Evaluation of Three Studies of Environmental Arsenic near the Morro do Ouro Mine operated by Kinross Gold, Minas Gerais, Brazil

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LIGHTNING SUMMARY

A study funded by the City of Paracatu in the vicinity of the Morro do Ouro Mine in Minas Gerais, Brazil, underestimated arsenic concentrations by filtering water samples prior to analysis, while a second funded by Kinross Gold did not report the methodology. Nevertheless, the city-funded study and a study funded by the Santa Rita Small Producers Association were in agreement in measuring elevated arsenic concentrations in surface water near the village of Santa Rita.

ABSTRACT

The City of Paracatu and Kinross Gold have each funded studies of environmental arsenic in the vicinity of the Morro do Ouro Mine north of Paracatu in Minas Gerais, Brazil. The city-funded study by the Mineral Technology Center (CETEM) found that the CONAMA and MS (Brazil National Council for the Environment and Ministry of Health) Class 2 Arsenic Standard (which applies to human consumption, irrigation, and swimming) was exceeded in 35% of surface water samples (N = 31), 0% of groundwater samples (N = 39), and 0% of treated water samples (N = 26). The Agricultural Soil Arsenic Standard was exceeded in 57% of soil samples (N = 21) and the Sediment Arsenic Standard was exceeded in 80% of fluvial sediment samples (N = 20). The study funded by Kinross Gold and carried out by INCT-Acqua found that the Class 2 Arsenic Standard was exceeded in 2% of drinking water samples from wells and taps (N = 57). By contrast, a study funded by the Santa Rita Small Producers Association found that the Class 2 Arsenic Standard was exceeded in 100% of surface water samples (N = 9) and groundwater samples (N = 6), and that the Sediment Arsenic Standard was exceeded in 100% of fluvial sediment samples (N = 2). The CETEM study underestimated all arsenic concentrations in water by filtering samples prior to analysis. The INCT-Acqua study did not report enough of the methodology or the results to be useful. Nevertheless, near the village of Santa Rita, the difference in the mean surface water arsenic concentrations reported by the CETEM and the small producer-funded study was not statistically significant (P = 0.08). It is recommended that (1) Kinross fund a comprehensive study of environmental arsenic with a priori approval of the methodology by all stakeholders and, (2) Kinross develop a plan for remediation of contaminated soil and fluvial sediment.
Fig. 1. Three studies have carried out measurements of arsenic concentration in surface water, groundwater, treated water, fluvial sediments, and soils in the vicinity of the Morro do Ouro Mine, which is operated by Kinross Gold north of the city of Paracatu in Minas Gerais, Brazil. The study by INCT-Acqua (2015) did not publish the coordinates of their sampling sites. The sampling sites of CETEM (2013) and dos Santos (2015) overlap only in the vicinity of the village of Santa Rita (see Fig. 2). Background is a Google Earth image dated June 12, 2017.
INTRODUCTION

Background and Objectives

Kinross Gold operates a gold mine called the Morro do Ouro Mine north of Paracatu in Minas Gerais, Brazil (see Fig. 1). The City of Paracatu and Kinross Gold have each funded studies of environmental arsenic in the vicinity of the mine. The city-funded study by the Mineral Technology Center (CETEM, 2013) found that the CONAMA and MS (Brazil National Council for the Environment and Ministry of Health) Class 2 Arsenic Standard was exceeded in 35% of surface water samples (N = 31), 0% of groundwater samples (N = 39), and 0% of treated water samples (N = 26). The Class 2 Arsenic Standard of 10 μg/L applies to human consumption; protection of aquatic communities; direct-contact recreation (such as swimming); irrigation of vegetables, fruit and park plants, gardens, sports and leisure fields; and aquaculture and fisheries (CETEM, 2013). The CETEM (2013) study further found that the Agricultural Soil Arsenic Standard of 35 mg/kg was exceeded in 57% of soil samples (N = 21) and that the Sediment Arsenic Standard of 17 mg/kg was exceeded in 80% of fluvial sediment samples (N = 20). The study funded by Kinross Gold and carried out by the National Institute of Science and Technology on Mineral Resources, Water and Biodiversity (INCT-Acqua, 2015) found that the Class 2 Arsenic Standard was exceeded in 2% of drinking water samples from wells and taps (N = 57). By contrast, a study funded by the Santa Rita Small Producers Association (dos Santos, 2015) in the vicinity of the village of Santa Rita (see Fig. 2) found that the Class 2 Arsenic Standard was exceeded in 100% of surface water samples (N = 9) and groundwater samples (N = 6), and that the Sediment Arsenic Standard was exceeded in 100% of fluvial sediment samples (N = 2).

In a wide-ranging critique of the social and environmental impact of the Morro do Ouro Mine, Above Ground and Justiça Global [Global Justice] (2017) wrote with respect to the three arsenic studies, “That such a disparate and seemingly irreconcilable range of findings and conclusions have emerged from the studies carried out to date underscores the need for robust, independent monitoring by public authorities of pollution and exposure levels in all areas within the mine’s influence, urban and rural.” Kinross Gold (2018a) wrote in a response to the critique by Above Ground and Justiça Global (2017), “Two detailed and separate independent clinical studies clearly show that arsenic from our operations is not a public health concern for the people of Paracatu and that arsenic concentrations in food, water and dust in Paracatu are normal.” Above Ground and Justiça Global (2018) repeated in their response, “As we conclude in our report, the disparate range of findings and conclusions from the studies carried out to date underscores the need for robust, independent monitoring by public authorities of pollution and exposure levels in all areas within the mine’s influence.” In a memorandum to the Business and Human Rights Resource Center, Kinross Gold (2018b) repeated their previous statement, “Two detailed and separate independent clinical studies clearly show that arsenic from our operations is not a public health concern for the people of Paracatu and that arsenic concentrations in food, water and dust in Paracatu are normal.” No response from Kinross Gold has acknowledged the existence of the third study by dos Santos (2015), although it was brought to their attention in the original critique by Above Ground and Justiça Global (2017).

The objectives of the present study are to address the following questions:
1) Were there significant differences in methodology among the three studies?
2) Were there significant shortcomings in methodologies among any of the studies?
3) Did the three studies of environmental arsenic actually reach different conclusions? Additional studies of arsenic in atmospheric dust (CETEM, 2013; INCT-Acqua, 2015), in food (INCT-Acqua, 2015), and in blood, hair and urine (CETEM, 2013) will not be discussed in this study. Before summarizing and critiquing the methodologies of the three studies, two important topics will be reviewed, which are the digestion and filtration of water samples prior to analysis, and the use of arsenic test kits.

![Fig. 2. In the vicinity of the village of Santa Rita, dos Santos (2015) carried out measurements of arsenic concentration in surface water at nine sites, in groundwater at six sites, and in fluvial sediments at two sites. In the same area, CETEM (2013) carried out measurements of arsenic concentration in surface water at six sites, in fluvial sediment and soil at five sites, and in groundwater at one site. The Santa Rita River flows to the east and south, so that the measurements by CETEM (2013) tend to be downstream of the measurements by dos Santos (2015). Background is a Google Earth image dated June 12, 2017.](image-url)
Digestion and Filtration

Modern analytical instruments, such as the inductively coupled plasma spectrometer or the atomic absorption spectrometer, require that the water sample be free of solid particles that could become trapped within the instrument. For that reason, all analytical laboratories digest samples prior to analysis. Digestion refers to the dissolution of solid particles using various combinations of heat, acids, hydrogen peroxide, and other reagents. Because some solid particles may have resisted dissolution, the water samples are further forced through an ultrafine (0.45-μm) filter prior to their introduction into the analytical instrument. The arsenic that was already present in the sample in the dissolved phase will not be affected by digestion or filtering. However, since some of the arsenic in a water sample is in the solid phase, digestion of the sample will increase the arsenic concentration in the dissolved phase by moving arsenic from the solid to the dissolved phase. The various solid phases of arsenic include the following (listed in order from least to most resistant to digestion):

1) ionically bound arsenic
2) strongly adsorbed arsenic
3) arsenic coprecipitated with acid-volatile sulfides, carbonates, manganese oxides, and very amorphous iron oxyhydroxides
4) arsenic coprecipitated with amorphous iron oxyhydroxides
5) arsenic coprecipitated with crystalline iron oxyhydroxides
6) arsenic oxides and arsenic coprecipitated with silicates
7) arsenic coprecipitated with pyrite and amorphous As$_2$S$_3$
8) orpiment and remaining recalcitrant arsenic minerals (Keon et al., 2001).

If a sample was filtered through a 0.45-μm filter prior to digestion, then only the original dissolved component of arsenic would be measured, and the resulting arsenic concentration is referred to as “dissolved arsenic.” If no pre-digestion filtering was done, and the digestion was carried out using hot concentrated nitric acid and 30% hydrogen peroxide so that all of the above solid phases were dissolved (USEPA, 2018), then all components of arsenic would be measured, and the resulting arsenic concentration is referred to as “total arsenic.” It should be noted that water samples can contain colloidal particles smaller than 0.45 μm that will pass through the filter and then be dissolved during the digestion process. In that way, the arsenic adsorbed onto the dissolved formerly-solid particles will be measured as dissolved arsenic, even though the arsenic was not present in the dissolved form in the original water sample. Therefore, the dissolved arsenic concentration measured using the pre-filtered method is always greater than the true dissolved arsenic concentration (dissolved arsenic concentration in the original water sample). Moreover, the arsenic concentration measured using the non-pre-filtered method is always less than the true total arsenic concentration (total arsenic concentration in the original water sample) because not all of the solid particles will be fully digested (which is why water samples are always filtered even after digestion). For the above reasons, the phrases “dissolved arsenic” and “total arsenic” are often retained in quotes. Many studies have carried out sequential extractions, in which increasingly aggressive solvents are used to progressively extract arsenic from more resistant solid phases. For example, one hour of digestion using 1M HCl at 25°C will extract arsenic from the above Solid Phase 3, so that the measured arsenic concentration will be a sum of the dissolved arsenic, ionically bound arsenic, strongly adsorbed arsenic, and arsenic coprecipitated with acid-volatile sulfides, carbonates, manganese oxides, and very amorphous iron oxyhydroxides (Keon et al., 2001).
The important question is: Should water samples be filtered prior to digestion or only after digestion? In other words, is it appropriate to measure “dissolved arsenic” or “total arsenic?” The answer is that it depends on the environmental and social context within which a water sample has been collected. Saar (1997) has written an excellent review of this subject and a briefer treatment can be found in Sanders (1998). Four examples will help to illustrate this point. The first example is water sampled from a monitoring well that has been placed into a layer with low hydraulic conductivity, such as a clay or shale layer. The act of pumping or bailing this well can mobilize small particles that would not normally be moving with the flow of groundwater. These samples should be filtered prior to digestion, since the digestion of the particles would result in a measured arsenic concentration that was not representative of the pore water in the clay or shale layer. The second example is water drawn from a shallow “backyard well” that a family is keeping for their emergency water supply. In a study in Utah carried out by the author and his students (Gherasim et al., 2016), the wells were often poorly constructed, and the water was slightly muddy. None of the well owners was going to drink a glass of muddy water, nor were they going to force the water through an ultrafine filter. Any well owner would let the water sit until the solid particles settle and then pour off the clear water (which would still contain the particles that were too fine to settle). Therefore, the sampling procedure involved following the same steps that would be followed by a well owner. The samples were allowed to sit for 24 hours, after which the relatively clear water on top (the supernatant) was poured off into a separate sample bottle. Then the supernatant was digested without any pre-filtering. In a third example, flowing water samples were collected from a pipe that led from a spring and emptied into a cattle trough (Emerman et al., 2018). Although these samples were muddy, the particles were in motion with the water and would be consumed by the cattle. Therefore, not only were the samples not filtered before digestion, but before removing an aliquot of sample for digestion, the sample bottle was vigorously shaken to ensure that a representative quantity of solid particles would be digested with the rest of the water sample. In fact, it is difficult to think of circumstances under which water samples that were collected from flowing water should be filtered prior to digestion.

The fourth and most important example is the case of a water sample collected from a tap that is intended for human consumption. If the water is relatively clear, then the typical practice would be to drink the water as it comes from the tap. Certainly no householder is using a pump or syringe to force the water through an ultrafine filter. Filtering the samples prior to analysis has the potential to significantly underestimate the arsenic load that is being delivered to the consumer. This point is emphasized by Saar (1997), “If direct ingestion from a drinking water source is involved, whole, unfiltered samples...are needed.” In some localities, there may be some typical pre-consumption practices. For example, consumers may boil the water or add bleach to the water or, as mentioned above, allow the water to settle. In those cases, the pre-digestion procedure should follow the same consumer practices. Additional case studies regarding the appropriateness of filtration are presented by Saar (1997). In some cases, both filtering and not-filtering can be shown to have shortcomings. The contemporary practice is to collect both filtered and unfiltered water samples, and to publish results for both “dissolved arsenic” and “total arsenic,” so that readers can decide for themselves which concentration is most appropriate for a given situation.
Arsenic Test Kits

Modern analytical instruments for water analysis, such as the atomic absorption spectrometer or the inductively coupled plasma spectrometer, can cost about $100,000 with considerable annual maintenance costs. On the other hand, arsenic test kits can be purchased in the price range of $100-$200. All commercial arsenic test kits operate according to the same general principles with minor variations. For example, in the Hach Arsenic Low Range Test Kit (Hach, 2018), sulfamic acid and powdered zinc are added to a water sample in order to create strongly reducing conditions that will reduce all forms of arsenic to arsine gas. The gas then reacts with mercuric bromide in a test strip to form mixed arsenic/mercury halogenides that discolor the test strip. The discoloration of the test strip is then visually compared with a color chart in order to determine the arsenic concentration. In the case of the arsenic test kit manufactured by Hach (2018), the color chart includes colors corresponding to arsenic concentrations of 0, 10, 30, 50, 70, 300, and 500 μg/L. It is possible to interpolate between colors, so that an operator could observe a discoloration of the test strip between the colors corresponding to arsenic concentrations of 10 and 30 μg/L and assign an arsenic concentration of 20 μg/L. By contrast, the precision of arsenic measurements for most analytical instruments can be as good as 0.1 μg/L.

Hundreds of studies of environmental arsenic have been carried out using the low-cost arsenic test kits, especially in low-budget projects in developing countries (Kamal et al., 2003; Emerman, 2004, 2005; Swain et al., 2006; Emerman et al., 2007; VanDam, 2007; Sandhi et al., 2010; Telfeyan et al., 2012; Mallioux et al., 2014; Ford et al., 2015; Khan et al., 2015; Mozumder et al., 2015; Pfeiffer et al., 2015). Some studies have verified the accuracy of the low-cost test kits by comparing the results with those obtained from analytical instruments (Hossain et al., 2006; Kar et al., 2014; Van Geen et al., 2015), while other studies have urged caution in reliance on the results of test kits (Feldmann, 2008; Welborn et al., 2012). One of the issues with the use of test kits is that they require a subjective comparison of colors, as opposed to the digital readout that would be obtained from an analytical instrument. Therefore, the reproducibility of the results from the test kit depends not just upon the equipment, but also upon the operator of the equipment. On that basis, each operator should make repeated measurements from the same sample in order to determine his or her own reproducibility. In addition, the subjectivity of the color comparisons can lead to intentional or unintentional bias, especially in contentious situations, so that double-blind studies may be necessary in some cases. For the above reasons, the contemporary practice in studies in developing countries is to use arsenic test kits to determine sites where arsenic concentrations may potentially be high, and then send the critical samples to a modern analytical laboratory for a more precise and accurate measurement of arsenic concentration.

METHODOLOGY

The first two objectives of this study were addressed by comparing the published methodologies found in CETEM (2013), INCT-Acqua (2015), and dos Santos (2015) with generally accepted principles of water sampling and analysis, most of which are discussed in Saar (1997) and Sanders (1998). The third objective was addressed by comparing the results of CETEM (2015) and dos Santos (2015) in the region of spatial overlap, which was the vicinity of the village of Santa Rita (see Fig. 2). This region covers all samples from dos Santos (2015),
including nine measurements of surface water, six measurements of groundwater, and two measurements of fluvial sediments. From the database in CETEM (2013), the region covers six measurements of surface water (Sites 3, 19, 20, 21, Y1 and Y2 in Table 3 of CETEM [2013]), five measurements of fluvial sediment and soil (the above sites without Site 21), and one groundwater measurement (Site 7 in Table 2 of CETEM [2013]). Note that, since the Santa Rita River flows to the east and south, the measurements by CETEM (2013) tend to be downstream of the measurements by dos Santos (2015). Since the region of overlap included only one groundwater measurement from CETEM (2013) and no soil measurements from dos Santos (2015), no statistical comparison of groundwater or soil measurements was possible. The statistical significance of the difference between the mean concentrations of surface water arsenic and fluvial sediment arsenic was assessed using the two-tailed, unpaired t-test. The reasons why there were no statistical comparisons with the database of INCT-Acqua (2015) are given in the Results section.

RESULTS

Summary and Critique of Methodology of CETEM (2013)

All samples collected by CETEM (2013) were analyzed using the ICP-MS (inductively coupled plasma – mass spectrometer). The detection limit was 0.5 μg/L for water and 0.5 mg/kg for soils and sediments. The minimum precision of arsenic analyses was ± 10% and the minimum accuracy (based on certified samples) was ± 5% (CETEM, 2013). The critical part of the methodology was that all water samples were forced through a 0.45-μm filter prior to analysis. This information does not appear until the Results section (p. 38 of CETEM [2013]), where it states, “The As contents obtained in the water correspond roughly to its dissolved fraction, filtered in 0.45 μm…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…This report considers the data of filtered water which represents higher risk.” As stated earlier, neither samples of drinking water nor samples of flowing surface water should be forced through an ultrafine filter prior to analysis. The CETEM (2013) report seems to be informing the reader that this generally-accepted principle of water sampling is even written into law in Brazil. The authors of the CETEM (2013) report also seem to be informing the reader that they deliberately violated the Brazilian regulatory requirements because they decided that filtered water represented a higher risk. It is not at all clear how they decided that water with a lower arsenic concentration represented a higher risk. In summary, all of the arsenic measurements by CETEM (2013) should be regarded as underestimates of the true arsenic concentrations.

The above critique applies only to the analysis of water samples by CETEM (2013) and not to their analysis of fluvial sediment or soil samples. There is no equivalent to pre-filtering for sediment or soil samples. CETEM (2013) followed the standard practice of sieving sediment or soil samples to remove the gravel-sized fraction (< 1.7 mm), which tends to be lacking in adsorbed contaminants (per unit mass) due to its low surface-area-to-volume ratio. Sieving is always followed by digestion to extract the arsenic from its various solid phases, after which the extractant is filtered prior to measurement with an analytical instrument. Based on the description of the methodology for sediment and soil analysis in CETEM (2013), there is no reason to believe that their arsenic measurements are biased either high or low.
An additional caution is that a significant amount of information is missing from the methodology in CETEM (2013). This missing information includes the answers to the following questions:
1) What were the sizes and materials of the sample containers?
2) Were samples preserved in the field?
3) How were samples stored prior to analysis?
4) How much time elapsed between sample collection and analysis?
5) How many replicates were collected at each site?
6) What reagents were used to extract arsenic from soil and sediment samples?

Summary and Critique of Methodology of INCT-Acqua (2015)

The study by INCT-Acqua (2015) is nearly entirely devoid of any methodology. Even the most basic information, such as the coordinates of the sample sites, is not given. For that reason, the sites studied by INCT-Acqua (2015) cannot be mapped along with the sites studied by CETEM (2013) and dos Santos (2015). The only methodology refers the reader to documents called “Planejamento de Amostragem de Efluentes Líquidos e Corpos Receptores [Planning of Sampling of Liquid Effluents and Receptor Bodies]” (ABNT, 1987a) and “Preservação e Técnicas de Amostragem de Efluentes Líquidos e Corpos Receptores [Preservation and Sampling Techniques of Liquid Effluents and Receptor Bodies]” (ABNT, 1987b). However, these are simply generic sets of procedures and do not clarify the particular procedures that were followed by INCT-Acqua (2015). For example, ABNT (1987b) states, “Amostras para análise de metais dissolvidos devem ser filtradas em membrana filtrante de porosidade 0,45 μm, imediatamente após a coleta, e então acidificadas [Samples for the analysis of dissolved metals must be filtered in a 0.45-μm porosity filter membrane immediately after collection, and then acidified].” However, nothing informs the reader whether the intention was to measure “dissolved arsenic” or “total arsenic.”

In addition to a lack of methodology, INCT-Acqua (2015) does not include enough detail about the results so that they can be compared with other studies. Besides the lack of coordinates, no particular measurements are stated for any particular sites, so that there can be no statistical comparisons with other studies. For example, although the study states that all water samples except one had arsenic concentrations below the Class 2 Standard, the value of that exceptional concentration was not stated. As another example, INCT-Acqua (2015) measured arsenic concentrations of 49 soil samples and then carried out further measurements on seven samples for which the arsenic concentration exceeded 55 mg/kg and seven samples for which the arsenic concentration was less than 55 mg/kg. However, the study never stated the total number of soil samples that were in each category. Based on the lack of methodology and results, I am sorry to say that I do not regard the study by INCT-Acqua (2015) as a “study” at all, but simply as an opinion that was funded by Kinross Gold. As a consequence, the study by INCT-Acqua (2015) is not considered further in this study.
Fig. 3. Arsenic concentrations reported by dos Santos (2015) seem to show an unrealistic degree of precision. Since the samples were concentrated by a factor of 10 prior to analysis, the raw (uncorrected for concentration) measurements for groundwater, for example, must have been 120, 150, 160, 120, 120, and 160 μg/L. Since the color chart that accompanies the QUANTOFIX arsenic test kit has gradations of only 0, 5, 10, 25, 50, 100, 250 and 500 μg/L, the reported concentrations suggest an unrealistic ability to interpolate between the colors. Table taken from dos Santos (2015).

**Summary and Critique of Methodology of dos Santos (2015)**

Fluvial and groundwater samples were collected by dos Santos (2015) in 1-L polyethylene bottles. These samples were evaporated to 100 mL in order to concentrate the arsenic. Arsenic concentrations were then measured using the Machery-Nagel QUANTOFIX Arsenic Test Kit (Machery-Nagel, 2018). There was no mention of filtration or digestion (aside from the use of the test kit reagents), so it should be assumed that none took place. For sediment analysis, dos Santos (2015) collected 5-kg samples and analyzed the fraction smaller than 1.7 mm. Arsenic was extracted using a Molisch’s Solution. Although it was not stated, it is assumed that the arsenic concentration of the extractant was analyzed using the same arsenic test kit. Arsenic concentrations reported by dos Santos (2015) are reproduced in Fig. 3.

The arsenic concentrations reported by dos Santos (2015) seem to show an unrealistic degree of precision (see Fig. 3). Since the samples were concentrated by a factor of 10 prior to analysis, the raw (uncorrected for concentration) measurements for groundwater, for example, must have been 120, 150, 160, 120, 120, and 160 μg/L. Since the color chart that accompanies the QUANTOFIX Arsenic Test Kit has gradations of only 0, 5, 10, 25, 50, 100, 250 and 500 μg/L (Machery-Nagel, 2018), the reported concentrations suggest an unrealistic ability to interpolate between the colors. Moreover, it is not clear what was the point of concentrating the samples. The samples could have been measured without concentration by removing a 100-mL aliquot from each sample bottle, and all arsenic concentrations for groundwater could have been read (with realistic precision) as either 10 or 15 μg/L. Although concentrating samples does not
necessarily affect the final results, it violates the general principle of avoiding unnecessary processing of water samples prior to analysis (Saar, 1997). Along the same lines, there should have been an effort to establish the reproducibility of the operator with respect to this instrument. For example, removing repeated 100-mL aliquots from the sample bottle and measuring their arsenic concentrations without concentrating the samples could have established the precision of the measurements very well.

**Fig. 4a.** Although dos Santos (2015) and CETEM (2013) used completely different methodologies, in the region of spatial overlap (near the village of Santa Rita), the difference between their mean values of surface water arsenic concentration was not statistically significant ($P = 0.08$), according to the unpaired, two-tailed t-test. The Class 2 Arsenic Standard (human consumption; protection of aquatic communities; direct-contact recreation; irrigation of vegetables, fruit and park plants, gardens, sports and leisure fields; aquaculture and fisheries) is shown for comparison. Uncertainties are one standard deviation.

Despite the unrealistic precision of the arsenic concentrations in groundwater and surface water reported by dos Santos (2015), it is emphasized that there is no reason to believe that the measurements are biased either too high or too low. On the other hand, the two measurements of arsenic concentration in fluvial sediment are almost certainly biased too low. According to dos Santos (2015), the arsenic was extracted using Molisch’s Solution. This is not a typical arsenic extractant; it is α-naphthol dissolved in ethanol, and is used to detect the presence of carbohydrates. Molisch’s Solution will extract some arsenic from solid phases, mostly arsenic weakly held by organic matter, but will not attack most of the solid phases of arsenic that were listed above.
Environmental Arsenic near the Village of Santa Rita

In the vicinity of the village of Santa Rita, the mean surface water arsenic concentrations were $21.8 \pm 3.9 \mu g/L$, as reported by dos Santos (2015), and $12.2 \pm 10.5 \mu g/L$, as reported by CETEM (2013), respectively, where the uncertainty is one standard deviation (see Fig. 4a). Despite the wide divergence in methodologies and the systematic underestimation by CETEM (2013), this difference is not statistically significant ($P = 0.08$). On the other hand, the difference between the mean fluvial sediment arsenic concentration of $36.0 \pm 1.4 \text{mg/kg}$, as reported by dos Santos (2015), and the mean fluvial sediment arsenic concentration of $1874 \pm 1232 \text{mg/kg}$, as reported by CETEM (2013), is statistically significant ($P = 0.003$; see Fig. 4b). Although the t-test was carried out on the logarithms of values, which is appropriate for measurements that span orders of magnitude, the difference would have been statistically significant ($P = 0.03$) even if the t-test had been carried out on the values themselves. Note that the mean fluvial sediment arsenic concentration obtained by CETEM (2013) exceeds the Sediment Arsenic Standard (17 mg/kg) by over two orders of magnitude. The difference in fluvial sediment arsenic concentrations measured by dos Santos (2015) and CETEM (2013) is most likely due to the weak extractant used by dos Santos (2015).
Fig. 5. Table 7 from CETEM (2017) shows in red numerous surface water sites that exceed the Class 2 Arsenic Standard (10 µg/L). This contradicts the repeated statement from Kinross Gold (2018a, 2018b) that “Two detailed and separate independent clinical studies clearly show that arsenic from our operations is not a public health concern for the people of Paracatu and that arsenic concentrations in food, water and dust in Paracatu are normal.”

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In red: Above 10 µg/L, guiding value for Waters Class 2 (CONAMA 317/2005) 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, 470/2009) and above 17 mg/kg, guiding value by CONAMA 344/2004 representing high probability of toxic effects to the biota. DI – Unavailable data.
DISCUSSION

It is now appropriate to return to the repeated statement from Kinross Gold (2018a, 2018b) that, “Two detailed and separate independent clinical studies clearly show that arsenic from our operations is not a public health concern for the people of Paracatu and that arsenic concentrations in food, water and dust in Paracatu are normal.” This statement is both misleading and false. It is misleading, first, because one of the studies (INCT-Acqua, 2015) was so lacking in detail that it hardly counted as a “study” at all. It is misleading, second, because while arsenic concentrations in food and dust might be “normal,” CETEM (2013) clearly showed numerous sites where arsenic concentrations in fluvial sediment and soil exceeded the Sediment Arsenic Standard and the Agricultural Soil Arsenic Standard, respectively (see Fig. 5). The most contaminated site (Site 2 along Rico Creek in CETEM [2013]) showed a fluvial sediment arsenic concentration of 4297.2 mg/kg (253 times the Sediment Arsenic Standard) and a soil arsenic concentration of 1752.9 mg/kg (50 times the Agricultural Soil Arsenic Standard). (I have placed “normal” in quotes because the issue is whether arsenic concentrations meet generally-recognized standards for public and ecosystem health, not whether they are “normal.” In fact, the arsenic concentrations in fluvial sediment and soil are “normal” for areas affected by gold mining.) The statement is misleading, third, because it completely ignores the existence of the third report by dos Santos (2015), although this report was brought to the attention of Kinross Gold by Above Ground and Justiça Global (2017).

The most important point is that the statement from Kinross Gold (2018a, 2018b) is false in that it contradicts the finding from CETEM (2013) that numerous sites show surface water arsenic concentrations that exceed the Class 2 Arsenic Standard (see Fig. 5). The most contaminated site (Site 9 along Rico Creek in CETEM [2013]) showed an arsenic concentration of 40.1 μg/L (four times the Class 2 Arsenic Standard). It should be recalled that all arsenic concentrations measured by CETEM (2013) are biased too low due to inappropriate filtering of water samples prior to analysis.

CONCLUSIONS

The chief conclusions of this study can be summarized as follows:
1) All measurements of arsenic from water sources in CETEM (2013) should be regarded as underestimates due to the inappropriate practice of forcing water samples through a 0.45-μm filter prior to analysis.
2) Measurements of fluvial sediment and soil arsenic concentrations in CETEM (2013) are probably not biased either high or low.
3) The methodology and results in INCT-Acqua (2015) are so lacking in detail that it cannot be compared with any other studies.
4) While dos Santos (2015) overstates the precision of his arsenic measurements, the results are probably not biased either high or low.
5) Although the studies by dos Santos (2015) and CETEM (2013) used completely different methodologies, in the region of spatial overlap (vicinity of the village of Santa Rita), the difference in mean surface water arsenic concentrations was not statistically significant.
RECOMMENDATIONS

Based upon the results of this study and those of dos Santos (2015) and CETEM (2013), the following recommendations are made:
1) Kinross Gold should fund without delay a comprehensive study of arsenic in water sources in the vicinity of the Morro do Ouro Mine, including surface water, groundwater and drinking water. The methodology for this study should be approved by all stakeholders prior to carrying out the study, including local residents, neighboring communities, public authorities and civil society organizations.
2) Kinross Gold should develop without delay a plan for remediation of soil and fluvial sediment that has been contaminated by gold mining.

ACKNOWLEDGEMENTS

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ABOUT THE AUTHOR

Dr. Steven H. Emerman has a B.S. in Mathematics from The Ohio State University, M.A. in Geophysics from Princeton University, and Ph.D. in Geophysics from Cornell University. Dr. Emerman has 31 years of experience teaching hydrology and geophysics and has 66 peer-reviewed publications in these areas. Dr. Emerman is the owner of Malach Consulting, which specializes in assessing the environmental impacts of mining for mining companies, as well as governmental and nongovernmental organizations.

REFERENCES


