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Mercury exposure through fish consumption in the urban area of Alta Floresta in the Amazon Basin

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Abstract

This work addresses the mercury exposure scenarios through fish consumption in the urban area of Alta Floresta, by comparing the different patterns of mercury exposure from fish ingestion for different population groups. This study was based on field surveys that could provide background information, such as the characteristics of Hg sources, characteristics of local and regional environment, Hg concentrations in different media, and the characterization of the local urban population. The urban area of Alta Floresta is one of the most important gold-trading centers in Amazonia, where approximately 1 ton of gold has been commercialized monthly. The general adult urban population is exposed to low-level mercury concentration via fish consumption with an average daily intake of 0.2 μg/kg (b.w.) and an estimated hazard quotient of 0.7. However, the fishermen families present an average daily intake of 2.2 μg/kg (b.w.) and a hazard quotient of 8.6. The children of fishermen families between 5 and 14 years old are the main risk group for Hg exposure via fish ingestion. Based on the uncertainty analysis, the Hg fish concentrations and the fish ingestion rate were found to be the main parameters affecting the variability of the model outputs.

Keywords: mercury; gold mining; exposure; fish consumption; risk assessment

1. Introduction

The gold rush in the early 80's in the Amazon Basin still has an unpredictable consequence for the environment and for the population directly exposed to mercury pollution. From existing data, it is known that high levels of mercury in fish present a serious health risk to the local population, especially to those living in riverside communities. Metallic mercury in the *garimpos* is used to amalgamate particulate gold. During the amalgamation process, a significant amount of metallic mercury finds its way into the surrounding water, soil and air. Once in the environment Hg^0 is oxidized to Hg^{2+}, which is then subjected to organic transformation and bioaccumulation into the aquatic food chain, of which humans are a top predator. In Amazonia, the population is exposed to organic and inorganic compounds via different pathways, resulting in different levels of exposure. These two forms of mercury, organic and inorganic,

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have some common properties but differ in toxicity and metabolic behavior. In Amazonia, some studies have shown that enhanced biotransformation of inorganic Hg compounds into organic Hg is occurring. Recent findings indicate that high methyl-mercury levels in carnivorous fish account for 85% to 100% of their total Hg in the amazonian aquatic environment (Agaki et al., 1993; Limaverde, 1996).

The way people are exposed to Hg depends on several other factors such as the levels of contamination in the environmental compartments, the existence of potential pathways for human exposure, the size, nature and habits of the community, and frequency and duration of the exposure. In the early 70's, a great amount of people came from the south of Brazil to different areas of the Amazon Basin. Consequently, a great number of people with different cultures and social characteristics were spread in Amazonia. This fact is important to understand why Alta Floresta has different levels of exposure in relation to other *garimpos* areas. Alta Floresta, has no riverside population. The average fish consumption for the general population in Alta Floresta is low when compared with the Amazon riverside population. However, the average concentration of total Hg in carnivorous fish are high compared with fish of others trophic levels. The fish resources to the urban area of Alta Floresta come mainly from Teles Pires River, which had a very intensive gold mining activity in the 80's. The species from this river account for almost 80% of the total species consumed by general population. This results in a high Hg level in fish consumed locally, ranging from 0.5 to 3.6 mg/kg (w.w.).

This study of exposure assessment for mercury was carried out in one of the most important gold-trading centers in Amazonia. Alta Floresta is a municipality in the state of Mato Grosso in the Amazon Basin. The urban area has a population about 46000. Despite the fact that gold-trading plays an important role in the local economy, Alta Floresta is similar to many other Amazonian areas, with very poor sanitary conditions and a high incidence of diseases such as malaria, hepatitis, tuberculosis, verminosis, which are characteristic of the underdeveloped regions with a very low average income. The paper intends to evaluate the Hg scenarios of exposure through fish consumption in the urban area of Alta Floresta.

2. Study area and methods

The area of Alta Floresta in the Northern part of Mato Grosso state is presented in Fig. 1. Its climate is typical of the Amazon Basin, hot, humid and tropical with temperatures ranging from 23 to 37°C, with heavy rainfall during the wet season (CETEM, 1992). The region started to be occupied in the 70's by the colonization project which had as aim to develop a large scale agricultural project. However, the "gold rush" in the early 80's in the Amazon Basin transformed the original social-economic project for the region completely. Since then, Alta Floresta became an important gold trade center for the Amazon region. About 25 tons of gold were purified and commercialized annually in Alta Floresta. This urban activity implied an average urban atmospheric emission factor ranging from 0.5 and 2.5 tons of Hg per year, until 1993 (Hacon et al., 1995). Since then, the gold trade started to reduce. However, the environmental effects of release of Hg will depend not only on the total Hg discharge, but also the Hg dispersal mechanisms and fate.

About 70% of the urban population of Alta Floresta come from the south of Brazil, with social and cultural habits very different from the indigenous

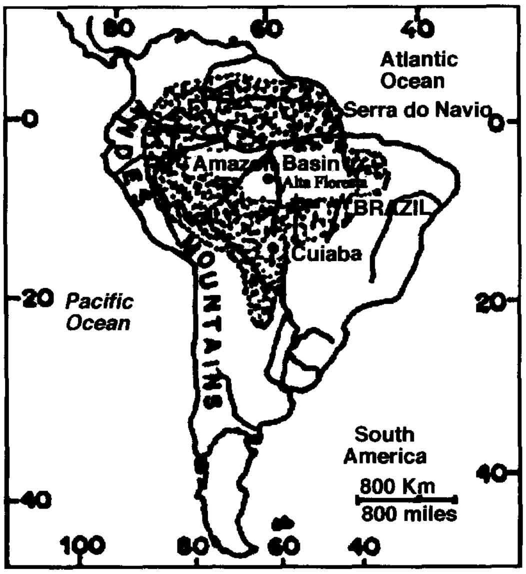

Fig. 1. Map of South America with the Location of the Amazon Basin and the urban area of Alta Floresta.

Amazonian population. About 42% of the population is aged between 15 and 34 (IBGE, 1991). The assessment of the exposure for the urban population of Alta Floresta was carried out through field surveys that could provide background information, such as the characteristics of Hg sources, characteristics of local and regional environment, Hg concentrations in different media, and the characterization of the local urban population. The last one was obtained by interviewing 150 people through questionnaires in order to obtain data on general identification, occupational activities, life conditions, habits and nature of the local population, with specific emphasis on fish preferences and consumption.

Mercury concentrations were measured in fish from local fish markets and from the Teles Pires, São João, and Cirstalino rivers in the surroundings of Alta Floresta. All fish were collected during the dry season (July to September) of 1993, and the samples were measured and weighted, and immediately frozen. A wide variety of carnivorous fish are eaten by local population, depending on the season.

The determination of total Hg in fish was performed by cold vapor atomic absorption spectrometry (CVAAS) after wet digestion (Campos and Curtis, 1990). Analytical quality was assured by many measures, such as a strick blank control (at least 3 blanks for a batch of 10 samples), duplicate analysis and the analysis of certificate reference materials. Table 1 presents some of the results. Also, the reproductivity of the analytical methodology was checked by the analysis of the same fish muscle. This test was performed in order to verify the representativity of the use of a 0.5 g aliquot to represent the concentration of the whole muscle. The variation founded (variation coefficient vc = 4.6.%) is recognized as a good reference.

Table 1
Results of the analysis of certificate materials

Certificate material	Reference value (μg/g)	Found values [c] (μg/g)
Albacore Tuna, NIST SRM 50	(0.95) [a]	0.91 ± 0.04
DORM 1, NRC	0.798 ± 0.074	0.796 ± 0.026
TONO [b]	0.45 ± 0.07	0.39 ± 0.02
Copepode homogenate (IAEA)	(0.28)	0.25 ± 0.02

[a] According to Bye and Paus (1979).
[b] Bortolli (1990).
[c] $n = 5$.

The Hg intake is estimated by the general equations for assessment of chronic exposure for ingestion (USEPA, 1989b):

$$I_{ing}\ (\mathrm{mg/(kg \cdot d)}) = \frac{FC \cdot IR}{BW} \quad (1)$$

where FC = fish Hg concentration (mg/kg), IR = fish ingestion rate (kg_{fish}/meal), and BW = body weight (kg).

Potential hazard is evaluated using the hazard quotient (HQ), a dimensionless quantity:

$$HQ_{ing} = \frac{I_{ing}}{RfD} \quad (2)$$

where I is defined in Eq. (1), and RfD is the chronic reference dose (RfD), that is an estimate of a daily exposure level for the human population, including sensitive groups of the population, which is likely to be without an appreciable risk of adverse effects during a lifetime. If the intake level exceeds the present RfD, there is a concern for potential adverse effects. The reference dose for chronic oral intake is 0.3 μg/kg b.w. (USEPA, 1989a; Stern, 1993; IRIS, 1993). Probabilistic calculations were performed using an uncertainty analysis code with a Monte Carlo simulation (Decisioneering, 1993). The Latin Hypercube Sampling method was used with 1000 simulation and the parameters that could contribute significantly to the uncertainty in the final model results were also identified. (Gardner, 1988; Rochedo, 1994).

3. Results and discussion

3.1. Exposure scenarios

Mercury levels in fish eaten by the urban population are high, especially for carnivorous fishes, that make up 95% of all locally eaten fish. Table 2 shows the species most consumed by the local population, the consumption rate, the average fish Hg concentration (mg/kg), and the weighted Hg average (mg/kg). The highest Hg concentrations are found in *Brachyplastystoma* spp. (Piraiba), which accounts for 29% of local consumption. The most consumed species is the *Paulicea Lutkeni* (Jau), accounting for about 33%. The carnivorous species that have a Hg level greater than 0.5 mg/kg make up 80% of the total consumption (Hacon et al., 1993). The fish preferences and rate of consumption of the population depend on the habits, the income level, and the cultural characteristics of the population.

The exposure scenarios of Alta Floresta, include different exposure pathways for the adults and children population, of both sexes. Although we know that Alta Floresta is not a fishermen village, we found important to include the fishermen group, even if they are a small group, because we can then compare their exposure to that of some riverside communities and with that of the urban general population.

This paper addresses only the simulation for the scenario of the exposure through fish consumption in the urban area of Alta Floresta. We have identified different exposure groups for this scenario. The groups were characterized in function of their feeding habits, mainly the fish consumption rate, and their members' activities and age. In Alta Floresta the groups simulated are the following: the general population, with three groups: one of adults and two of children, and two fishermen groups: one which includes the fishermen and their wives, and one which includes their children:

group 1 — adult general population ($n = 99$)
group 2 — children of general population from 5 to 14 years old ($n = 72$)
group 3 — adult fishermen group ($n = 12$)
group 4 — children of fishermen families from 5 to 14 years old ($n = 8$)
group 5 — children from general population under 5 years old ($n = 60$)

The daily intake of Hg for the urban population was estimated assuming a weighted average fish concentration of 1.3 mg/kg. In the present study it was assumed that all Hg in fish occurs as methyl-Hg (Agaki et al., 1993; Limaverde, 1996) with an absorption of 100% by the human body. We observed that 10% of the population interviewed does not eat any type of fish. For the rest of the population, fish consumption ranged from 5 up to 180 g/d. This variation is caused mainly by differences in eating habits and age. The fisherman (group 3) are the group with the highest fish ingestion rates (110 g/d on average). Group 4 presented an average rate ingestion of the 80 g/d. The average consumption for the general adult group studied (group 1) is about 8 g/d. The children general group (group 2) have 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 average for the fisherman offspring under 5 years old and children from the general population (group 5). The ingestion rate for the whole group under 5 years old (group 5) was also 5 g/d.

3.2. Exposure assessment

The values of the parameters used in the modeling of exposure assessment are presented in Table 3.

Table 2
Mercury levels in fish consumed by the urban population in Alta Floresta, Amazon Basin. Total Hg in mg/kg (w.w.)

Fish species	Regional name	n	Consumption rate (%)	Average concentration	Standard deviation	Weighted average
Brachyplatystoma spp.	piraíba	7	29.30	2.75	0.62	0.80
Paulicea lutkeni	jaú	12	33.25	1.00	0.66	0.33
Piasgioscion spp.	pescada	4	1.36	0.77	0.17	0.01
Pseudoplatystoma fasciatum	pintado	21	14.30	0.60	0.63	0.09
Brachyplatystoma flavicans	dourada	6	3.86	0.53	0.29	0.02
not known	jiripoca	4	0.45	0.38	0.21	0.01
Hoplias malabaricus	traíra	8	6.81	0.36	0.14	0.03
Serrsalmus spp.	piranha	12	3.86	0.29	0.12	0.01
Cichla ocellarie	tucunaré	11	4.77	0.28	0.11	0.01
Mylossoma spp	pacú	13	1.36	0.08	0.06	0.01
Prochilodus nigricans	curimata	5	0.68	0.08	0.038	0.01

n = number of samples.

Table 3
Range of variation and distribution type for each parameter in the intake equation

Parameter	Unit	Average	Minimum	Maximum	Type of distribution
Hg concentration	mg/kg	1.3	0.0004	3.58	lognormal
fish ingestion group 1	kg/d	0.008	0.003	0.11	lognormal
fish ingestion group 2	kg/d	0.005	0.003	0.05	lognormal
fish ingestion group 3	kg/d	0.110	0.040	0.18	lognormal
fish ingestion group 4	kg/d	0.080	0.040	0.155	lognormal
fish ingestion group 5	kg/d	0.005	0.01	0.05	lognormal
adult (b.w.)	kg	58	42	86	triangular
4 to 15 yrs old (b.w.)	kg	32	18	40	triangular
1 to 4 yrs old (b.w.)	kg	15	10	30	triangular
RfD-Hg	μg/kg · d	0.3	0.1	0.5	triangular

Table 4 shows the results for the intake and the Hazard Quotient (HQ) for fish ingestion for all groups studied in Alta Floresta. One observes that the dose value for the group 3 (adult fishermen), is eleven times higher than that of the group 1, related to the general adult urban population. Based on average estimate of HQ (0.2), the adult population (group 1) as a whole would be unlikely to experience adverse health effects due to this exposure pathway. However, the maximum HQ value for this group shows that the individuals with the maximum ingestion rate value 0.11 kg/d (Table 3), should be carefully investigated. The adults fishermen presented an average daily intake of 2.2 μg/kg, which is 7.5 times higher than the reference dose from EPA (0.3 μg/kg · d) (IRIS, 1993). The maximum value for HQ, 76.5, indicates a great concern in relation to these exposed individuals. Despite the fact that the urban population of Alta Floresta on the average, does not eat much fish as compared with amazonian riverside communities, whose average ingestion rate is estimated to be up to 200 g per day (Boischio and Barbosa, 1993), special concern should be given to the critical groups, such as women of childbearing age because the fetus is well-known to be very sensitive to methyl-mercury concentrations.

Table 4 also shows the results of the intake and the hazard Quotient (HQ) for the population groups under 15 years old. Comparing the 3 groups studied in the urban area of Alta Floresta, the highest intake value, 3.5 μg/kg · d, for this exposure pathway, is for the group 4, the children of the fishermen families, from 5 to 14 years old, This intake value is about 12 times higher than the reference dose, and about 18 times higher than the dose estimated for the same age group related to the general population. The average HQ value for group 4 is 8.8, which suggests that the most sensitive people may presenting subclinical effects. However, the evidence of this exposure can be difficult to be detected due to the great number of diseases usual in this region, such as malaria. On the other hand, the maximum HQ value

Table 4
Results of the exposure assessment for the urban population groups. Exposure by ingestion of fish

Group	Dose	Risk quotient				
	(μg/kg)2	average	deviation	min.	max.	distrib.
adult — general	0.2	0.7	1.2	0.01	18.3	ln [a]
adult — fishermen	2.2	8.6	8.5	0.64	76.5	ln
children 1–4 years	0.5	1.4	0.6	0.12	9.2	ln
children 5–14 years	0.2	0.9	0.7	0.07	6.2	ln
children of fishermen 5–14 years	3.5	8.8	8.7	0.5	75.0	ln

[a] lognormal.

(75), represents a threat for these young exposed. This group is at risk of adverse health effects, as a result of exposure to Hg in the fish they eat. Given the fact that the urban population have been subjected to Hg exposure for more than 8 years, part of this group most probably has been exposed prenatally and perinatal. This means that they may be already adversely affected. This group, as a whole, should be better investigated, in relation to their fish consumption habits and their Hg levels in hair and blood. They also should be evaluated in terms of clinical and neurological exams, psychological and behavioral tests, which may characterize mild effects.

For group 5, children between 1 and 4 years old, the average intake value is 0.5 μg/kg · d. This group presents a low fish ingestion rate (5 g/d). However, it is exposed at the same levels of Hg in fish (1.3 mg/kg) as the adults. So, taking into account their average body weight of 15 kg, one has to realize that this internal dose is higher than the adults. Based on average estimate of HQ (1.4) from Table 4, it would be unlikely for this group to experience adverse health effects due to this exposure pathway. However, the maximum HQ value, shows that some individuals of this group may have higher Hg ingestion rate due to fish consumption.

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 research studies on since a better knowledge of actual values will lead to a reduction of uncertainty of risk estimates (Rochedo, 1994). The uncertainties of the exposure scenarios are due to different factors, as the variety of fish species consumed depends the season of the year. Our study was carried out during the dry season, when the variety of the fish species is

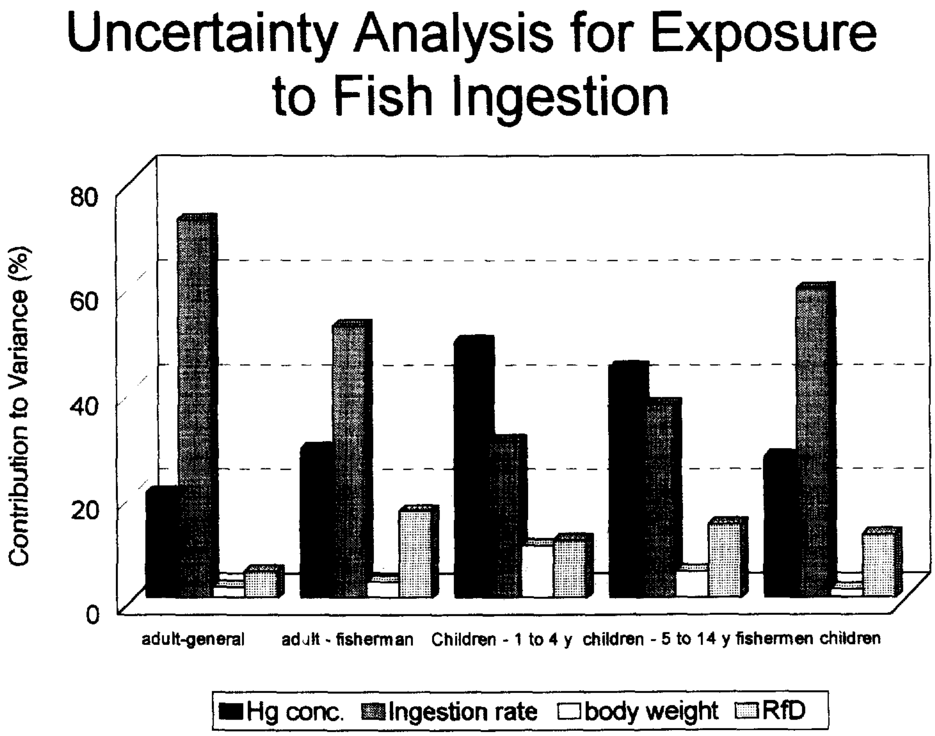

Fig. 2. Uncertainty analysis for exposure due to fish ingestion.

less than in the rain season. This fact can reduce the fish ingestion during this period. One has to realize that the seasonality of the region is a important point. Also, the migration of people from the *garimpos* area to the urban area, during the rain season, brings some effects on the habits and the activities of the local population. The sensitivity chart (Fig. 2) shows the contribution to the variance, for each parameter of Eqs. (1) and (2), for the hazard quotient. For both scenarios and for adult and children populations, the main contribution to the variance were the variability of the ingestion rate (IR) and the Hg concentration in fish (CF). These are the parameters with the greatest effect on the variability of the model. Most of this uncertainty is unavoidable as it reflects the different fish species available and consumption habits of the population.

4. Conclusions

The results presented in this paper allow to indicate that the general adult and children population is exposed to low levels of Hg exposure through the fish ingestion pathway. However, 80% of the carnivorous fish consumed by the population have Hg levels above 0.5 mg/kg. This study shown that the colonization process as well as the cultural and social characteristics of the population, are the main reason for the low fish ingestion rate of the urban population. We can affirm that the general urban population, does not face a significant health effects from this pathway exposure. However, the fishermen and their families, including the children, have shown to be the concerning risk groups. These groups with high fish consumption and high intake values, specially the ones with the maximum HQ values may be adversely affected, with some mild symptoms, which may be difficult to distinguish from similar symptoms caused by endemic disease, such as malaria.

The use of the quantitative uncertainty analysis allowed the determination to which parameters one must focus research studies on since a better knowledge of actual values will lead to a reduction of the uncertainty of risk estimates. For the population as a whole, uncertainties would be reduced by studies on parameters associated to the ingestion rate of fish, although a large part of the uncertainty on exposure assessment for populations is unavoidable, as it comprises differences among individuals and their habits and uses of the environment. For the fish-eating groups the local health regulatory body should advise the local population on which fish are safest to eat, according to the season of the year.

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