RISK ASSESSMENT OF MERCURY IN ALTA FLORESTA. AMAZON BASIN - BRAZIL

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ABSTRACT. In the last 15 years gold mining activity has been the main source of the mercury (Hg) emissions into the atmosphere in the Amazon Basin. The first phase of gold production takes place in remote areas. In general the second one happens in the local urban area, where the gold is commercialized and sent to the great economic centers. In the last 3 years, this activity started to decline as a consequence of the high cost of the gold production but in the Municipality of Alta Floresta, the gold trade still plays an important role in the local economy.This paper addresses the assessment of the Hg exposure scenarios and their quantitative risk for inhalation of metallic Hg vapor and for ingestion of total Hg, using indirect exposure measurements, for different age groups of the urban area of Alta Floresta. This work took into account the field study which provided background information, such as characteristics of local and regional environment, Hg concentrations in different environmental media, and the character of the local urban population. The mean levels of Hg in the atmosphere of the urban area ranged from 210 ng/m^3 to 880 ng/m^3. Alta Floresta has no riverside population and there is a low fish consumption rate of 8 g/d among the general population. However, mercury levels in locally consumed carnivorous fish, ranged from 0.3 to 3.6 mg/kg, depending on the species and on the period of the year. The levels of mercury in soil surrounding the residential areas near the Hg emissions sources, ranged from 0.05 to 4.10 mg/kg. Hg in soil may represent an important source of mercury ingestion for local children up to 4 years of age. The mean Hazard Index estimated for the general adult population was 1.4. For the general population, regarding the number of persons exposed in the urban area, inhalation of metallic Hg vapor is the main route of exposure. The results for water ingestion for all groups are negligible. For families of fishermen the Hazard Index was estimated to be 9.3, with a contribution of 92% from fish ingestion.

1. Introduction

In the Amazon, metallic mercury has been widely used in gold production by the informal mining sector known as "garimpos". Since the late seventies, gold has been extracted from soil or river sediments through amalgamation with mercury; the amalgam is then heated, giving off mercury vapors while leaving the ore. This Hg has the potential to contaminate the environment, being transported long distances before being deposited on the earth's surface and entering the aquatic food chain. The second phase of gold production occurs in urban areas, where the gold trading takes place. The gold from garimpos has some impurities of which Hg accounts for 2 to 8%. The amalgamated gold is repeatedly burnt to completely separate the two components, until reaching pure gold. From 1980 until 1994 the gold trade in the urban area of Alta Floresta had an estimated production ranging from 1 to 2 tons of gold per month (Hacon *et al*, 1995). The Hg vapor is emitted directly into the urban atmosphere, where a population of about 46,000 inhabitants has been potentially exposed to Hg emissions during the last 15 years.

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The health risk assessment of Hg should approach the regional, local and multimedia aspects of Hg fate and transport in this environment. Alta Floresta is a municipality in the state of Mato Grosso in the Amazon Basin, 800 km away from Cuiabá, capital of the state. It is not a riverside area but the Teles Pires River, 67 km from the urban area, is a main fishing resource for the region, with an important role for the local economy due to the intensive gold mining activity established in the decade of the 80's. Teles Pires River contributes about 80% of the fish consumed by the local population of Alta Floresta. Mercury deposited into water bodies is transformed into methylmercury (MeHg) through the activity of bacteria present in soil, sediments and suspended particulates in water. Organic mercury gets into the trophic chains where it can be biomagnified a million fold between initial transformation and the ultimate predatory species, mainly fish. Recent findings indicate that MeHg levels in carnivorous fish from Alta Floresta rivers accounts for 85% to 100% of total Hg (Akagi *et al*, 1993). The largest predatory fishes from Amazon rivers present the highest MeHg levels. However, the fish consumption pattern for the general population of Alta Floresta is low, which makes this local scenario different from that for the riverside population.

The population of Alta Floresta is exposed to organic and inorganic compounds via different pathways. Exposure and effects of toxic substances depend on various factors: levels of contamination in the medium, the existence of potential pathways for human exposure, the size and nature of the community likely to be exposed and the duration and magnitude of the exposure. The great majority of the inhabitants of Alta Floresta has different social and cultural characteristics than other Amazon communities (Boischio *et al*, 1995, Hacon, 1996). This fact is important in understanding why Alta Floresta has a different exposure scenario in relation to other "garimpo" areas.

2 STUDY AREA AND METHODS

The present study has been carried out in the urban area of Alta Floresta, in the Southern part of Amazon Basin. The region started to be occupied in the decade of the 70's by a private colonization project, which had the aim of developing a large scale agricultural project. However, the "gold rush" in the early's 80 in the Amazon Basin transformed the original social-economic project for the region into an important gold trade center. About 70% of the population came from south and southeast of Brazil with social and cultural habits different from the indigenous amazonian population. The main economic activity of this region is the gold trade, which until 1994, was responsible for an average emission factor of Hg for the atmosphere, ranging from 0.5 and 2.5 tons of per year (Hacon *et al*, 1995). The variation of the Hg emissions depends on variables such as the type of technology of the "garimpo", the amount of Hg amalgamated by kg of gold, the total amount of gold trade and the current price of gold. Those people from the gold shops are primarily exposed to Hg emissions at the workplace and also in the urban environment. For the general population, the Hg from the urban atmosphere is the main source of exposure. Hg contamination has been studied at the workplaces and the environment of the region of Alta floresta since 1990 (CETEM 1992; Hacon *et al*, 1993; 1995; Hacon, 1996). These studies provided background information, such as the characteristics of Hg sources and Hg concentrations in different environmental media, physical, social and economic characteristics of local and regional environment. People in Alta Floresta, as well as many other areas of Amazon Basin, have been exhaustively studied and used as information sources for Hg exposure studies but it has been difficult to get biological samples from them. Through the present methodology, one is able to simulate the potential health risk, identifying the spot groups that should be of the greatest concern.

2.1 Characterization of the population

In 1992, a survey about the concern of Hg contamination in the urban area was carried out among the residents, gold trade dealers and local governments. In 1993, as result of this survey, an extension of 50 km^2 of the urban area, which concentrates about 70% of the urban population and all gold dealers shops were integrated into the present study in order to evaluate Hg exposures. The next step was to assess a sample of the population that could simulate the various groups related to Hg exposure in the urban area. A sample of 160 adult inhabitants from a random list have been interviewed during the dry season (May to September). About 50% of the interviewed individuals were from the local trading and the other 50% from homes, between 15 and 60 years old and from both sexes. A questionnaire was applied in order to get demographic, anthropometric measures (weight and height), socio-economic and occupational activities information, and dietary habits, with emphasis on fish preferences and consumption (Hacon, 1996). To estimate the amount of fish ingested we have weighted the amount of fish to be consumed in the next meal in 10 % of households. The information about the groups under 15 years old was obtained from interviews with their parents. The information drawn from this survey was fundamental to identifying potential exposure pathways for Hg and to define the exposed groups.

Occupational exposure in this study includes individuals from both sexes who work in the gold trade activity who are directly and indirectly exposed to metallic Hg vapor emissions due to the amalgam burning. The exposure in the workplaces (gold shops) is intermittent, with the higher concentrations occuring during the burning time. When the shops have a reasonable exhausting system, a large part of the Hg emissions goes to the external atmosphere. Otherwise, most of it remains indoors and it gets dispersed through the doors and windows.

2.2 Environmental Contamination

A multimedia approach to the environmental monitoring program for Hg was carried out, taking into account the Hg emission sources and the main Hg contamination pathways for the urban population of Alta Floresta (Hacon, 1996). Mercury is present in the atmosphere in particulate and gaseous phases and in various chemical forms. In Alta Floresta metallic mercury vapor (Hg^0) accounts for about 90% of the total Hg in the atmosphere. Hg measurement programs were established for water, fish, and for outdoor and indoor air, the later inside the gold trade shops. Secondary data has been used to estimate the exposure due to soil ingestion. The soil ingestion rate for children was obtained from the literature and personal judgement (Hacon, 1996). This program was carried out during the dry season because it is the worst period in terms of air quality, due to the intensity of the "garimpo" activity, which coincides with the biomass burn period. Three sites were set up for air Hg samples in the urban area. The location of the stations took into account meteorological parameters, sources of Hg emissions and residential and work places. Gaspar station, in the central area of the city, is close to the majority of gold dealers shops. Airport station is upwind and Boa Nova station is downwind relative to the predominant wind direction.

The initial aim, in relation to the indoor Hg sampling program, was to use individual sampler systems to evaluate the workers Hg exposure during the time of amalgam burning but this was not possible due to the internal conditions of the gold shop and the lack of permission from the gold dealers to use the samplers only during the burning period (Hacon, 1996). Thus, our option was to evaluate the Hg exposure indoor through the average exposure at the workplace. Four gold shops were chosen for this assessment, taking into account internal burning conditions, number of workers and the amount of gold commercialized weekly (>10 kg/week) (Hacon *et al*, 1995). Total Atmospheric Hg was sampled in two successive bubble traps containing 5% KMnO4 in sulfuric acid 2N. The flow-rate of about 1 liter per minute was controlled by rotameter. The same sampling system was used for indoor and environmental samples.Trapping efficiency was better than 90%. Inside the gold shops, we assume that the exposure to Hg is 100% in vapor phase, estimated using the 90% percentile indoor Hg concentration distribution (X90%). This approach was chosen considering the distance from the amalgam burning place inside the shops and the location of the sampling system used, in order to have a better evaluation of the workers's exposure. The indoor Hg exposure levels ranged from 70 to 40 600 $\mu g/m^3$. This range is dependent on the season and the amount of amalgam burnt daily (Hacon, 1996).

The inhalation rate varies with age, sex, and physical activities. The average value for inhalation rate used for adults and children is 20 m^3/d and 10 m^3/d, respectively (EPA, 1989 b). We assume the same inhalation rate value for gold shop workers as that for the general public, because their activity does not require physical effort, corrected for the estimated exposure time. We also assumed 100% of absorption of Hg by the lungs.

The water bodies and wells used for water supply were sampled using a acid solution of

$K_2Cr_2O_7$ at 0,01% and HNO_3 at 5% (Campos *et al*, 1990). The different fish species were weighed and immediately frozen (Hacon *et al*, 1993). The mercury analysis was performed by cold vapor atomic absorption spectrometry (CVAAS) after wet digestion. The gold trap technique has been used for measurements of Hg in water. The detection limit for total Hg was of 10 ng/m^3 for air, 0,3 ng/l for water and 0.1 μg/kg (w.w) for fish (Campos *et al*, 1990). Analytical quality was assured by several methods such as a blank control (3 blanks for a batch of 10 samples), duplicate analysis and the analysis of reference materials with the Interlaboratory Comparison Program, Ottawa, Canada.

2.3 Exposure Assessment

Probabilistic calculation was used to evaluate the urban population exposure and to estimate the risks for different groups of the population. The parameters used as input for the modelling are presented in Table 1. The Hg dose rate was estimated for different routes and variable values dependant on site conditions and/or the characteristics of the potentially exposed population group. The general equations for assessment of chronic exposure for ingestion and inhalation were applied (EPA, 1989a):

a) Ingestion intake.

$$I_{ing}\ (mg/(kg.d)) = \frac{IC\ .\ IR}{BW} \qquad (1)$$

where: IC = Fish or soil Hg concentration (mg/kg) or water (ng/l)
IR = Ingestion Rate, (kg_{FISH} / meal, l_{water}/day, kg_{soil}/day)
BW = Body weight, (kg)

b) Inhalation intake.

$$I_{air}(mg/(kg.d)) = \frac{CA\ .\ IR}{BW} \qquad (2)$$

where: CA = Hg concentration in air, (mg/m^3)
IR = inhalation rate, (m^3/d)
BW = Body weight, (kg)

c) Potential health risk.

The hazard quotient (HQ) is calculated as the dimensionless ratio of the estimated dose rate, I, to the selected reference dose (RfD) μg/kg/day:

$$HQ = \frac{I}{RfD} \qquad (3)$$

If HQ is less than one, there is no anticipated risk for adverse health effects. If HQ is equal to or greater than one, there is a possibility for adverse health effects to occur for sensitive population groups. For risk assessment purposes it is better if one can determine a Reference Dose (RfD) which is protective even for the most sensitive groups of the population. The oral RfD for both inorganic and methyl mercury is 0.3 µg/kg/d b.w (Young, 1992). There is no reference dose for inhalation. The usual way is to use the reference concentration for inhalation (RfC) 0,3 µg/m³ (IRIS, 1993) however, even knowing that organic and inorganic Hg pose different risks, we assume the same RfD value (0.3 µg/kg/d) to simulate the inhalation and ingestion exposure and to estimate the potential risk. Although recognizing that different exposure routes can lead to different risk end points, in this work for the comparison of relative relevances, all doses have been summed to get a combined hazard quotient for each studied group.

Table 1-Values of the input parameters for the Risk Assessment Modelling.

parameters	unit	distrib.	mean	s.d
[Hg] water	ng/l	ln	3,0	1.8
[Hg] Fish	µg/kg	n	1320	737
[Hg] environmental air	µg/m³	ln	0.5	0.92
[Hg] indoors air	µg/m³	ln	26.2	2.82
[Hg] Soil	mg/kg	ln	0.23	0.02
water ingestion rate (adult)	l/d	t	2.0	-
water ingestion rate (children)	l/d	t	1.0	-
fish ingestion rate - Group 1 e 3	kg/d	ln	0.008	0.006
fish ingestion rate - Group 5	kg/d	ln	0.005	0.006
fish ingestion rate - Group 4	kg/d	ln	0.005	0.006
fish ingestion rate - Group 2	kg/d	ln	0.110	0.045
fish ingestion rate - Group 6	kg/d	ln	0.080	0.025
soil ingestion rate - Group 4	kg/d	ln	0.005	0.025
workers's inhalation rate	m³/d	t	10	-
inhalation rate for general	m³/d	t	20	-
inhalation rate for children-	m³/d	t	10	
body weight - adult population	kg	t	60	-
body weight - workers	Kg	t	65	
body weight - children (5- 14)	Kg	t	32	
body weight - chidren (1- 4)	kg	t	15	
RfD total Hg	µg/kg/d	lu	0.3	-

ln = lognormal lu= log uniform t= triangular

2.4 Uncertainty Analyses

Probabilistic calculations were performed for the quantitative uncertainty analysis by Monte Carlo simulation, using the Crystal Ball software (Decisioneering, 1993). The Latin Hypercube Sampling method was used with 1000 iterations to define the probabilistic distribution of the variables and identify the parameters that could significantly contribute to the uncertainty on model predictions (Gardner, 1988; Rochedo, 1994). For the uncertainty analysis, each parameter is associated with a distribution described by a mean value, a standard deviation and maximum and minimum values. These values are those most representative of the assumed distribution (e.g., arithmetic mean for a normal distribution and geometric mean for a lognormal distribution). The distributions have been chosen according to state of art scientific evidence and personal considerations about the studied scenarios.

3 - Results and Discussion

The baseline exposure scenario for the urban population of Alta Floresta is a low level chronic exposure. This scenario includes different exposure pathways for both adults and children populations. The groups were characterized in function of their pattern of exposure, fish consumption habits, activities and age:

For adults - Group 1- The general population
Group 2- the fishermen's families
Group 3- workers from the gold shops.

For children - Group 4- children from general population (1-4 years old)
Group 5-children from the general population (5-14 years old)
Group 6- fishermen's children (5-14 years old).

3.1 Characterization of the urban population

The age range from 15 to 34 years old, represents 68% of the sample population and also represents the range of age of the economically active. This feature may be explained by the colonization process of the region in the early 80's (Hacon, 1996). In relation to the occupational activity, 34% of the women, between 17 to 39 years old, mentioned having worked in the "garimpos" activity, as cookers. All of them, reported having suffered from malaria, which is seen as a confounding variable relative to the symptoms of Hg contamination. Nowadays, they are household workers and are not directly exposed to metallic Hg vapor emissions. However, they are still exposed to secondary levels, from the urban environment atmosphere. 30% have been working in the urban area, close to the gold shops, as sellers in commercial activities or in administration. 36% are household workers and have never worked out. For men, 70% reported to have worked in "garimpo" activity, of which 44.5% burnt amalgam at least part of the time during 5 years. In relation to sanitary conditions, 82 % of the adults interviewed use water from wells, without any type of primary treatment, and about 16% use water from a supply system.

3.2 Exposure Assessment

The exposure level for a standard water consumption of 2 l/d for the adult population was estimated to be 0.1 ng/kg/d. This exposure route can be regarded as negligible.

The levels of Hg in carnivorous fish are high, ranging from 0.3 to 3.6 mg/kg (w.w), as in many other areas of the Amazon Basin (Akagi *et al*, 1993; Malm *et al*, 1990; Aula *et al*, 1995). About 95% of the fish consumed by the urban group are carnivorous fish. The highest Hg concentrations were found in *Brachyplastystoma spp* (Piraiba), that accounts for 29% of local consumption. The Hg concentration in this specie ranged from 1.7 to 3.6 mg/kg. The most consumed species is the *Paulicea Lutkeni* (Jau), accounting for about 33% of local consumption and has Hg concentrations ranging from 0.4 to 2.7 mg/kg. The carnivorous species that have an average Hg level greater than 0.5 mg/kg make up 80% of the total consumption (Hacon *et al*, 1993). The daily intake of Hg for the urban population was estimated assuming a weighted average fish concentration of 1.3 mg/kg (Hacon, 1996). About 10% of the urban population interviewed does not eat any type of fish. The fishermen (group 2) are the people with the highest average fish ingestion rates (110 g/d). Groups 1 and 3 presented the same average fish ingestion rate of 8 g/. Group 4 (children, 1-4 years old) has an average rate ingestion of the 5 g/d. The statistic F-test showed that there is not a significant difference between the fish ingestion rate for all children in this age range. The highest fish consumption was verified in group 6, fishermen's children, above 5 years old, with a mean ingestion rate of 80 g/d. The body weights for the different groups were used to correct the estimated total daily Hg dose.

In play-grounds close to the gold shops, Hg concentration reaches values up to 9 $\mu g/m^3$ in air and 4 mg/kg in soils. The Hg in soils is due to the deposition process, and can vary as a function of the Hg rate emission, the distance from the source and meteorological parameters. The soil exposure was estimated for group 4 (children below 5 years), due to their exhibited mouthing behavior, because soil and dust particles were observed on their hands during normal playing activities, and also due to the proximity of the residential and school areas to the gold shops.

We assume the same mean exposure levels of metallic Hg vapor, 0.5 $\mu g/m^3$, for all of the urban population, that comprises people resident or workers of the urban area, although the air concentrations measured ranged from < 0.02 to 5.8 $\mu g/m^3$. Only for the workers from the gold shops, were different exposure patterns regarded. These workers are exposed about 10 hours per day to high Hg levels (mean 26.2 $\mu g/m^3$) and the rest of the time they are exposed to the same environmental concentrations as the general population. The women workers from the gold shops, in general do not burn amalgamam directly, because they work in administrative tasks. However, due to cultural habits, they stay indoors all the time while men usually go out very often to drink or to talk.

Table 2 shows the results for mean dose and hazard quotients (HQ) for the different exposure pathways, with a confidence level of 95%. Group 1, the general urban population, would be unlikely to experience adverse health effects due to all pathways. However, the maximum HQ values for ingestion (18.3) and inhalation (9.5) show that there may be individuals with critical values which should be better investigated. For group 2, fishermen's families, the fish ingestion is the main exposure pathway, with an Hg daily intake of 2.23 μg/kg bw, which is about 7.5 times higher than the reference dose. This exposure pathway contributes 92% to the hazard index. The HQ for this group (8.6) is a value of concern, mainly for pregnant women as it is known that Hg may reach the fetus with health consequences for the child. The maximum HQ value for this group (76.5) indicates that some individuals, mainly the more sensitive ones, have a great probability of exihibiting adverse health effects.

Group 3, the gold shops's workers, presented a mean inhalation dose estimated at 4.5 μg/kg/d, equivalent to a HQ of 9.21 The maximum value for HQ (48.2) indicates the probability of critical sub-groups. Even being intermittent, the Hg exposure can be characterized as a chronic exposure, taking into account the time, magnitude and duration of the exposure. Comparing the average exposure levels (26.2 $\mu g/m^3$) with the threshold limit value (TLV) for Hg vapor in the workplace (50 $\mu g/m^3$), the Hg exposure levels in the gold shops are below the threshold, despite the fact they have a long-term (8 years) exposure. Nevertheless, it is the frequent complaint of workers that they have symptoms that can be attributed to Hg intoxication (tremor, erethism, paresthesia, insomnia, lack of self-control, weakness, renal alteration). It is difficult to associate these to Hg exposure due to the presence of confounding variables, caused by parasitic, infection, endemic, and other diseases. However, the highest value from the hazard quotient (48.2) may be strongly correlated with these symptoms.

For group 4, children between 1-4 year old, inhalation of Hg vapor contributes 36.4%, fish 45.4% and soil ingestion 18%, for the total dose. The total daily dose for this group is 1.1μg/kg/ bw, 3.6 times higher than the total Hg RfD of 0.3 μg/kg bw. The probabilistic values for the maximum inhalation and ingestion HQ show the possibility of the existence of critical sub-groups which have to be better investigated. Taking into account that this group was exposed since the pregnancy stage, they should be followed-up and studied in terms of dose-response relationship.

For group 5, the general urban population's children from 5 to 14 years old, , the main exposure pathway is inhalation from the urban air, with a contribution of 72%, while the ingestion of fish contributes 28% to the total dose. The maximum value for this group also confirms the importance of the inhalation route, with a HQ of 22.5. Group 5 has an average low fish ingestion rate and consequently a low HQ for ingestion. However, the individuals with the highest ingestion rate, 50g/d, showed HQ of 6.2 for this route of exposure.

Table 2 - Risk Assessment For The Different Groups of the Population

Groups	Routes of Exposure	Medium	dose µg/kg/d	Hazard Quotient (HQ)		
				mean	max.	distr.
Group 1	ingestion	water	0.0001	0.0003	0.002	ln
		fish	0.2	0.7	18.3	ln
	inhalation	air	0.2	0.7	9.5	ln
	Hazard Index		0.41	1.43	28.0	
Group 2	ingestion	water	0.0001	0.0003	0.002	ln
		fish	2.23	8.60	76.5	ln
	inhalation	air	0.2	0.7	9.5	ln
	Hazard Index		2.44	9.33	86.2	
Group 3	ingestion	water	0.0001	0.0003	0.002	ln
		fish	0.2	0.7	18.3	ln
	inhalation	air	4.50	9.21	48.2	ln
	Hazard Index		4.70	9.93	66.7	
Group 4	ingestion	water	0.0002	0.07	0.3	Ln
		soil	0.2	0.5	2.0	Ln
		fish	0.5	1.4	9.2	Ln
	inhalation	air	1.0	3.5	11.7	Ln
	Hazard Index		1.72	5.47	23.2	
Group 5	ingestion	water	0.0001	0.03	0.3	Ln
		fish	0.2	0.9	6.2	Ln
	inhalation	air	0.5	1.5	22.5	Ln
	Hazard Index		0.70	2.43	29.0	
Grupo 6	ingestion	water	0.0001	0.03	0.3	Ln
		fish	3.50	8.82	75.0	Ln
	inhalation	air	0.5	1.5	22.5	Ln
	Hazard Index		4.0	10.4	98.0	

For group 6, fishermen's children, fish ingestion is the main exposure pathway with a mean Hg daily dose of 3.5 μg/kg bw. This value is above the LOAEL (lowest-observed-adverse-effect level, 3 μg/kg bw), recognized as the lower limit for paraesthesia symptoms. This exposure route contributes about 85% for the Hazard Index. The probabilistic maximum HQ values for this exposure is 75, confirming the existence of critical sub-groups in the children's population. This study shows a moderate fish consumption by the urban population of Alta Floresta. However, one has to take into account that even with about half the ingestion rate in relation to the riverside population (200g/d) (Boischio *et al*, 1995), the levels of Hg in carnivorous fish from the Teles Pires River are a threat to this group of the population.

3.3 Uncertainty Analysis

The use of the quantitative uncertainty analysis allowed the determination of the most sensitive parameters in the overall uncertainty assessment of risk. This analysis is an important tool for decision making, providing information that could not be obtained from the standard point estimate approach, and giving guidance to which parameters one must focus ones research studies on, since a better knowledge of actual values will lead to a reduction of uncertainty of risk estimates (Rochedo, 1994).

The uncertainty charts (Figures 1 and 2) show the probabilistic results for the contribution to the uncertainty of individual hazard quotient for each group studied and Table 3 presents the uncertainty contribution associated with each exposure route to the Hazard Index.

The uncertainty chart (Fig 1) shows that, for group 1, inhalation and fish ingestion have about the same contribution to the variability of the Hazard Index. The parameters of ingestion rate and Hg concentration in the urban atmosphere, dominate the uncertainty with a contribution of 72.3% and 94% to the variance, respectively, as presented in Table 3. For group 2, the Hazard Quotient is 9.3. The ingestion of fish is the route that dominates the variability of the Hazard Index, being the ingestion rate parameter with the greatest contribution for the variance. Hg concentrations in the atmosphere, even presenting the highest contribution for the variance (94%), does not have a great effect on the variability of model predictions. For group 3, the inhalation route dominates the variability of the model, being the Hg concentration at workplace parameter with the great contribution for the variance (97%). Some of this uncertainty is unavoidable however, because there are some factors interfering with this variable, such as microambient conditions, amount of amalgam burnt daily, sampling location, among others, which can be better investigated. Water ingestion does not contribute significantly for any group exposed to Hg.

We regarded a static model for the children exposure. However, we know that for this population group, age is an important factor of variability associated with habits. The hazard index for groups 4 and 5 were estimated in 5.5 and 2.4 respectively. The soil ingestion pathway, is not so important when compared with fish ingestion and air inhalation. The uncertainty chart (Fig 2) shows for groups 4 and 5 that the HQ for inhalation is the main contribution to the variability of the Hazard Index and the Hg concentration in the urban atmosphere dominates the uncertainty, with a contribution of 90% and 95% to the variance, respectively. This variability is due to the large range of Hg concentrations in the urban atmosphere from 10 μg/m3 to 5400 μg/m3, which varies with the amount of Hg emitted daily to the atmosphere, meteorological parameters and distance from the residences to the emission sources. For group 6 (fishermen families's children) the hazard index is 10. The fish ingestion is the route that dominates the variability of the hazard index, being the ingestion rate parameter that contributes with 59% for the variance. Hg concentrations in air also have some contribution to the variance.

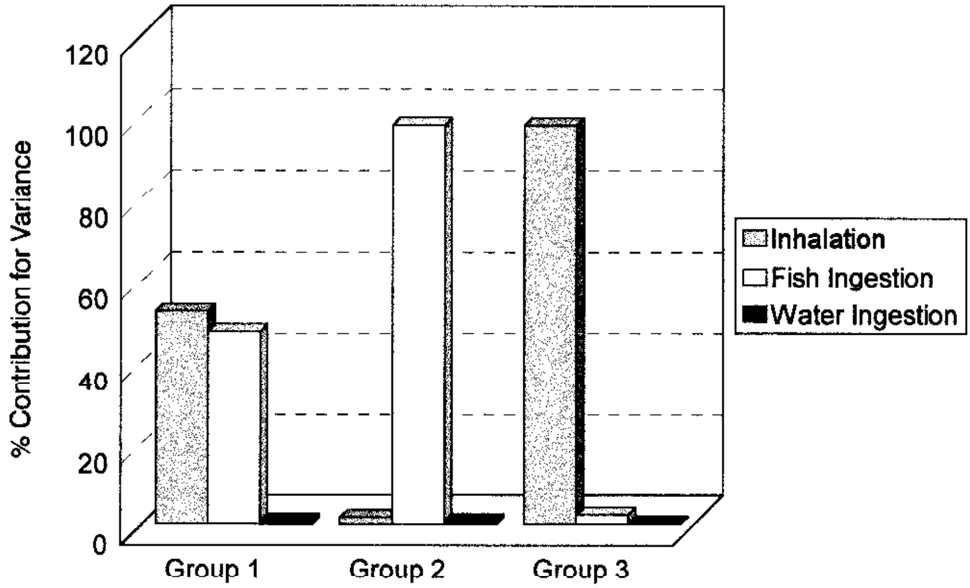

Figure 1 - Uncertainty Analysis for Adult Population Scenarios

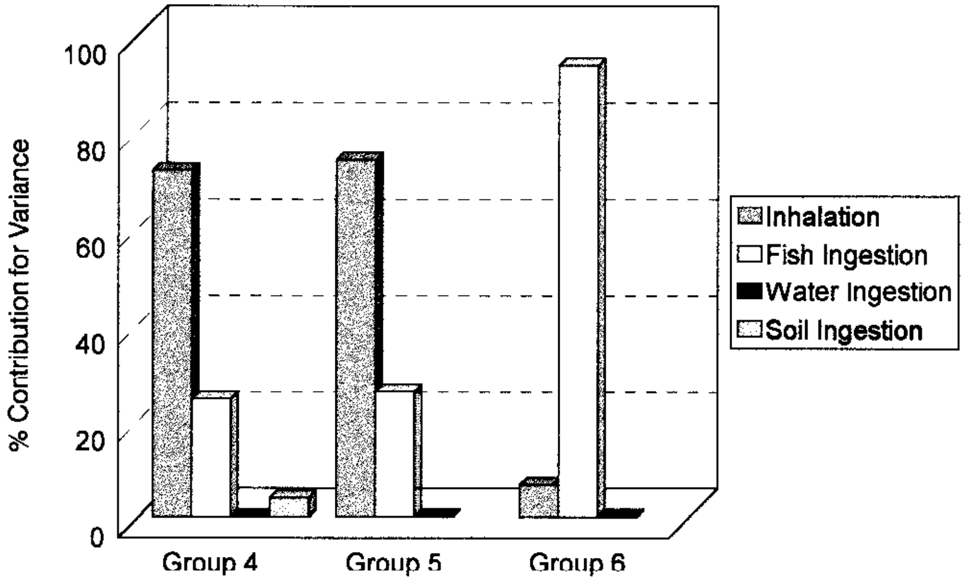

Figure 2 - Uncertainty Analysis for Children Population Scenarios

Table 3 - Uncertainty Analyis for the Exposure Scenario

Groups	Route exposure	Medium	Contribution for the variance (%)			
			[Hg]	Rates	B.W	RfD
Group 1	Ingestion	water	77.5	-	4.5	17.8
		fish	20.0	72.3	2.0	5.0
	Inhalation	air	94.0	0.2	2.0	3.8
Group 2	Ingestion	water	77.5	-	4.5	17.8
		fish	28.5	52.0	3.0	16.5
	Inhalation	air	94.0	0.2	2.0	3.8
Group 3	Ingestion	water	77.5	-	4.5	18.0
		fish	20.0	72.3	2.0	5.0
	Inhalation	air	97.0	1.5	1.5	-
Group 4	Ingestion	water	93	-	7	-
		fish	49	30	10	11
		soil	7	18	30	45
	Inhalation	air	90	0.5	3.5	6
Group 5	Ingestion	water	96	2	2	-
		fish	44	37	5	14
	Inhalation	air	95	-	0.5	4.5
Group 6	ingestion	water	96	2	2	-
		fish	27	59	1.5	12
	inhalation	air	95	-	0.5	4.5

4- Conclusion

The baseline exposure scenario for the general urban population of Alta Floresta is the low level chronic exposure. However, the health risk assessment methodology allowed the identification of spot groups, who can be regarded as risk groups for each exposure pathway. In relation to workers, a great deal of the information on effects associated with inhalation exposure to Hg vapor comes from studies conducted with occupational workers. However, in Alta Floresta, the gold shop workers can not be compared with the traditional mining or industrial workers, as they have different exposure patterns, professional behavior and habits, in relation to workers with a formal activity, where the work legislation is applied and enforced. Nevertheless, this is the group with the highest priority in terms of dose-response relationship. In relation to fish ingestion, the women from the fishermen's families are the spot group. Not only them but also their children should be followed up,on in terms of neurological damage.

In relation to the children's population, the health risk groups, with the maximum HQ value, should have a great priority, because there is evidence that children may be more susceptible to Hg toxicity because of increased absorption and retention of Hg and the high sensitivity of their developing nervous system. In addition, some children are hypersensitive to mercury exposure.

In Alta Floresta during the dry season we observed a high incidence of respiratory diseases. However, this can also be associated with the period of biomass burning, when the levels of particulate material increases to 25 times higher than that during the rainy season. Nevertheless, it is difficult to determine whether effects observed in the exposed population are directly attributable to Hg exposure due to the presence of multiple confounding variables, such as malnutrition, parasitic, infectious and endemic diseases (malaria), poor health care and lack of information on Hg intoxication among local doctors. The difficulties are associated with the non- specific nature of individual symptoms, and the lack of a clear diagnostic criteria for low-dose Hg intoxication.

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