Estimation of mercury released from an abandoned gold mine in Minas Gerais, Brazil

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José Fernando Miranda[1,2]
https://orcid.org/0000-0002-7998-1117
Adilson Curi[1,3]
https://orcid.org/0000-0002-1163-7846
Hernani Mota de Lima[1,4]
https://orcid.org/0000-0002-5595-4149

[1]Universidade Federal de Ouro Preto – UFOP,
Escola de Minas,
Departamento de Engenharia de Minas,
Ouro Preto – Minas Gerais - Brasil.

E-mails: [2]j.miranda@ufop.edu.br, [3]curi@ufop.edu.br,
[4]hernani.lima@ufop.edu.br

Abstract

Mining is very important to the economic, political and social development of the Minas Gerais State in Brazil ever since the time the country became a Portuguese colony in the early 1500s. However, few researches have been conducted to evaluate the environmental impacts associated with the mining activity at this time. There are many abandoned mines in Minas Gerais; these are mainly gold mines inherited from the colonial period, which have been considered to represent a considerable environmental liability. However, when a road was constructed in a rural area of the municipality of Descoberto, Minas Gerais, in 2002, a significant amount of mercury was detected in an abandoned gold mine. In 2014, the State Public Prosecutor's Office found both the State of Minas Gerais and the State Environmental Agency liable and responsible for this occurrence and ordered them to design an intervention project for the contaminated area that involved mine closure. This article provides information on how mercury contamination occurred and estimates the amount of mercury present in the contaminated area, with the aim of supporting proposals of alternative remediation, monitoring and management therein. This study includes a historical survey of mining operations in the region and a brief history of the use of mercury in amalgamation. Estimations are made of the amount of gold produced and the amount of mercury released into the environment between 1850 and 1892. Results show an estimated mass of 820 kg of mercury contained in soils and sediments within an area smaller than 1 hectare.

keywords: abandoned mines; gold; mercury; contamination; estimation.

1. Introduction

In the past, mercury was widely utilized for gold and silver amalgamation. As such, ancient gold mining sites are areas of huge concern because mercury may have been deposited in surrounding soils and aquatic ecosystems. Extremely high levels of mercury concentrations have remained in soils, sediments and water around some ancient gold mining sites since their activities have ceased to exist (Rimondi *et al*., 2012), which has contributed to a high pollutant concentration (Lacerda and Salomons, 1992; Veiga *et al*., 2002). However, remediation of sites contaminated by mercury is often a complex task, since it requires a precise assessment and evaluation to enable selection of the best techniques for use in avoiding long-term risks and minimizing and eliminating contamination.

In the municipality of Descoberto, during the construction of an access road on a rural property in December 2002, metallic mercury exuded from the cut slope. The site was later identified as an abandoned gold mine. In order to gain a full understanding of the situation and to estimate the amount of mercury released into the Descoberto environment, this article presents a review of the gold amalgamation process, provides information on how the mercury contamination occurred and estimates the amount of mercury present in the contaminated area, with the aim of supporting proposals of alternative remediation, monitoring and management therein.

Brief history of gold amalgamation

Mercury has been used in the extraction of metals dating from 500 BC, after the Romans had recognised the properties of gold amalgamation and for recovering the metal (Azevedo, 2003). The use of this process subsequently proliferated throughout the world over time, eventually reaching the Americas in around the 16th Century, where gold and silver found in Bolivia and Peru were amalgamated (Studnicki-Gizbert and Schecter, 2010). Reports about the use of mercury for gold amalgamation are found in Bovet (1883), Ferreira (1885) and Eschwege (1979).

In Brazil, two methods using mercury were practiced during the colonial period in gold mining. The most common was the addition of mercury in a vessel containing the concentrated material. The amalgamation process was conducted and the material washed to remove the impurities (Eschwege, 1979). The other method, described by Courcy (1997), was used in the Mina da Passagem in Mariana/Minas Gerais. The method consisted of adding mercury on the washing tables in order to facilitate the amalgamation of the fine gold contained therein. Since then, mercury has been thoroughly used for gold amalgamation in several artisanal mines around Brazil, especially in the Amazon region as described by Lacerda and Salomons, 1992; and Veiga *et al*., 2002.

Location and characterizantion of the contaminated site

The abandoned mine site is located in the municipality of Descoberto 370 km from Belo Horizonte, in the Zona da Mata, in the State of Minas Gerais. It is located in the Zona da Mata Mineira (geographical coordinates 21.45° S and 42.96° W) in the southeast portion of Minas Gerais (Figure 1). The area of the mine is located within the Grama Creek basin.

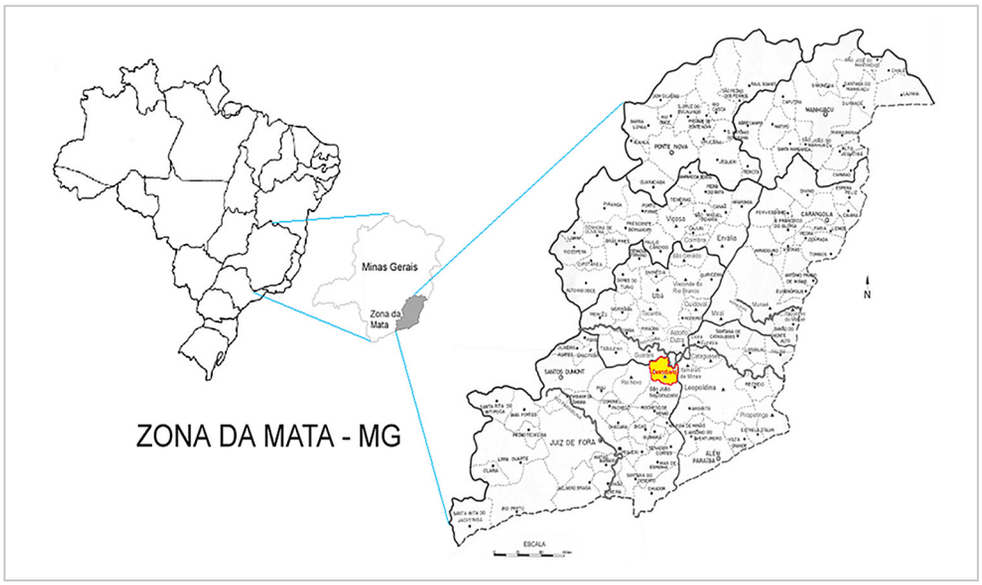

Figure 1 - Location of the municipality of Descoberto in the Zona da Mata Mineira Source: Adapted from Noce et al. 2003

Figure 2 shows the predominance of faceted quartz grains and pebbles in the subsurface with diameters up to 5 cm, which are probably waste from auriferous gravel and contain the highest concentrations of mercury within the contaminated area.

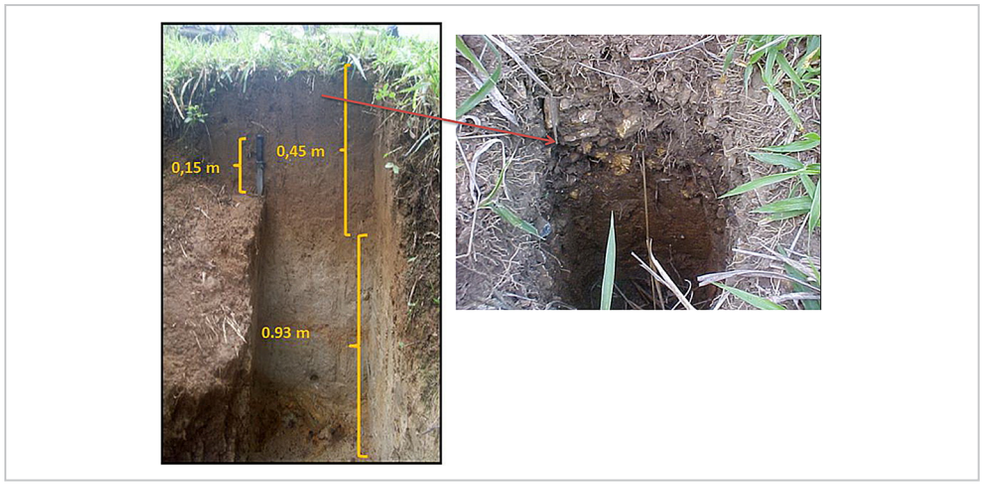

Figure 2 – Contaminated area soil profile. On the right, quartz pebbles in the contaminated area. Source: Adapted from Oliveira (2014) and FEAM and CDTN (2006).

Brazilian mercury legislation

Although not a mercury producer, Brazil has guidelines and standards to regulate the use and handling of mercury, due to the large use of this element in artisanal mines. Different governmental institutions of the Executive and Legislative Power enact these rules, which create a complex system of management. Table 1 gives the limits of mercury and it recommended reference values for mercury concentration. It also shows alert and intervention values in the soil, sediments and surface waters in various areas as a function of their use, depending if the area is residential and/or industrial, according to the Brazilian and International regulations.

Table 1 - Mercury reference values for alert and intervention.

Monitored Medium	Limit	Note	Reference
Potable water	0.001 mg/L	Water for human consumption	6
Subterranean water	0.001 mg/L	Based on the use of fuel	1, 3
Surface water	0.0002 mg/L 0.002 mg/L	Water Class 1 and Water Class 2 Water Class 3	4
River bottom sediment	0.170 mg/kg 0.486 mg/kg	ISQG (level for sediment quality) PEL (probable effect level)	7
Soil	0.05 mg/kg	Reference value	2, 6
	0.5 mg/kg	Alert value	
	12 mg/kg	Value of intervention (agricultural scenario)	
	36 mg/kg	Value of intervention (residential scenario)	
	70 mg/kg	Value of intervention (industrial scenario)	
Reference: reference values if soil quality; Mercury			
1. According to Resolution CONAMA N° 430/2011 (Brasil, 2011)			
2. According to Resolution CONAMA N° 420/2009 (Brasil, 2009)			
3. According to Resolution CONAMA N° 396/2008 (Brasil, 2008)			
4. According to Resolution CONAMA N° 357/2005 (Brasil, 2005)			
5. According to Portaria 2914/2011 (Brasil, 2011a)			
6. According to CETESB – DD 256/2016/ (CETESB, 2016)			
7. According to CCME – 1995 (CCME, 1995)			

Mercury contamination assessment in descoberto

The average mercury content in different types of global soils ranges from 0.58 to 1.8 mg/kg and the world average is estimated at 1.1 mg/kg (Xu *et al*., 2015). Table 2 presents the concentrations of results of mercury from previous soil, sediment and surface water contamination assessments. An outlier value of 986 mgHg/kg in soil was found in a possible sluice site. This grade of Hg supports the evidence of an abandoned mine. Other studies detected values lower than the recommended level of danger (0.5 mg/kg of mercury). However, these levels are still worrisome, since they are above the reference level. There was no mercury contamination below a depth of 100 cm.

Table 2 - Concentration of total mercury in soils, sediments and surface waters within the descoberto region

Local	Hg Total Soils (0 to 100 cm) (mg/kg)	Hg Total Sediments (mg/kg)	Hg Total Surface Waters (mg/L)	References
Rico stream	986	0.75	0.75	FEAM and CDTN (2005)
Grama creek	-----	0.02 to 0.16	0.02	
Rico stream	-----	0.23	0.24	FEAM and CDTN (2006)
Grama creek	0.02 to 0.88	0.07 to 0.17	0.02	
Rico stream	------	0.23	2.98	Marques et al. (2006)
Grama creek	0.24	0.02 to 0.06	0.24	
Rico stream	-----	0.51	2.83	Alexandre (2006)
Grama creek	0.003 to 0.34	0.02	0.43	
Rico stream	-----	0.42	2.83	Tinôco (2010)
Grama creek	0.26 to 0.55	0.20 to 0.61	0.43	
Rico stream	-----	-----	-----	Durão Jr et al. (2009)
Grama creek	0.2 to 41	-----	-----	
Rico stream	0.3 to 0,17	1.67	-----	Oliveira (2014)
Grama creek		0.03 to 0.19	-----	

For river sediments, studies found concentrations above reference values, yet they were below dangerous values. All concentrations were within the range of non-dangerous values according to CONAMA resolution (Brazil, 2009). In sampling campaigns, Alexandre (2006); Marques *et al.* (2006) and Tinôco (2010) observed an increase in values during the dry season. Nevertheless, in the rainy season, the increase in flow velocity of surface waters causes an accumulation of mercury in the sediments, suggesting that metal present in the soil is subsequently conveyed into the watercourse. Miranda *et al.* (2009) determined a value of 0.43 mg/kg for the background of mercury in the soils at the Grama Creek basin and 0.34 mg/kg for the background in sediments. The Student T-test showed no significant differences between background values determined for the soils and sediments.

Gold production in descoberto region

Several studies describe the process of gold production by artisanal miners in Minas Gerais and highlight the decline in production over time due to the lack of suitable mining techniques (Coelho, 1994; Eschwege, 1979; Ferrand, 1998; Pinto, 1979). By the end of 1820 the arrival of British companies initiated the modern and efficient mining techniques for rock gold mining. The British also began operating underground mines and improved the amalgamation process (Capanema, 2013; Silva, 1997).

The fall in artisanal production, due to exhaustion of the alluvial deposits in the Quadrilátero Ferrífero, prompted miners to move to the east of Minas Gerais. In the Zona da Mata, the municipality of Descoberto was established after the discovery of gold deposits in the region. According to Silva (1997) a farmer found gold in a small creek of his property, and this news hastened the move of miners from the Quadrilátero Ferrífero to the Zona da Mata region. Colluvium and alluvium were mined similar to those in the Quadrilátero Ferrífero. Amalgamation occurred during the concentration process, and mercury was later introduced directly into the sluices (Silva, 1997).

It is difficult to quantify the amount of mercury used in the Descoberto region, as well as to estimate the amount of metal released into the environment. There is a lack of production records, and thus, there are only historical narratives of mining sites and the techniques employed along with the remaining activities are known.

Silva (1977) describes the richest gold mines in the Descoberto region as being located in an area known as St. Joseph, where the mountain slopes are quite steep. This description faithfully depicts aspects of the geomorphology in the Grama River basin region, particularly some of the sub-basins of its tributaries as follow:

'[...] the gold mines on the Gramma farm, in the parish of Descoberto in the municipality of São João Nepomuceno, are made up of extensive and vigorous layers of gold gravel and settle on almost the entire immense basin of the Descoberto stream, a small watercourse of 2 1/3 to 3 leagues that flows into the Rio Novo on the left margin [...]'.

'[...] The layers of the gold gravel in this region are usually covered by a clay crust easy to be dismantled [...]'.

'[...] This gravel accompanies the more or less pronounced ripples of the terrain on which they lie, has a thickness ranging from 0.50 to 1.50 m and covers an area of more than 8,286.50 m^2 ...'

'[...] the main layers of gold gravel were located in places known by the names of

- *Descoberto stream. In 300 pannings of 10 kg of gravel or 3,000 kg (medium term) 2.136 grams of gold.*
- *Carlos Mine in the same proportions 1.120 grams of gold.*
- *Antonio stream in the same proportions 7.363 grams of gold.*
- *Antonio Maximiliano stream in the same proportions 21.441 grams of gold [...]'.*

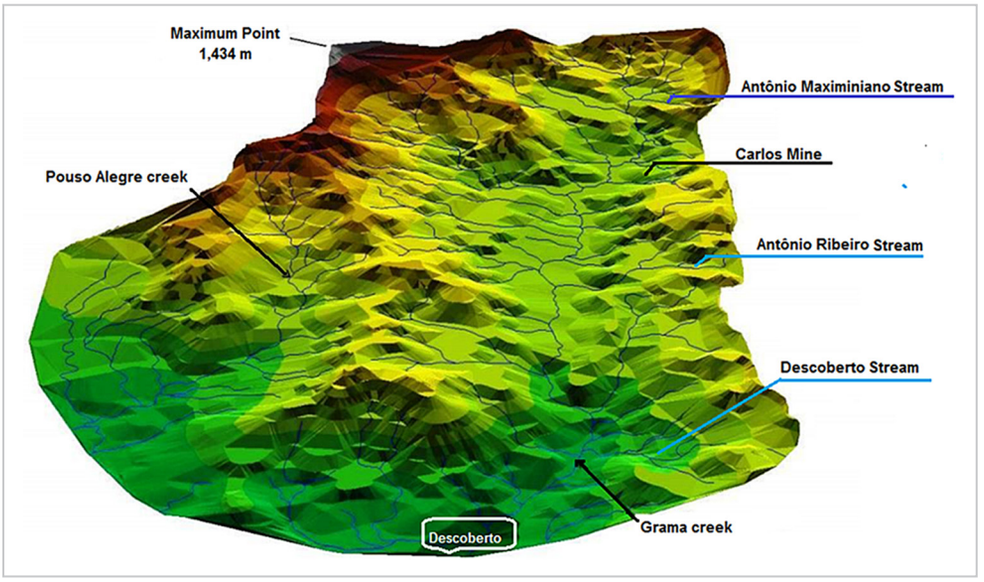

Figure 3 - Relief of the Descoberto area, highlighting the mined areas. Source: Adapted from Pereira Filho & Sartori (2013)

The study of Pinto (1979) describes gold production in the Minas Gerais state from 1700 to 1800 (Figure 4); an average fall in gold production of approximately 20–25% occurred every 10 years after the year 1745.

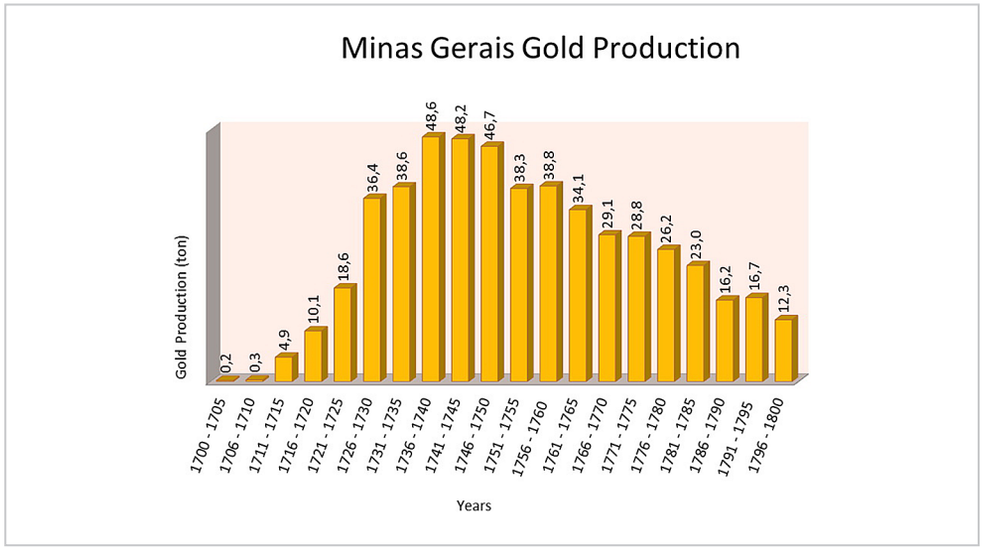

Figure 4 – Gold production of Minas Gerais State, Brazil.

As the Descoberto gold production was never reported, this study estimates production by considering a drop of 10% per year from 1824 to 1892, when the H. Milliet company left the region. According to Silva (1977) and Pinto (1979) studies, the authors estimate that between 1850 and 1892, the British mining company produced approximately 1,553 kg of gold (Figure 5).

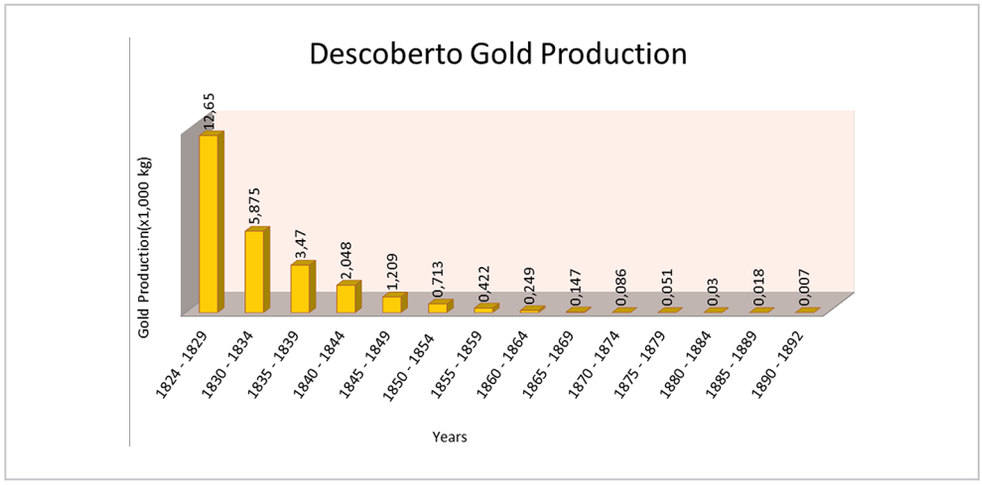

Figure 5 - Gold production of Descoberto, Minas Gerais State,
Brazil from the inception (1824) till the end (1892). The H. Millet Company operated from 1850 to 1892.

Estimation of mercury in the mine site

In order to estimate the amount of mercury used in Descoberto, the Emission Factor (EF) - amount of mercury released in the environment to produce 1.0 kg of gold, of which 40% is lost in soils and sediments as metallic Hg (Lacerda and Salomons, 1992; Nriagu 1993, 1994; Pfeiffer and Lacerda, 1988; Robins and Hagan, 2012; Swain *et al.*, 2007) was adopted. According to Alpers and Hunerlach (2000), in the mid-1850s, gold was concentrated in sluices by adding mercury. Yet, considering Bovet (1882), Ferreira (1885) and Eschwege (1979) descriptions, the authors deduce the British company employed the same technique and that part of the mercury lost stayed in the mining site.

The amount of mercury used for gold amalgamation over time is a function of the ore content and the skill of the miners. In literature, EFs range from 1.0 to 4.0 kg of mercury per kg of gold produced. For example, EF of 2.0 to 4.0 (Mallas & Benedicto, 1986); EF equal to 1.2 (Pfeiffer and Lacerda, 1988); EF equal to 1.3 (Lacerda & Salomons, 1992); EF equal to 1.2 (Nriagu, 1993, Veiga, 1997 and Robins & Hagan, 2012. Since no reference exists in the case of Descoberto, the authors considered an average EF value of 2 kg of mercury/kg of gold produced in order to estimate the amount of mercury released in the mining site. The authors also adopt a mercury loss of around 40% during the amalgamation process.

An EF of 2.0 results in 3,360 kg of mercury released in the Descoberto region from 1850 to 1892 by the British Company H. Millet. Thus, the loss of mercury in soils and sediments in the region can be estimated as 1,344 kg of mercury (considering a 40% loss) as shown in Table 3.

Table 3 – Mercury released in soils and sediments in Descoberto region by the British Company

Years	Gold Production (kg)	EF= 2 kg Hg/1 kg Au)	Loss (40%)
1850 - 54	715	1,430	572
1855- 59	420	840	336
1860 - 64	250	500	200
1865 - 69	145	190	76
1870 - 74	85	170	68
1975 - 79	55	110	44
1880 - 84	35	70	28
1885 - 89	20	40	16
1890 - 92	5	10	4
Total	1,730	3,360	1,344

Furthermore, in order to estimate the amount of mercury in the contaminated area (Figure 6), data compiled in the studies of Alexandre (2006); Durão Jr *et al.* (2009); Marques *et al.*, (2006); Oliveira (2014); and Tinôco (2010) have been considered. These studies concentrate in a contaminated area of about 0.9 ha along the Rico stream, tributary of the Grama Creek. These studies found contamination within the first 100 cm depth of soil, thereby providing a total of 9000 m³ of contaminated soil, with an average mercury content of 50 g/t. Therefore, considering that 1 m³ of soil in the region is equivalent to 1.82 t, a total amount of 16,380 tonnes of contaminated soil exists, which contains approximately 820 kg of mercury.

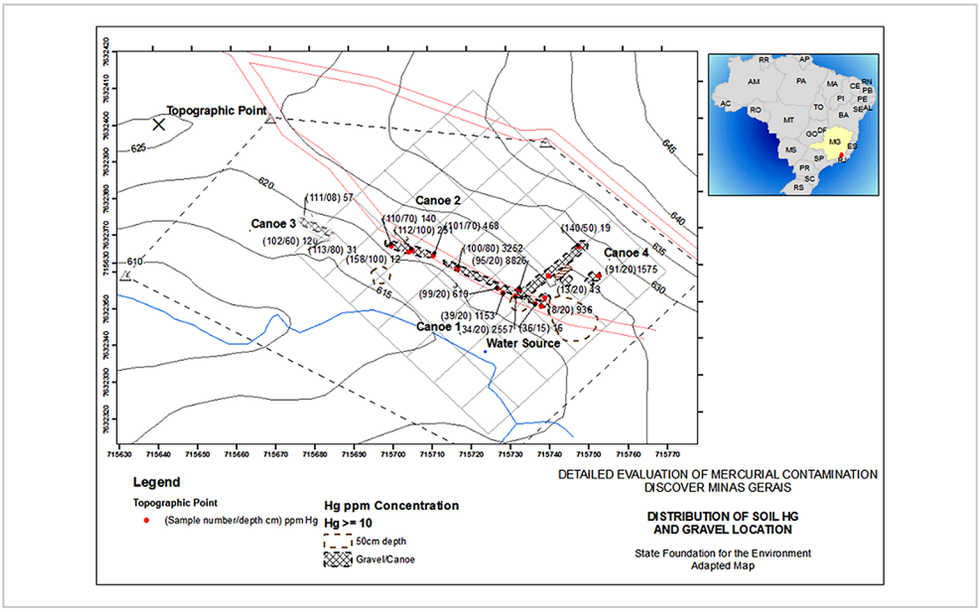

Figure 6 - Contaminated Area, highlighting the canoes as Hot Spot's. Source: Adapted from FEAM & CDTN (2006).

Final considerations

Two hypothetical sources of the mercury in the contaminated area are considered. The first is that the deterioration of mercury barrels abandoned on site released mercury, which penetrated the surface soil into a depth of 100 cm. The second relates to the amalgamation process conducted into the sluices. The remains of mining works and tools, such as sluices, piles of washed gravel and water channels corroborate this hypothesis.

The second hypothesis is also used to explain the route of mercury contamination and to estimate the amount of mercury released in Descoberto region. Accordingly, this study considered the second hypothesis to explain the source of mercury and to estimate the amount of this metal released in the old mining site.

Historical reports were used to estimate the amount of gold produced in Descoberto. This study has shown that an amount of 3,360 kg of mercury to an EF of 2.0, has been released in the Descoberto region from 1850 to 1892 by the British Company H. Millet. Consequently, this study estimates a releasing of 1,344 kg of mercury to soils and sediments.

However, data compiled from previous studies focusing on soil contamination along the Rico stream Grama Creek have found 820 kg of mercury. As shown by Oliveira (2014), the concentration of Hg decreases with the increase of contaminated soil profile depth. However, a significant increase in Hg concentration in sediments and soils during the rainy season was observed. This difference is certainly related to thetransport of contaminated soil and sediments by hidric erosion occurring over 130 years of erosion and by bioaccumulation and biomagnification processes.

And finally, the lack of a more holistic view of the issue has made it

difficult to understand the problem and it has also limited the choice of suitable remediation alternatives. Whereupon, this article highlights that the characterization of the area as an abandoned mine or orphan mine, could facilitate the elaboration of an adequate remediation plan, observing the current guidelines for a mine closure implementation.

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References

ALEXANDRE, S. C. ***Caracterização de área contaminada por Hg em descoberto - Minas Gerais.*** 2006. 60 f. Dissertação (Mestrado) – Universidade Federal de Viçosa, Viçosa, 2006.

ALPERS, C. N.; HUNERLACH, M. P. ***Mercury contamination from historic gold mining in California:*** U.S. Geological Survey Fact Sheet 061-00. California: USGS, 2000. 6p. Available at: https://pubs.usgs.gov/fs/2000/fs06100/pdf/fs06100.pdf. Acessed in 12/02/2017.

AZEVEDO, F. A. ***Toxicologia do mercúrio.*** São Carlos/SP: Editora RiMa: Editora Intertox, 2003. 272 p.

BOVET, A. de. A indústria mineral na província de Minas Gerais - primeira parte: ferro e ouro. ***Annaes da Escola de Minas de Ouro Preto.*** Ouro Preto, n. 2, p. 25-99, 1883.

BRASIL. Ministério do Meio Ambiente. Conselho Nacional de Meio Ambiente. Resolução CONAMA Nº 357/2005. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providências. ***Diário Oficial da União:*** seção 1, Brasília, DF, n. 053, p. 58-63, 18 mar. 2005.

BRASIL. Ministério do Meio Ambiente. Conselho Nacional de Meio Ambiente. Resolução CONAMA Nº 396/2008. Dispõe sobre a classificação e diretrizes ambientais para o enquadramento das águas subterrâneas e dá outras providências. ***Diário Oficial da União:*** seção 1, Brasília, DF, n. 66, p. 64-68, 07 abr. 2008.

BRASIL. Ministério do Meio Ambiente. Conselho Nacional de Meio Ambiente. Resolução CONAMA Nº 420/2009. Dispõe sobre critérios e valores orientadores de qualidade do solo quanto à presença de substâncias químicas e estabelece diretrizes para o gerenciamento ambiental de áreas contaminadas por essas substâncias em decorrência de atividades antrópicas. ***Diário Oficial da União:*** seção 1, Brasília, DF, n. 249, p. 81-84, 30 dez. 2009.

BRASIL. Ministério do Meio Ambiente. Conselho Nacional de Meio Ambiente. Resolução CONAMA Nº 430/2011. Dispõe sobre condições e padrões de lançamento de efluentes, complementa e altera a Resolução no 357, de 17 de março de 2005, do Conselho Nacional do Meio Ambiente - CONAMA. ***Diário Oficial da União:*** seção 1, Brasília, DF, n. 92, p. 89, 16 maio 2011.

BRASIL. Ministério da Saúde. Portaria n.º 2.914, de 12 de dezembro de 2011. Dispõe sobre procedimentos de controle e de vigilância da qualidade da água para consumo humano e seu padrão de potabilidade. ***Diário Oficial da União:*** seção 1, Brasília, DF, p. 43-49, 04 jan. 2012.

CAPANEMA, C. M. ***A natureza política das Minas:*** mineração, sociedade e ambiente no século XVIII. 2013. 233 f. Tese (Doutorado em História) - Faculdade de Filosofia e Ciências Humanas, Universidade Federal de Minas Gerais, Belo Horizonte, 2013.

CCME (Canadian Council of Ministers of the Environment). ***Protocol for the derivation of Canadian sediment quality guidelines for the protection of aquatic life.*** CCME EPC-98-E. Ottawa: CCME, 1995. Available at: http:// http://ceqg-rcqe.ccme.ca/download/en/226/ . Acessed in: 12/02/2017.

CETESB - Companhia Ambiental do Estado de São Paulo. Decisão de Diretoria Nº 256/2016. Valores Orientadores Para Solos e Águas Subterrâneas. ***Diário Oficial Estado de São Paulo:*** seção 1: Poder Executivo, São Paulo, edição nº126 (219), p. 55-56, 24 nov. 2016.

COELHO, J. J. T. ***Instrução para o governo da capitania de Minas Gerais.*** Belo Horizonte: Fundação João Pinheiro, Centro de Estudos Históricos e Culturais, 1994. 399p. (Coleção Mineiriana. Série Clássicos).

COURCY, V. E. ***Seis semanas nas minas de ouro do Brasil.*** Belo Horizonte: Fundação João Pinheiro, Centro de Estudos Históricos e Culturais, 1997. 129p. (Coleção Mineiriana. Série Clássicos).

DURAO JR, W. A.; PALMIERI, H. E. L.; TRINDADE, M. C.; AQUINO BRANCO, O. E.; FILHO, C. A. C.; FLEMING, P. M.; SILVA, J. B.; Windmoller, C. C. Speciation, distribution, and transport of mercury in contaminated soils from Descoberto, Minas Gerais, Brazil. ***Journal of Environmental Monitoring,*** v. 11, n. 5, p. 1056-1063, 2009. DOI:10.1039/b813997k.

ESCHWEGE, W. L. V. ***Pluto Brasiliensis.*** Belo Horizonte (MG) : Itatiaia, São Paulo : EDUSP, 1979. 222 p. (Coleção Reconquista do Brasil, v. 58).

FERRAND, P. ***O ouro em Minas Gerais (Brasil).*** Belo Horizonte: Fundação João Pinheiro. 1998. 366 p. (Coleção Mineiriana).

FERREIRA, F. I. ***Diccionario geographico das minas do Brazil.*** 1ª edição. Rio de Janeiro: Imprensa Nacional, 1885. 754 p.

FUNDAÇÃO ESTADUAL DO MEIO AMBIENTE. CENTRO DE DESENVOLVIMENTO DA TECNOLOGIA NUCLEAR. ***Diagnóstico da contaminação ambiental em Descoberto, Minas Gerais, em decorrência do afloramento de Hg em dezembro de 2002.*** Relatório Final. Belo Horizonte: CDTN, 2006. 199p.

FUNDAÇÃO ESTADUAL DO MEIO AMBIENTE. CENTRO DE DESENVOLVIMENTO DA TECNOLOGIA NUCLEAR. ***Diagnóstico da contaminação ambiental em Descoberto, Minas Gerais, em decorrência do afloramento de Hg em dezembro de 2002.*** Relatório de progresso. Belo Horizonte: CDTN, 2005. 166p.

LACERDA, L. D.; SALOMONS, W. ***Mercúrio na Amazônia:*** uma bomba relógio química? Rio de Janeiro: CETEM/CNPq, 1992. 78 p.

MALLAS, J.; BENEDICTO, N. Mercury and gold mining in the Brazillian Amazon. ***Ambio,*** v. 15, n. 4, p. 248-249, 1986.

MARQUES, E. A. G.; ALEXANDRE, S. C.; MIRANDA, J. F.; FINEZA, A. Caracterização de área Contaminada por Hg no município de Descoberto MG. *In*: CONGRESSO BRASILEIRO DE MECÂNICA DOS SOLOS E ENGENHARIA GEOTÉCNICA, 13.; SIMPOSIO BRASILEIRO DE MECÂNICA DAS ROCHAS, 4.; CONGRESSO LUSO-BRASILEIRO DE GEOTECNIA, 3., 2006, Curitiba. ***Anais[...].*** COBRAMSEG, 2006. 6 p.

NOCE, C. M.; ROMANO, A. W.; PINHEIRO, C. M.; MOL, V. S.; PEDROSA-SOARES, A. C. Geologia das Folhas Ubá e Muriaé. *In*: PEDROSA-SOARES et al. (eds.). ***Geologia e recursos minerais do sudeste mineiro.*** Belo Horizonte: COMIG, 12. 2003. p 623-659.

NRIAGU, J. O. Legacy of mercury pollution. ***Nature,*** v.363, p.589. 1993. Available at: https://doi.org/10.1038/363589a0. Acessed in: 13 oct. 2017.

NRIAGU, J. O. Mercury pollution from the past mining of gold and silver in the Americas. ***Science of The Total Environment,*** v. 149, n.3, p. 167-181, 1994. Available at: https://doi.org/10.1016/0048-9697(94)90177-5. Accessed in: 13 oct. 2017.

OLIVEIRA, G. A. ***Avaliação dos níveis atuais de Hg total em área contaminada no município de Descoberto – MG.*** 2014. 95 f. Dissertação (Mestrado Acadêmico em Geografia) - Instituto de Ciências Humanas, Universidade Federal de Juiz de Fora, Juiz de Fora, 2014.

PEREIRA FILHO, H. R.; SARTORI, M. A. ***Plano de Manejo Reserva Particular do Patrimônio Natural Alto da Boa Vista – I e II.*** Descoberto, MG: BIOPRESERVAÇÃO Consultoria e Empreendimentos Ltda. 2013. 289p. Available at: http://www.icmbio.gov.br/portal/images/stories/docs-planos-de-manejo/rppn_alto_da_boa_vista_IeII_pm1de2.pdf. Accessed in: 25 nov. 2017.

PFEIFFER, W. C.; LACERDA, L. D. Mercury inputs into the Amazon Region, Brazil. ***Environmental Technology Letters,*** v. 9, n. 4, p. 325-330. 1988. Available at: https://doi.org/10.1080/09593338809384573. Accessed in: 4 oct. 2017.

PINTO, V. N. ***O ouro brasileiro e o comércio anglo-português:*** uma contribuição aos estudos da economia atlântica no século XVIII. 2. ed. São Paulo: Nacional, 1979. 346p.

RIMONDI, V.; GRAY, J. E; COSTAGLIOLA, P; VASELLI, O.; LATTANZI, P. Concentration, distribution, and translocation of mercury and methylmercury in mine-waste, sediment, soil, water, and fish collected near the Abbadia San Salvatore mercury mine, Monte Amiata district, Italy. ***Science of the Total Environment,*** v. 414, p. 318-327, 2012. Available at: https://doi.org/10.1016/j.scitotenv.2011.10.065. Accessed in: 4 oct. 2017.

ROBINS, N. A.; HAGAN, N. A. Mercury production and use in colonial andean silver production: emissions and health implications. ***Environmental Health Perspectives,*** v. 120, n. 5, p. 627-631, 2012. DOI: https://doi.org/10.1289/ehp.1104192.

SILVA, D. G. B. (org.) ***Os diários de Langsdorff.*** Campinas : Rio de Janeiro : AIEL FIOCRUZ, 1997. 400 p. V. 1: Rio de Janeiro e Minas Gerais, 8 de maio de 1824 a 17 de fevereiro de 1825.

STUDNICKI-GIZBERT, D.; SCHECTER, D. The environmental dynamics of a colonial fuel-rush: silver mining and deforestation in New Spain, 1522 to 1810. ***Environmental History,*** v. 15, n. 1, p. 94-119, 2010. Available at: http://envhis.oxfordjournals.org/content/15/1/94.full.pdf+html?sid=9b14420c-814a-42b6-ad23-4727f8d1d168 . Accessed in: 12 dec. 2016.

SWAIN, E. B.;JAKUS, P. M.; RICE, G.; LUPI, F.; MAXON, P. A.; PACYNA, J. M.; PENN, A. F.; SPIEGEL, S. J.; VEIGA, M. M. Socioeconomic Consequences of Mercury Use and Pollution. ***A Journal of the Human Environment,*** v. 36, n. 1, p. 45-61. 2007. Available at: https://doi.org/10.1579/0044-7447(2007)36[45:SCOMUA]2.0.CO;2. Accessed in: 3 may 2017.

TINÔCO, A. A. P.; AZEVEDO, I. C.; D'ALMEIDA D.; MARQUES, E. A. G.; MOUNTEER, A. H.; MARTINS, C. P.; NASCENTES, R.; REIS, E. L.; NATALINO, R. Avaliação de contaminação por mercúrio em Descoberto, MG. ***Engenharia Sanitaria e Ambiental,*** v. 15, n. 4, p. 305-314, 2010. Available at: https://dx.doi.org/10.1590/S1413-41522010000400003. Accessed in: 30 jan. 2017.

VEIGA, M. M. ***Introducing new technologies for abatement of global mercury pollution in Latin America.*** Rio de Janeiro: Ed. UNIDO/UBC/CETEM, 1997. 94 p. ISBN: 85-7227-100-7.

VEIGA, M. M.; SILVA, A. R. B.; HINTON, J. J. O garimpo de ouro na Amazônia: aspectos tecnológicos, ambientais e sociais. *In*: TRINDADE, R. B. E.; BARBOSA FILHO, O. (ed.). ***Extração de ouro:*** princípios, tecnologia e meio ambiente. Rio de Janeiro: CETEM/MCT, 2002. cap.11, p. 267-295.

XU, J.; BRAVO, A. G.; LARGERKVIST, A.; BERTILSSON, S.; KUNPIEN, J. S. R. Souces and Remediation techiniques for mercury contaminated soil. ***Environment International,*** v. 74, p. 42-53, 2015. Available in: http://www.sciencedirect.com/science/article/pii/S0160412014002748. Accessed in: 28 apr. 2017.

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