu as a contribution to the knowledge of the Municipality environmental characteristics; this report will be submitted to City Hall in April 2014.

Other complementary activities are related to the delivery to City Hall of all scientific documents produced within the scope of this research project during the presentation of theses, dissertations and publication of scientific contributions in specialized magazines and journals.

CONCLUSIONS

The results obtained indicate that:

(i) The average arsenic contents in urine of the Paracatu sampled population (both in areas served by PSF Amoreiras and Paracatuzinho served by PSF Paracatuzinho) resulted between 1 and 5 µg/L of arsenic, a range of contents considered exposure background; they are also below the average contents found in the US population (7,49 µg/L) and close to

the contents observed in the Brazilian urban population with no history of arsenic exposure of State of São Paulo (4,00 µg/L). Such results indicate low environmental exposure of Paracatu population to arsenic ;

(ii) The arsenic concentrations in the blood do not differ between the areas studied in Paracatu and are, in average, above the contents found in non-exposed population which is less than 1 µg/L, such biomarker being little used;

(iii) The results of arsenic concentration in the hair of the Paracatu sampled population exhibit no significant differences between the two areas studied and are below 1 ppm, therefore being within the literature normality ranges;

(iv) Clinical tests of patients with history of chronic skin troubles did not detect cases of skin troubles recognizably caused by chronic exposure to arsenic;

(v) The Paracatu water supply system show no contamination by As and therefore do not represent an important way of exposure being in line with the applicable legislation and the COPASA monitoring data;

(vi) The average As concentration calculated for the sampling period (May 2011 to June 2012) is 5,7 ng/m³ with maximum value of 18,8 ng/m^3 and minimum value of 0,7 ng/m^3;

(vii) Stations with highest average As concentration values in the studied period are Alto da Colina, Arena (including PM 10) and União which are located in the prevailing direction of winds in the region and are closer to the gold mining area;

(viii) The average As concentration in the MP10 of Arenas Station is 5,1 ng/m³ with maximum value of 12,4 ng/m^3 and minimum value of 1,7 ng/m^3;

(ix) The dry period with less precipitation and higher average wind speed corresponded to the period with higher As concentrations in the atmosphere;

(x) The hourly range with higher speed of winds and gusts is between 15 and 21.00 hours possibly increasing the dispersion of dust

produced by detonations from the gold mining front which occurs in such period of time;

(xi) In average, the As concentration in the MP10 corresponded approximately to 30% of the concentration in PTS;

(xii) The average As concentration is within the expected figures (5 to 7 ng m^{-3} ; Maggs, 2000) for European urban areas and well below the expected for US urban areas (20 to 100 ng m^{-3}); but above the recommended level for human health protection considering risk of carcinogenic effects of 1 case for each 100.000 exposed people;

(xiii) It is important to monitor the As contents in MP10 and in MP 2,5;

(xiv) As a rule the soils, sediments and river waters from the Rico Creek and Entre Ribeiros Brook hydrographic sub-basins (which are within the direct influence of gold mining) appear in non-conformity with the quality references defined by CONAMA Resolutions;

(xv) The quality and quantity of water from Rico Creek basin improve on receiving the contribution of water in good quantity and quality from Espalha Creek;

(xvi) The Escuro River sub-basin (considered as control in this study) where the main impounding of water of Paracatu supply is located (Santa Isabel Creek) presents good quality of water according to the legislation;

(xvii) The results of As contents in worms clearly indicate that there is availability of As to the land biota. In acute test it was not possible to verify adverse effects to invertebrates which indicates absence of ecological risk to the tested species; however this is a line of research to be yet investigated .

FINAL CONCLUSION AND RECOMMENDATIONS

Arsenic concentrations in the main human environmental exposure ways (household supply water and atmospheric particulate material) may be considered low. The results exhibit tendencies to higher arsenic contents in the atmosphere near the gold mining area and in favor of the prevailing direction of winds, that is, from the gold mining towards the urban area.

In general the environmental results indicated low human exposure to arsenic and were confirmed by the results of arsenic concentrations in biological matrixes of blood, hair and urine, revealing lower contents or equal to levels considered normality references or even of non-exposed populations in several countries.

The epidemiological study indicated that the population shows no mortality rates by types of cancer with association to arsenic exposure above the observed levels for several Brazilian cities, regions and in the country with no cases of skin diseases referred to arsenic exposure.

The results of this project should be considered as a current scenario of the environmental exposure of Paracatu urban population and a reference of environmental contamination levels and human exposure in the city which shall develop monitoring systems for periodic follow-up of such levels in the long run.

We should consider that the closure of Morro do Ouro Mine is scheduled for 2040, but that mined area, the industrial area and the tailings containment basins will remain, The systematic and permanent communication with the population is fundamental for the knowledge and follow up on arsenic contents (and/or other contaminants) in the mining company property areas, in adjacent areas and areas of direct and indirect as grounds for discussion on the plans for closure of the Mine.

5. RECOMMENDATIONS TO PARACATU CITY AUTHORITIES

Short-term activities include the access to the Municipal Secretariat of Health of periodic monitoring of arsenic exposure by the gold mining company workers aiming to follow up the general health conditions of those exhibiting arsenic concentrations in the urine above the average of the general population. Such follow up may mean the generation of knowledge on arsenic toxicology bringing inestimable contribution to scientific knowledge and health management in the city. Other activities include the support to the conservation of Espalha Creek basin, essential for maintenance of quantity and improvement of quality of water in the Rico Creek basin, the assessment of types and frequency of cancer in Paracatu young population, monitoring of arsenic contents in MP10 and MP2,5 at least in the monitoring points of Alto da Colina, Arena and União, the installation of air quality samplers (total, MP10 and MP 2,5) for assessment of metal contents focusing on lead, in inhabited area near the lead and zinc mining, the quantification of arsenic contents and characterization of solid material present in the gold mining tailings settlement basins, aiming to assess the potential atmospheric dispersion of such material, the behavior of arsenic concentration in alternate and cyclic flood and dry areas and potential bioavailability of arsenic in these materials as fundamental data for the technical discussion on the resulting environmental quality and closure of the Mine.

Also it is important to continue with the monitoring of metal contents in household supply water (surface and ground water) in the city and increase the monitored network to include the wells belonging to the alternative household supply system under the Paracatu City Hall responsibility; the continuance of monitoring of metal concentration in waters, sediments and soils of Rico Creek, Entre Ribeiros Brook and Escuro Creek basins (including the river flow rate measurement) and the detailing of river basins with agricultural activities aiming to know the metal contents including arsenic in local farming products especially vegetables, fruits command rice (including seeds).

A pilot study of arsenic environmental exposure in children is suggested with scientific interest for effects under low environmental doses.

For that our recommendation to the Paracatu Public Authorities is the creation of an environmental health surveillance system oriented towards the assessment of environmental contamination, assessment of risks and human exposure to metals (and/or other important pollutants in anthropogenic / economic activities) especially but not limited to, arsenic and lead in Paracatu. Such actions require the reinforcement and continued qualification, especially of the technical staff of Municipal Secretariats of Health and Environment and include de acquisition of equipment and training under supervision of an institution of recognized technical capacity. It is suggested that researches of assessment of environmental contamination and risks associated with human health and the environment should be ongoing and encouraged in Paracatu, since this present study should be considered as a reference, the ground zero in the generation, organization and systematic integration of data on the human environmental exposure to arsenic in Paracatu. It is worth emphasizing that the change in the characteristics of the gold ore exploited in the last years (from oxide to sulfide) may generate impacts on the current arsenic contents. In a city having mining and farming as important economic activities, environmental monitoring should not be sporadic but rather systematic and comprehensive. For that it is essential to increase the qualification and the number of local professionals in these areas of knowledge, which may be conducted with the support from learning and research institutions existing in the city in technical cooperation with consolidated interdisciplinary research centers in Brazil and abroad.

Equally important are the actions for permanent quality communication with the population and the development of studies on topics that include assessment of environmental, economic and social impacts of economic activities including mining and their implications on the territory sustainable development.

BIBLIOGRAPHY

ASTDR, 2007. Toxicological profile for Arsenic. August 2007; 500p.

Caldwell, K.; Jones, R., Verdon, C; Jarret, J., Caudill, S; Osterloh, J. Levels of urinary total and speciated arsenic in the US population: National Health and Nutrition Examination Survey 2003-2004 Journal of Exposure Science and Environmental Epidemiology (2009), 19, 59-68

CAL EPA- California Environmental Protection Agency. Arsenic in the environment., 2012

CETESB. *Qualidade do Ar: Poluentes*. Available at: <http://www.cetesb.sp.gov.br/ar/Informa??es-Básicas/21-Poluentes>. Access on 8 July 2012.

CONAMA. Resolution 420. December, 2009.

George CM et al. 2013 Approaches to Increase As Awareness in Bangladesh An Evaluation of an As Education Program. Health Education & Behavior 40: 331-338.

Mertens, F., Saint-Charles, J. & Mergler, D. 2012. Social communication network analysis of the role of participatory research in the adoption of new fish consumption behaviors. Social Science and Medecine 75: 643-650.

National Research Council of the National Academies (2013). Critical aspects of EPA´s IRIS assessment of inorganic arsenic. Interim Report.

National Health and Nutrition Examination Survey, 2008-2009

PREFEITURA Municipal de Paracatu. História. Available at: <http://www.paracatu.mg.gov.br/index.php?m=layout_paginas_4.php&paginas_id=1>. Acccess on 8 July 2012.

Pillai A, Sunita G, Gupta VK. A new system for the spectrophotometric determination of arsenic in environmental and biological samples. Analytica Chimica Acta 2000; 408: 111-5.

USEPA. Sampling Chemical Speciation of Arsenic in Water and Tissue by Hydride Generation Quartz Furnace Atomic Absorption Spectrometry – Method 1632. Office of Science and Technology Eng. and Analysis Division, Washington, DC, 1998.

U.S. Evironmental Protection Agency. Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air – Compendium Method IO-3.1: Selection, Preparation and extraction of Filter Material. Cincinnati, Ohio, 1999.

USEPA/RAGS: Human Health Evaluation: Part A. 1989.

Santos, E. 2002. *Resultados do estudo de saúde humana realizado na Comunidade do Esbolão, Santana-Amapá*.

Valente, T.W., & Davis, R.L. 1999. Accelerating the diffusion of innovations using opinion leaders. *The Annals of the American Academy of Political and Social Science* 566: 55-67.