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Environmental Exposure to Mercury in Gold Mining: Health Impact Assessment in Guainía, Colombia

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ABSTRACT

Artisanal gold mining is an ancient practice that remains used in present times. Occupational exposure to mercury has been investigated in several studies, but effects related to its use in gold mining have been less addressed. Several studies are found in the literature, specially related to the gold rush in South America, and the impact of the practice along the Amazon rivers. Due to the informal characteristics of the practice, gold mining with mercury has not been well registered; thus, exposure assessment of riverine populations involved in this practice and its health effects (especially at the nervous system level) are of public health concern. An approximate health risk assessment is performed, using mercury concentrations in 65 blood samples taken from a riverine population in the Guainia region of Colombia. Concentration of mercury is used to estimate body burden of mercury and correlate it to percentage cases of paraesthesia in the population sample. An existing dose-response relationship from an Iraqi outbreak is taken here to extrapolate data previously analyzed in the literature. A 24.5% excess risk of paraesthesia among the miners and a 24.3% excess risk of paraesthesia in non-miners, (both attributable to methyl mercury exposure) is found among the study sample of the Guainia Region in Colombia. Although results are based in several assumptions and extrapolations from other studies, they reveal an important health impact of actual gold mining processes in this region of Colombia. Results here must drive the attention of public health practitioners to undergo further studies and promote remedial procedures and monitoring programmes, for the well being of the population and the improvement of the environment.

Key Words: Gold mining, risk assessment, environmental health

RESUMEN
Exposición ambiental a mercurio en la minería aurífera: evaluación del impacto sobre la salud en Guainía, Colombia

La minería aurífera artesanal es una práctica antigua que persiste en la actualidad. la exposición ocupacional a mercurio ha sido estudiada en varios estudios, pero no así los efectos asociados a su uso en la minería aurífera. existen varios estudios sobre el impacto de la minería del oro en Sur América, especialmente en las regiones ribereñas del río amazonas. debido a las características de informalidad de este proceso, la exposición de las poblaciones ribereñas y los efectos sobre la salud (especialmente del sistema nervioso) son una preocupación para la salud pública. una aproximación de la evaluación del riesgo para la salud fue realizada, utilizando las concentraciones de mercurio en 65 muestras de sangre tomadas de una población ribereña procedente del departamento de Guainía (Colombia). esta concentración de mercurio es usada para estimar los niveles capaces de afectar el organismo y correlacionarlos con el porcentaje de casos de parestesia en la muestra poblacional. una relación dosis-respuesta encontrada en un brote epidémico en irak es tomada para extrapolar los datos previamente analizados en la literatura. un 24,5% de exceso de riesgo para parestesias entre los mineros y un 24,3% de exceso de riesgo de parestesia entre los no mineros atribuible a la exposición a metil-mercurio se encontró en una muestra de individuos proveniente del departamento del Guainía en Colombia. aunque los resultados se basan en varias suposiciones y extrapolaciones de otros estudios, estos sirven para poner en evidencia el importante impacto sobre la salud de los procesos de la minería aurífera en Colombia. los hallazgos deberían llamar la atención de los salubristas públicos para realizar futuros estudios y promover medidas de control y programas de monitoreo, así como mejorar el bienestar de la población y el ambiente.

Palabras Claves: Minería aurífera, evaluación del riesgo, salud ambiental

In Latin America, the gold rush has been a phenomenon of periodical occurrence during the past century. Among some countries, artisanal gold mining has become an important alternative for people searching for economic ways to survive and evade social marginalisation (1). As a consequence, the release of mercury (Hg) during the gold extracting process is affecting not only the environment, but also creating an important public health problem among workers and those in the general population affected by the amalgamation process. Several studies have been conducted in the area of mercury contamination and assessed its relationship with occupational exposures (2). However, health effects among gold mining workers in river basins have been less evaluated. In recent years, this issue has been addressed especially in Brazil, country that ranks first in South America and second in the world in terms of gold production (3). Environmental research and health effects of mercury use in gold mining have been basically done along the Amazon River basins in this country (3-5).

In Colombia, although ranking second in South American annual gold production (3), with informal mining increasingly taking place in the last 15 years, research concerning this issue is scarce. Searching databases, few reports about Colombia have been published in the subject (5-7). Reports received by the Environmental Health Laboratory at the National Institute of Health in Colombia, (LSA-INS) motivated a recent study to determine mercury levels in blood and risk perception among an exposed population in the Guainia Region, near the Inirida river basin (8). In this paper I consider the growing significance of risk assessment as a tool for health evaluation and environmental cost of certain practices versus its economic and social benefits (9). Having this into account, using some data collected from the recent report in the Guainia Region, a health risk impact approach is given to the particular circumstances of gold mining in this Amazon region of Colombia.

BACKGROUND

Brief history

Artisanal gold mining is a practice well known in the past, still performed in the present. Its origins can be documented since 2700 BC, when Carthagians and Phoenicians traded with mercury from mines located in Spain. The specific amalgamation technique, described by Caius Plinius in his book "Natural History" (50 AD), is similar to the procedure used today in gold mining areas to recover the element (3). Other uses of mercury are also registered since ancient times. Around 1000 BC, Chinese used mercury sulphide as a red alye pigment, known as vermilion. Hipocrates and Galen also recorded mercury toxic effects in the Graeco Roman world (10). Human poisoning by methyl mercury was reported among laboratory assistants in the 1940's; perhaps the very first record of occupational exposed workers (11). Mercury has also been used in medical treatments, as in syphilis, (15^{th} century until Word War II) and as part of antiseptics, laxatives and scabicides. Today it is still incorporated in amalgam dental fillings (10). The recognition of mercury as environmental hazard and threat to human health, came between the 1950's and 1960's, with the Minamata and Niigata disease episode. People of the area consumed fish from the water Bay that had been contaminated by an industrial effluent of methyl mercury (12). Also, in 1971, three epidemic poisoning events with methyl mercury (from 1955-1972) occurred in Iraq. In this case, people consumed bread prepared with seed grain, which was treated with the compound for agricultural purposes (13,14). The above has shown that mercury has been widely related to human activities. This review will focus on its application in gold recovery during amalgamation processes.

South American context

In South America, alluvial gold mining is a practice recorded since the Spanish colonizers used it to implement it for gold recovery. There has been estimated that from the 1550's until the 1880's, an approximate amount of 200,000 metric tonnes of mercury were released to the environment (3). According to the literature, a number of different gold rushes have taken place in past decades (1,3). In Brazil alone, it is calculated that 2000 tones of mercury have been discharged to the environment while the present gold rush has been taking place (3). High concern is being given recently to this issue, not only because of the potential harmful in terms of the environment, but also to the human populations that find benefit (directly or indirectly) from the practice. It is estimated that there are at least between 500,000 and 1 million miners, for all Latin American countries joined together. At least a fifth of that number will correspond to Colombia only (15). Recent research has been undertaken in particular in the Brazilian amazon where not only rivers but also man –made reservoirs are of great concern (3).

In Colombia, few reports have been published in the scientific literature regarding studies in the field (8). Due to its status of informal practice, poor attention from official institutions has been paid, and safe occupational practices are very unlikely to occur. A description and assessment of a particular case in this country will contribute to understanding the potential of mercury as a hazard in this region, and bring the attention of those who might be involved or in power to implement corrective procedures in this setting.

The amalgamation process

Mercury is an avid gold collector, both constituting a kind of paste that enables one to obtain the solid material in an ore (1). This gives mercury an effectiveness that combined with its relatively low cost, makes it a suitable method of implementation by artisanal miners, to extract the mineral from its natural occurrence, specially in deprived areas with economic and social constraints. The amalgamation process in gold recovery has two applications (1):

1. Recovery of fine gold from an ore. This application is the one that produces tailings, consequently polluting the bodies of water in which the process is done.
2. Extraction of gold in order to obtain a high quality product, easily stored in a person's pocket.

Making use of gravity, an initial (almost clean) concentrate is obtained, suitable for smelting. The gravity process is done usually using shaking tables, spirals, automatic panners, etc. This is appropriate to obtain a concentrate that can be smelted and used for posterior commercialization. (e.g. sold to a bank). When the mineral portion is separated from the amalgam by panning, the tailing formed is usually dumped into a stream, an then this is called a "hot spot" (16). Recovery of gold particles is then done through burning or heating the amalgam. The main source of emission derives from burning the amalgam in open pans. This procedure produces a dore containing 2-5 % of residual mercury. The second part of the process intends to remove this residual, by melting the dore at gold shops, which entails further release of mercury vapours to the environment (16).

Thus, two parts of the process involve human hazards: The dumping of mercury into river streams, contaminating the water and making its way to the food chain via micro-organisms and fish; and when burning the amalgam (especially in closed spaces -such as gold shops-) the vapour form of mercury is inhaled and can be potentially harmful to the body.

HEALTH IMPACT ASSESSMENT

Hazard identification

Mercury is an element present in nature in different physical and chemical forms. The ones discussed in this review are those relevant to human exposure and health effects, i.e.: Elemental mercury vapour (Hg^{o}), and subsequent methylation of inorganic mercury, resulting in methylmercury (CH_3 Hg).

Source of exposure

Mercury is emitted to the environment (mainly as elemental mercury) originated from degassing of the earth's crust. This emanation comes mainly from land areas (e.g. volcanic gases), riverbeds and ocean floor. Natural emissions might be of approximately 10,000 tonnes per year (17,19). Human activities account for another portion of the mercury released to the environment (1). It is estimated that world –mining of mercury is around 10 000 tonnes/year. This figure varies year by year, according to the commercial value of the metal. Also, pollution of water by mine tailings is reported to be significant (20). Thus, it is difficult to separate quantitatively the contributions of each source to the environmental presence of mercury.

Human made sources include: Fossil fuel combustion, production of steel cement, electrical industry, control instruments in home and industry, laboratory and medical instruments (17); exposure of patients, dentist and their assistants to mercury through dental amalgam (17). mercury is still used in gold extraction, as described in this review. Mercury as part of seed dressing for agricultural purposes (13). Mercury present in soaps and creams used to achieve lighter skin tone, although currently reduced (17). Exposure to mercury in confined areas represents a high- risk source of toxicity. This type of exposure is applicable to incidents well reported in the literature, such as the Minamata Bay contamination (12), and the food contamination in Iraq (13).

Another uncertainty in determining mercury in the environment is that concentrations of the compound in non-polluted atmosphere and natural bodies of water can be so low, that it might not be possible to find a trace of them (18).

Cycling

To understand how mercury ends up causing health effects in humans, is important to picture the global cycle of the compound on the environment. Mercury is an element of natural occurrence. Its chemical form can always change. It is emitted to the atmosphere coming from both human and natural sources, as elemental vapour (Hg^{o}); eventually it will go back to earth through rain water, finally sinking in the sediments of earth, oceans and lakes. From there, microorganisms are able to transform inorganic mercury to methyl mercury. Eventually, due to its lypophilic characteristics, fish will end up absorbing the element, and biomagnification will occur through the food chain (18,21). Thus, in terms of human exposure in gold mining we have two main sources: Mercury vapour generated when burning the amalgam. (outdoors or indoors), methyl mercury in fish, as part of diet among the people that inhabit a particular area where gold mining is done.

Dose-response assessment

The following is a summary of biological exposure to mercury and the consequences in terms of health effects. The main exposure to animals is the release of mercury compounds into water supplies (22). Methyl mercury circulating in terrestrial and especially in aquatic foodchains causes risks to the reproductive success as well as to the health of wildlife (17). In here, I concentrate on dose-response effects on humans, particularly relevant for this assessment.

Human studies
Health effects in humans caused by mercury are mainly through inhalation in occupational settings, (due to its vapour characteristics) and via fish consumption (methyl mercury) (23).

Effects of mercury vapour exposure
The effects of such an exposure vary, depending on duration and intensity of the exposure. Table 1 shows some signs and symptoms present following direct inhalation exposure due to heating of metallic mercury (23).

Effects of methyl mercury exposure
The central nervous system is the target organ in humans following exposure to methyl-mercury. One of the first recorded events involving this exposure, with available epidemiological evidence, was the Minamata Disaster, during the 1950's and 1960's (26). At this Japanese Bay, a chemical company was releasing mercury, used in the production of acetaldehyde. The chemical bio-magnificated via the food chain, resulting in high mercury concentrations in fish and thus mercury poisoning through its consumption. People revealed symptoms compromising sensory, (mental confusion, stupor, coma) visual and auditory functions. Fatal cases were also registered (27).

The most pertinent finding during the following years, has been a syndrome that resembles cerebral palsy developed by infants, children of mothers that consumed methylmercury contaminated fish during pregnancy (28). Indeed, examination of these patients revealed mental retardation and abnormal neurological signs, (e.g. primitive reflex and dysarthria) among other symptoms (29,30). Thus, growing concern is being showed on the effects of in utero methyl mercury exposure. Following the Iraq episode in the early 1970's, (an outbreak poisoning by ingestion of bread contaminated with methyl mercury fungicide), a study by Clarkson et al. found that levels of methyl mercury in mothers were predictive of adverse effects in the offspring (21). Later, a study performed in a primarily fish -eating population, (Seychelle Islands) showed a correlation between decreasing activity scores in children and increasing maternal mercury levels (21). However, controversy around these findings persists, and results are still difficult to interpret. In summary, the association with a relatively low level of mercury exposure in-utero (particularly through maternal fish diet) and neurological effects deserves careful examination; meanwhile, evidence remains inconclusive (11,21).

Table 1. Summary of effects caused by inhalation exposure to mercury vapour (23)

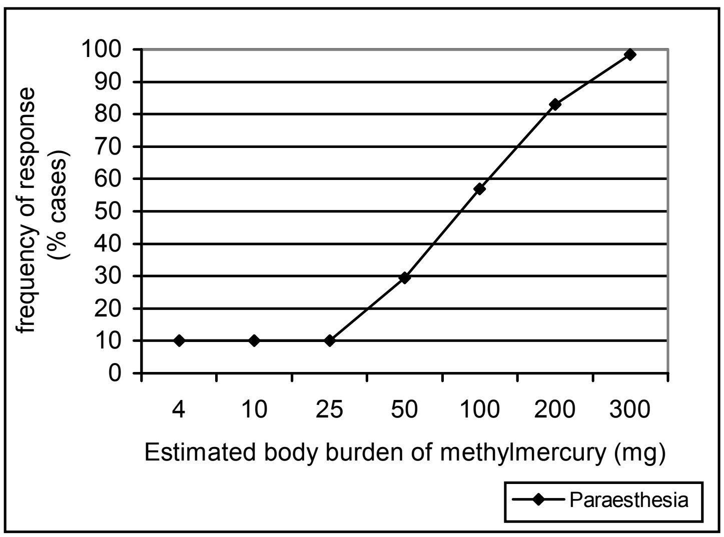
Heavy exposure (hours – days) 5-10mg/m^3	Moderate, repeated exposure (days – weeks) 0.05 mg/m^3- few mg/m^3	Lower, long lasting exposure (months-years) < 0.05 mg/m^3
Respiratory distress, Damage in lungs tissue. Excitability and tremors.Renal failure may develop	Behavioural and personality changes (e.g. shyness, insomnia). Mercury poisoning: gingivitis & salivation as the most common signs.	"Micro-mercurialism": Weakness,fatigue, weight loss. Memory disturbance. Minor renal tubular effects[24, 25].

Dose- response relationship

The most appropriate dose response relationship found through this review, is best characterized by data from previous studies from the methyl mercury fungicide poisoning in Iraq. During the period between 1971-1972, rural communities across the whole country prepared bread with grain treated with the fungicide (13). Consumption started by October 1971, and the first hospital admissions began by December of the same year. Exposure limits varied from the individual intake of few slices of contaminated bread consumed, (low non-toxic intake) to periods as long as 2 months of daily intake. (Some cases with intense signs of poisoning) (13,17,23). The initial effects were symptoms of paraesthesia, followed by signs of ataxia, dysarthria and hearing loss. A dose-effect curve for paraesthesia is reproduced below, modified from the WHO report on Methyl mercury (17).

The above graph shows that for paraesthesia, there is a background frequency of about 10 % up to the threshold of 25 mg, indicated by the parallel line of the horizontal axis. At higher values of body burden, the frequency of response rises in proportion to the logarithmic of the body burden (the horizontal axis has a logarithmic scale) (17). Subsequent reanalyzes of the Iraqi data (31) combined individual thresholds and the metabolic model of methyl mercury to estimate blood concentrations that would result from long-term daily intake of methyl mercury (17). Then, blood levels were related to body burdens using: group average numbers of loaves consumed, average content of methyl mercury per loaf, and number of days of consumption (40 to 50 days) (13,17,32). Finally, combining all the information above, an overall estimate of the risk of paraesthesia was obtained (17).

Fig. 1. Dose response relationship for methylmercury exposure (17)



Exposure assessment

For the assessment of the particular case in the Colombian Amazon Region, a description of their main features follows (8):

The zone analyzed in this assessment is at the South East region of Colombia. It is located at the basin of river Inirida (Guainia), with an approximate population of 7400 people. Its main job derives from the exploitation of alluvial gold; they use mercury for the amalgamation process, in an artisanal way and without any regulations. A small descriptive study was done between October 1998- January 1999 (8), to determine mercury levels in blood; also, a risk perception survey was conducted to determine knowledge of health related effects to mercury exposure. 65 blood samples were taken, 42 from miners and 23 from non-miners; these subjects are between 13-63 years of age. (Mean: 31,78 years). The gold mining activities in this particular region can be recorded since the late 1980's beginning of 90's, from reports performed by the environmental and sanitary division and presented to local authorities in the area (33). Miners perform their activities and amalgamation processes most of the time outdoors, and inhabitants of the region are used to wash their clothes, have fish -meals (captured from the Inirida waters) and eat near the river. Risk perception of exposure to mercury is limited, and sometimes incorrect. Most of the surveyed people considered mercury present in air and water; few knew its presence in fish and water food.

Assumptions

According to the information above, in order to perform a hazard estimate the following assumptions are made:

Individuals exposed
The assessment assumes that a significant exposure to mercury is occurring in the riverine population of the Guania region, through mercury from gold mining activities. The study sample (8) is assumed to be representative from the adult population of the area. In addition, it is likely that through fish consumption almost all of the 7 400 people are exposed to the hazard.

Type of exposure
Miners are exposed both to mercury vapour through amalgamation and methyl mercury through fish consumption. In here, we assume that this exposure is presumably very low, because this process is mainly done outdoors and vapour gets disperse through the atmosphere. Therefore, the emphasis will be on the effects of methyl mercury through fish consumption as the main hazard, although there is some additional exposure to mercury vapour and thus some metabolism of organic to inorganic mercury in the bodies of individuals (34).

Duration and Intensity of exposure
There is no available data of amount of fish consumption, neither concentration of methyl mercury in fish from the river in the area. Thus, data and or / assumptions made from previous published studies regarding this issues are taken here to perform the assessment. (I.e. exposure period: 2-3 months; blood samples taken at an average of 65 days after cessation of exposure; average concentration of mercury: 1.4 mg Hg in each bread loaf, body

weight: 50 kilograms) (13). Nevertheless, concentrations of mercury in blood samples from miners, non-miners and the total population sample are used in here to characterize the population hazard.
Risk characterization

The information collected in both dose-response relationship and exposure assessment are combined here to obtain an approximate excess risk for the study sample, assuming that it is representative of the whole village population in the Guania region.

Using the metabolic model from the Iraqi incident (17), the body burden of 25-40 mg of mercury is equivalent to a blood level of 250-400 μg/liter. Thus, we can apply this equivalent value to our data from the Guainia region, and take the blood level values to estimate body burdens in the population sample. This is done dividing blood levels by 10, to obtain body burden. To simplify calculations, interval percentages for paraesthesia were averaged in each category of body burden. Then, percentage cases of paraesthesia (lost of sensation at the extremities of hands and feet) were calculated from the amount of subjects for each burden category. Results are shown in Table 2.

Table 2. Cases of paraesthesia in the study sample, attributable to methyl mercury exposure

Body Burden Mg Hg	Predicted average of % cases paraesthesia	Miners	Miners Cases Expected	Non miners	Non miners Cases Expected
0-25	<10%	3	0.3	2	0.2
25-50	20%	17	3.4	8	1.6
50-100	45%	19	8.6	12	5.4
100-200	73%	3	2.2	1	0.7
TOTAL	65 individuals	42	14.5	23	7.9

From the above we can say that, from our sample population a total of 14.5 cases of paraesthesia among 42 miners will be expected. Meanwhile, 7.9 cases of paraesthesia from 23 miners will occur. This numbers do not exclude background levels.

As shown in table 3, a mercury level threshold of 25 mg is equivalent to background level of 10 % cases of paraesthesia (13,17). Applying this finding to our study sample (65 individuals), background level is 6,5 %; i.e. percentage of cases with paraesthesia not attributable to the exposure.

In the study sample: 65 persons; (42 miners, 23 non-miners)

Excess cases in non-miners: 7,9 – 2,3 = 5,6 5,6/23 = 0,06 24,3 %
Excess cases in miners: 14,5 – 4,2 = 10,3 10,3/42 = 24,5 24,5 %

Thus, we can expect 24,3 % excess risk of paraesthesia associated with methylmercury exposure among non-miners, and 24,5 % excess risk of paraesthesia attributable to methyl mercury, in the study sample of the Guainia Region in Colombia. Table 3 shows a summary of the main characteristics regarding this assessment.

Table 3. Health Risk Assessment of methyl mercury exposure from gold mining: summary of main features

Health effect	Paraesthesia
Routes of exposure	Food (fish consumption) Vapour exposure (burning amalgam) (not taken into the analysis)
Persons more likely to be exposed	Miners : Food and vapour Entire population: Food More Susceptible: Children –prenatal exposure- (not analyzed in here)
Number of people exposed	In the population sample (65 individuals): 42 miners 23 non-miners
Previous data	Methyl mercury poisoning in Iraq (13) WHO, IPCS, 1991(17)
Exposure	Magnitude: measured through blood samples (8), compared to previous study results (13,17). Duration and timing: unclear; assumptions taken from previous study (13) (see text).
Threshold	Body burden: 25 mg of mercury
Findings (study sample)	Excess cases of paraesthesia attributable to methyl mercury exposure: Non Miners: 24,3 % Miners: 24,5 %

Uncertainties and limitations of the assessment

The following are some of the uncertainties and limitations through the health risk assessment process presented here:

- Calculations made to obtain a quantitative estimate of health impact are based on a study in an Iraqi population. Characteristics of people involved in that event may be different from the ones in the Guainia area (e.g. daily intake of fish, body weight, etc).
- Paraesthesia is used here as an end point indicator of effect, available from previous studies. It should be noted that this symptom is not uncommon in unexposed people; other effects might be important to discuss, and possibly more relevant.
- Parameters such as mercury concentration in fish, local background levels, average and seasonal variations in fish consumption, and mercury discharge in the river are presumably different in our study population from those applied on the Iraqi study.
- Samples taken here to perform the risk characterization are from adult population of the Guainia region. Susceptible population such as pregnant woman and children are not in this analysis, due to lack of data.
- Exposure to mercury in miners is likely to be from two sources: fish consumption and amalgam burning. The last one is not taken in the analysis and according to the results, effects on miners through both exposures might represent higher effects among them, compared to the rest of the population.
- The dose-response relationship used here is based in a study of de 1970's (13) and subsequent estimates and assumptions are based on the initial model 36). Is difficult to determine to what extent these assumptions are still valid and applicable to any current situation.
- Individual variables that may alter mercury blood concentrations or its metabolism, (e.g. alcohol) are not included in this assessment, and may modify effects of mercury exposure in this or any given population.

Limitations such as lack of reliable data and thus, rough estimates to obtain a risk measure, are two constraints for the validity of this assessment.

DISCUSSION

A dose-response model from a previous study is taken here to perform all calculations in the population sample from the Guainia region in Colombia. The only reliable data from the region are mercury concentrations in blood samples from 65 individuals. Although most characteristics of the Iraqui exposure are different from the situation in this region, calculations indicate an excess of nearly 20 % cases of paraesthesia among miner workers. Also, almost 95 % of the blood levels found in the study samples were higher than 200 μg/L, associated with a 5 % risk of neurological damage in adults (17).

These findings indicate an important health effect that can be attributable to this particular hazard.

Assuming that this is not a migratory population and that percentage of miners and non-miners is approximately the same as for the population sample, we could say (doing a rough estimate) that 65 % of the population (4 810 individuals) are miners, and 2 590 individuals (35 %) are non miners. We will then have 155 non-miners excess cases of paraesthesia, and approximately 914 excess cases of paraesthesia among the miner population. Clearly, the above are very crude calculations; perhaps a more detailed population distribution, (including age groups, pregnant women and children, etc) could help to perform best reliable estimates and clarify the current situation in the Guainia Region.

Mercury contamination in this gold mining setting is assumed to be principally by fish consumption; discharge of mercury in the river is high (8), imposing to this population an important threat through fish consumption. However, according to the assessment, the percentage of cases among miners is higher compared to percentage in the non-miner population. Although gold miners perform their jobs most of the time outdoors, mercury vapour could be one explanation to the higher percentage of paraesthesia cases among this particular group.

Although a mild symptom for methyl mercury exposure, paraesthesia is the first manifestation of the poisoning with the compound, which might result on a more severe damage to the central nervous system (32). An interesting approach could be to analyze to which extent paraesthesia could be predictive of future neurological damage in these individuals, with long periods of exposure. This could be done through initial identification of susceptible populations through clinical examination, and correlate findings with laboratory studies (e.g. blood, hair, urine samples). Also, is important to determine which of those mentioned would be the best biomarker indicators in order to investigate a particular outcome, before conducting a more detailed study.

Lack of data regarding population distribution in the area, makes difficult to make assumptions about percentage of children that might be affected by the exposure. Since there is increasingly evidence of prenatal exposure effects of methyl mercury in neurological development (11,29,35), it will be worthwhile to determine this effect in the population, e.g. by comparing hair levels in mothers and correlate them with postnatal development (35).

CONCLUSIONS AND RECOMENDATIONS

Previous assessments have already shown the importance of evaluating mercury effects in human health (32,36). However, gold mining activities will remain where easily extractable alluvial gold persists, until exhaustion of the source (1). In Colombia, there are several places that present this particular hazard (6,8), thus outlining the need for remedial options that prove effective for implementation in the area. In here, the first target is the riverine population. Miners and their families must be convinced that exposure to mercury is a serious threat to their health, and therefore, to their future productivity as individuals and as part of the community (1). Once this is fulfilled, remedial procedures can be achieved. Two approaches are:

- Systemic solutions: involving institutions and agencies that facilitate implementation of remedial procedures. (e.g. creation of processing centers to amalgamate concentrates, thus reducing emissions) (16).
- Individual solutions: miners adopting control measures (e.g. equipment that reduces mercury emissions) (15).

In both cases mentioned above, interest of the local population, technical assistance and educational programs are fundamental for the success of remedial procedures in the area (1,15,16). Another recommendations may include: Follow up and careful observation of health effects related to mercury (e.g. clinical records) (37), monitoring programmes of mercury levels (e.g. in water, fish, sediments) to identify specific polluted sites (16), massive educational campaigns to inform people about mercury exposure (e.g. booklets describing mercury sources, dietary recommendations, etc) (1). Although this may seem a simplistic approach to characterize health impact of gold mining activities in the Guainia region, evidence presented here seems crucial to support future evaluations of neurological symptoms among this population. In addition, it is highly recommended to emphasize future studies in this area on newborns and children.

A health risk assessment approach to this gold mining setting might seem inaccurate due to the uncertainties and limitations that had been taken in to account. Still, when resources to develop detailed studies are restricted, limited health data can be used as a tool to investigate current situations such as the one taking place in the Colombian region of Guainia. Perhaps more risk assessment evaluations are needed to compare findings and improve the health and the environment of communities exposed to mercury and other environmental hazards.

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APPENDIX

Compartment model (17)

The accumulation phase in the whole body or in a tissue compartment is described by the equation:

$A = (a/b) (1-\exp [-b \times t])$

Where: A = the accumulated amount a = amount taken up by the body daily

B = the elimination constant t = time

The elimination constant is related to the biological-half time $T_{1/2}$ by the expression:

$T_{1/2} = \ln 2 / b$

And a is related to the daily dietary intake (d) by the expression:

$A = f \times d$

where f is the fraction of the daily intake taken up by the body (or organ).

At a steady state, the accumulated amount (A) is given by:

$A = a/b$

While the steady-state mercury concentration in blood (C) in µg/litre is related to the average daily dietary intake (in µg mercury) as follows:

$$C = f \times d/b = \frac{0.95 \times 0.05 \times d}{0.01 \text{ days}^{-1} \times 5 \text{ liters}} = 0.95 \times d$$

Assuming that:

the average weight is 50 kg (13).

0.95 of the intake is absorbed, that 0.05 of the absorbed amount goes to the blood compartment

blood volume is 5 liters on average

that elimination constant is 0.01 days $^{-1}$

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