Revista Brasileira de Enfermagem
REBEn
SUPPLEMENTARY EDITION 5
THE EVOLUTION OF NURSING IN THE 200 YEARS OF FLORENCE NIGHTINGALE
ORIGINAL ARTICLE

Prevalence and factors associated with mercury exposure in riverside communities in the Brazilian Western Amazon

Prevalência e fatores associados à exposição ao mercúrio em comunidades ribeirinhas na Amazônia Ocidental Brasileira

Prevalencia y factores asociados a la exposición al mercurio en las comunidades de ribeirina en la Amazonía occidental brasileña

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How to cite this article:
Mendes VAM, Santos DAS, Farias ES, Carvalho DP, Bastos WR. Prevalence and factors associated with mercury exposure in riverside communities in the Brazilian Western Amazon. Rev Bras Enferm. 2020;73(Suppl 5):e20200100. doi: http://dx.doi.org/10.1590/0034-7167-2020-0100

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Submission: 04-07-2020 **Approval:** 06-19-2020

ABSTRACT

Objective: to verify mercury exposure prevalence and identify its possible associated factors in two riverside communities in the Madeira River basin of the Western Brazilian Amazon. **Method:** a cross-sectional study comprising 95 children and adolescents. Age cycle, school attendance, Bolsa Família, number of siblings, meals, fish consumption, height by age were measured. Binary logistic regression was used to verify relationships between mercury exposure and its possible associated factors. **Results:** the general prevalence of mercury exposure was 46.3%; children, 35.4%; and adolescents, 57.4%. Associated factors were fish consumption ($_{a}$OR=1.84; $_{95\%}$CI 1.56-2.16), age cycle ($_{a}$OR=2.50; $_{95\%}$CI 1.09-5.7), parasites ($_{a}$OR=1.22; $_{95\%}$CI 1.02-2.71), and short stature ($_{a}$OR=1.32; $_{95\%}$CI 1.05-2.02). **Conclusion:** mercury exposure prevalence in riverside children and adolescents was considered worrying, with association with fish consumption, adolescence, parasites, and short stature.
Descriptors: Child; Adolescent; Heavy Metal; Risk Factors; Environmental Exposure.

RESUMO

Objetivo: verificar a prevalência da exposição ao mercúrio e identificar seus possíveis fatores associados em duas comunidades ribeirinhas da bacia do Rio Madeira da Amazônia Ocidental Brasileira. **Método:** estudo transversal composto por 95 crianças e adolescentes. Foram mensuradas as seguintes variáveis: ciclo de idade, frequência à escola, Bolsa Família, número de irmãos, refeições, consumo de peixe, estatura por idade. A regressão logística binária foi utilizada para verificar relações entre a exposição ao mercúrio e seus possíveis fatores associados. **Resultados:** a prevalência geral de exposição ao mercúrio foi de 46,3%; para crianças, 35,4%; para adolescentes, 57,4%. Os fatores associados foram consumo de peixe (OR_{a}=1,84; $IC_{95\%}$ 1,56-2,16), ciclo de idade (OR_{a}=2,50; $IC_{95\%}$ 1,09-5,7), presença de parasitas (OR_{a}=1,22; $IC_{95\%}$ 1,02-2,71) e baixa estatura (OR_{a}=1,32; $IC_{95\%}$ 1,05-2,02). **Conclusão:** a prevalência de exposição ao mercúrio em crianças e adolescentes ribeirinhos foi considerada preocupante, com associação ao consumo de peixe, adolescência, ter parasita e baixa estatura.
Descritores: Crianças; Adolescentes; Mercúrio; Fatores de Risco; Exposição Ambiental.

RESUMEN

Objetivo: verificar la prevalencia de exposición al mercurio e identificar sus posibles factores asociados en dos comunidades ribereñas en la cuenca del Río Madeira en la Amazonía occidental de Brasil. **Método:** estudio transversal compuesto por 95 niños y adolescentes. Se midieron las siguientes variables: ciclo de edad, asistencia a la escuela, Bolsa Família, número de hermanos, comidas, consumo de pescado, talla por edad. La regresión logística binaria se utilizó para verificar las relaciones entre la exposición al mercurio y sus posibles factores asociados. **Resultados:** la prevalencia general de exposición al mercurio fue del 46,3%; para niños, 35,4%; para adolescentes, 57.4%. Los factores asociados fueron consumo de pescado (OR_{a}=1.84; $IC_{95\%}$ 1.56-2.16), ciclo de edad (OR_{a}=2.50; $IC_{95\%}$ 1.09-5.7), presencia de parásitos (OR_{a}=1.22; $IC_{95\%}$ 1.02-2.71) y baja estatura (OR_{a}=1.32; $IC_{95\%}$ 1.05-2.02). **Conclusión:** la prevalencia de exposición al mercurio en niños y adolescentes ribereños se consideró preocupante, con una asociación con el consumo de pescado, la adolescencia, los parásitos y la baja estatura.
Descriptores: Niños; Adolescentes; Mercurio; Factores de Riesgo; Expossición a Riesgos Ambientales.

INTRODUCTION

Mercury (Hg) in the Amazon region has been recognized since the 1980s, when gold mining had its activities intensified[1-2]. Several studies[3-4] also point out that disordered use and occupation of Amazonian soil, in addition to deforestation and fires, has contributed to the release of Hg to aquatic ecosystems.

Upon entering the waters of the great Amazonian rivers, its chemical form is changed from inorganic to organic, Hg to MeHg (methylmercury)[5]. This process is called methylation and occurs gradually promoted by photochemical action and, mainly, by the action of anaerobic microorganisms[6]. Due to its lipophilic characteristics, MeHg tends to bioaccumulate and biomagnify in the muscle tissue of fish along the food chain[3].

This makes eating fish the primary means of human contamination for the most toxic chemical form of mercury. (MeHg)[7-9]. Approximately 95% of MeHg is absorbed by the gastrointestinal tract, with the ability to overcome blood-brain and placental barriers, which can cause irreversible damage to development[10]. Its toxicology with main characteristic in damages to the central nervous system has been well reported in the international scientific literature.

Several studies[11-15] have assessed human exposure to Hg to riverside communities in the Amazon region. These communities have a direct relationship between distance between cities and fish consumption, since fish is their main source of protein[7,12]. Riverside communities of important tributaries of the Amazon River (*Negro*, *Tapajós*, and *Madeira* rivers) have high concentrations of mercury, becoming the most exposed worldwide. Geographic isolation and low family income are prominent features in mercury concentrations in these areas[6,15].

Average Hg concentrations higher than those recommended by the Pan American Health Organization (PAHO) were found, limited to 7.0 $mg.g^{-1}$, when quantifying hair samples[16]. There are cases that exceed PAHO's limit value by more than 10 times[9].

Exposure has been an object of concern due to risks of manifesting this toxicity in these populations, especially vulnerable groups such as children and women of childbearing age[14]. Above all, it is well known that long-term exposure to MeHg can cause problems in motor development, visual dysfunction and oxidative stress[9,15].

Therefore, it is important to develop research, with different methodological approaches, to assess exposure levels and metabolic changes and to elucidate their possible associated factors. Studies with this bias should aggregate laboratory and sociodemographic information, to relate different variables that allow proxy indicators to contribute to a better understanding of exposure and its effects on health.

This study is relevant for addressing regional peculiarities such as geographic isolation; high fish consumption; low family income; lack of information; lack of basic sanitation; and restricted access to health services[17]. Such peculiarities provide important epidemiological information to monitor and assess exposure to Hg and the potential effects of its toxicology on those from riverside groups. Therefore, public health agencies should be informed about the lifestyle of communities in the Lower *Madeira* River and provided with data on mercury exposure, to encourage discussion with health authorities regarding implementing health surveillance strategies for the Amazonian population.

OBJECTIVE

To verify mercury exposure prevalence and identify its possible associated factors in two riverside communities in the *Madeira* River basin of the Western Brazilian Amazon.

METHODS

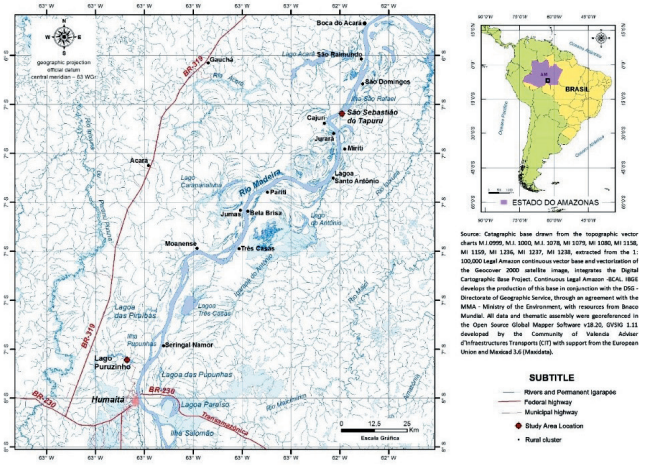
Ethical aspects

This study was submitted and approved by the Research Ethics Committee of *Universidade Federal de Rondônia*. Before data collection and samples, all individuals who agreed to participate in the research signed the Informed Consent Form (ICF). It was necessary for mothers to sign to agree authorizing their children to participate. For individuals aged> 12 to <18 years, it was necessary to sign an ICF for minors. Participants were approached and guided about the research objectives, with a balance of benefits and harms.

Design, period, and place of study

This is a cross-sectional study, not probabilistic for convenience, based on STROBE. It was carried out in two riverside communities in the *Madeira* River basin in the state of Amazonas, *Puruzinho* Lake and *São Sebastião do Tapurú* (AM) from April to August 2017. The choice for these areas took into account high concentrations of mercury in the hair of riverside residents in studies carried out in the region[12-13].

Puruzinho Lake is considered a semi-isolated community located 13 km downstream from the municipality of Humaitá, AM, about 40 minutes by motorboat. As it is closer to the urban area, residents have greater access to goods and services. Moreover, all families, except one, have electricity.



Source: Laboratory *of* Environmental Biogeochemistry Wolfgang Christian Pfeiffer*/UNIR.*
Figure 1 - Study area showing the riverside locations of *Puruzinho* and *Tapurú* in the Lower *Madeira* River, Amazônia, Brazil: *São Sebastião do Tapurú* - latitude 6° 31'53,54" S longitude 62° 19'35,61" W; and *Lago do Puruzinho latitude* - 7° 22'14,31" S and longitude 63 ° 03'32,71" W

The community of *São Sebastião do Tapurú* is an isolated community because it is about 120 km from the urban area, and boat is the only possible means of transportation, approximately 12 hours. Fisheries and agriculture (banana and cassava

plantation) are resources for the income and subsistence of the riverside diet. Some residents work on gold mining dredges, in the region's low water period that occurs between August and October. Electricity in homes is provided by generators, but not all families own the equipment.

Population; inclusion and exclusion criteria

The population of these two communities comprised approximately 250 people, including adults and children. This study included children aged two to nine years old and adolescents aged 10 to 19 years old[18]. The sample consisted of 95 participants, 48 children and 47 adolescents, of whom 32 lived in *Puruzinho* Lake and 63 in *São Sebastião do Tapurú*. Participation was voluntary with signature of the ICF by guardians as well as the ICF for minors by adolescents. Children and adolescents who do not live in the communities visited were excluded.

Study protocol

Data collection was carried out where riverside residents lived using a form that included open and closed questions prepared by the researchers regarding demographic, socioeconomic, and food consumption aspects.

The biological sample was collected by having their hair cut by the researcher trained, with contamination-free stainless scissors, in the occipital region close to the scalp. All samples were grouped and placed in a labeled envelope and taken to *Laboratory* of *Environmental Biogeochemistry Wolfgang Christian Pfeiffer*. Subsequently, they were washed with EDTA (0.01%), dried overnight at 50 °C, (dry weight 0.035g) and digested with 5 mL of HNO_3/H_2SO_4 (1:1) and 4 mL of 5% $KMnO_4$. Digestion happened at 70°C for 40 minutes. The determination of total Hg in the digested samples was performed according to Bastos et al.[18-19], followed by the reduction of elemental Hg vapor determined by the cold vapor atomic absorption spectrometry system, with flow injection system (FIMS CVAAS). Precision and accuracy of Hg determinations were ensured by using samples in duplicates of certified reference material (International Agency Energy Atomic IAEA - 086), with recoveries of 107%. The risk assessment for mercury exposure followed PAHO guidelines[20] on human exposure (< 7.0 $mg.kg^{-1}$).

Assessing intestinal parasitosis was performed by means of feces samples collected in sterilized bottles, transported in a timely manner and kept in a refrigerated container at the accredited clinical analysis laboratory, Labiomed, Porto Velho, RO. Classification was made in a qualitative way considering the presence of eggs or parasites, regardless of the quantity.

Children and adolescents were assessed by weight and body height. Weight was measured using a portable electronic scale, with a maximum capacity of 150 kg and precision of 0.1 kg, model JGS 22, brand Bleurer® (Germany). Height was measured with an anthropometer, Indaiá®, with 0.1 cm precision and mandatory measurement in the supine position for children aged <24 months. To measure the height of children aged 24 months and older, a portable anthropometer of Altura Exata® was used, with an accuracy of 0.1 cm.

Based on the measures of weight and body height, calculation of body mass index/age (BMI)=weight (kg)/m^2 was determined. To classify the nutritional status of children and adolescents, z score was used, with the aid of the ANTHRO program (WHO Anthro, Geneva, Switzerland) for children under 5 years old and ANTHRO PLUS for individuals aged 5 to 19 years. The cutoff points of z score, corresponding to BMI-for-age, were classified according to risk for underweight (<z score - 1); eutrophy (> z score=-1 and <z score=+1); risk for overweight (> z score=+1 and <z score=+2). Height/age was classified as risk for short stature (<z score - 1); adequate height (> z score=-1 and <z score=+2), recommended by the WHO[21].

The variables related to the predisposing factors were sex (male and female); age (children from two to nine years old, adolescents from 10 to 19 years old[18]); number of siblings (less than or equal to two and greater than two siblings); school attendance (yes or no); participation in *Bolsa Família* (benefited or not benefited); fish consumption (less than twice a week and greater than or equal to twice a week); number of meals per day (less than three and more or equal to three meals); intestinal parasites (absence or presence); height for age (risk for short stature or adequate height); and BMI (risk for underweight, adequate weight, and overweight)[21].

Analysis of results, and statistics

Data entry was performed in the Excel program. Subsequently, they were transferred to the IBM SPSS® statistical package, version 20.0 (IBM Corp., Armonk, United States). Associations between independent variables were tested with the Stata MP® statistical package, version 11.0 (StataCorp., College Station, United States). The chi-square test for heterogeneity (categorical variables) and linear trend (ordinal variables) was used to compare mercury exposure prevalence greater than or equal to 7.0 mg.kg-1 between the categories of independent variables. The level of significance was set at 5%. To assess the crude ($_c$OR) and adjusted ($_a$OR) association of mercury exposure (0=no risk and risk=1) with fish consumption and enteroparasitosis, binary regression was used. The significance of the model variables was assessed by the Wald test for heterogeneity and linear trend, when appropriate. To create the multivariable model, variables with a p value <0.20 in crude analysis were considered, all of which were maintained in the final model.

RESULTS

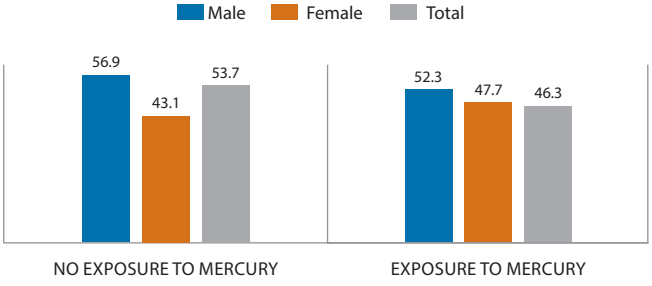
The sample consisted of 95 riverside residents, divided into two groups, with a general average age around 9.96 ± 4.80. The average age for the group of children (n=48, 50.5%) was 6.05 ± 3.09 and for adolescents (n=47, 49.5%), 13.96 ± 2.28.

Figure 2 shows the general prevalence of mercury exposure around 46.3%, with a predominance of children and adolescents belonging to the male sex (52.3%).

Most are children (50.5%), *Tapurú* community residents (66.3%); who attend school (63.2%); benefited from *Bolsa Família* (80.0%); have more than two siblings (55.8%); with consumption greater than or equal to three daily meals (70.5%); fish consumption more than twice a week (87.4%); with no parasites (68.4%); adequate height (56.8%); and adequate BMI (73.7%) (Table 1).

All variables that had the highest prevalence (%) of exposure to contact with mercury were adolescents (57.4%); from the *Puruzinho* community (46.9%); who attended school (46.7%);

benefited from *Bolsa Família* (46.1%); with less than or equal to two siblings (52.4%); consume equal or more than three meals a day (56.7%); fish consumption more than twice a week (47.0 %); with parasites (50.0%); risk for short stature (53.7%); and risk for underweight (50.0%) (Table 1).



Note: p>0.05 chi-square

Figure 2 – Prevalence (%) of mercury exposure with nonexposure of less than 7.0 mg.kg-1 and exposure greater than or equal to 7.0 mg.kg-1 in two riverside communities (*Puruzinho* and *Tapurú*) by sex, located in the Western Brazilian Amazon in the municipality of Humaitá - Amazonas state, Brazil

Table 1 - Prevalence (%) of mercury exposure greater than or equal to 7.0 mg.kg-1 versus the independent variables of two riverside communities (*Puruzinho* and *Tapurú*) located in the Western Brazilian Amazon in the municipality of Humaitá, Amazônia, Brazil

Variables	n (%)	n	%	*p*
Age cycle				0.017*
Children	48 (50.5)	17	35.4	
Adolescents	47 (49.5)	27	57.4	
Communities				0.172*
Puruzinho	32 (33.7)	15	46.9	
Tapurú	63 (66.3)	29	46.0	
School attendance				0.168*
Yes	60 (63.2)	28	46.7	
No	35 (36.8)	16	16.8	
***Bolsa Família				0.201*
Benefited	76 (80.0)	35	46.1	
Not benefited	19 (20.0)	9	9.5	
Siblings				0.049
≤2 siblings	42 (44.2)	22	52.4	
>2 siblings	53 (55.8)	22	41.5	
Meals				0.046*
<3 meals daily	28 (29.5)	13	46.4	
≥3 meals daily	67 (70.5)	38	56.7	
Fish consumption				0.001*
<2 times a week	12 (12.6)	5	41.7	
≥2 times a week	83 (87.4)	39	47.0	
Parasites				0.011*
Absence	65 (68.4)	29	44.6	
Presence	30 (31.6)	15	50.0	
Height/age				0.047*
Risk for short stature	41 (43.2)	22	53.7	
Adequate height	54 (56.8)	22	40.7	
BMI/age				0.387**
Risk for underweight	10 (10.5)	5	50.0	
Adequate	70 (73.7)	33	47.1	
Risk for overweight	15 (15.8)	6	40.0	

*Note: *Chi-square test for heterogeneity; **Chi-square test for linear trend; ***Bolsa Família (family allowance) is a social welfare program of the Brazilian government, part of the Fome Zero network of federal assistance programs.*

In the adjusted analysis, shown in Table 2, they remained positively associated with exposure: adolescents with 1.5% more chance of exposure to Hg (OR=2.50 - $_{95\%}$CI 1.09; 5.75); fish consumption equal or more than twice a week (0.84) (OR=1.84 - $_{95\%}$CI 1.56; 2.16); presence of parasites (0.22) (OR=1.22 - $_{95\%}$CI 1.02; 2.71); and risk for short-height-for-age (0.32) (OR=1.32 - $_{95\%}$CI 1.05; 2.02).

Table 2 - Multiple and adjusted logistic regression for mercury exposure greater than or equal to 7.0 mg.kg-1 and associated factors in children and adolescents from two riverside communities (Puruzinho and Tapurú) in the Western Brazilian Amazon in the municipality of Humaitá, Amazônia, Brazil

Variables	$_{c}$OR	$_{95\%}$CI	*p*	$_{a}$OR	$_{95\%}$CI	*p*
Fish consumption						
<2 times a week	1			1		
≥2 times a week	1.87	1.60–2.19	**<0.001***	1.84	1.56–2.16	**<0.001***
Age cycle						
Children	1			1		
Adolescents	2.46	1.08–5.63	0.033*	2.50	1.09–5.75	0.031*
Parasites						
Absence	1			1		
Presence	1.24	1.04–2.95	0.011*	1.22	1.02–2.71	0.017*
Height/age						
Risk of short stature	1.68	1.09–3.82	0.001*	1.32	1.05–2.02	0.002*

*Note: *Wald test for heterogeneity; **Wald test for linear trend. CI: Confidence Interval.*

DISCUSSION

This study describes the possible factors associated with mercury exposure in children and adolescents in riverside communities in the Brazilian Amazon region. The results show that mercury exposure is a factor of concern in the population studied.

The general prevalence found was 46.3% of mercury concentration above 7.0 mg.kg-1 in human hair, according to PAHO guidelines[20]. This result reveals a public health problem as it exposes this population to risk of mercury poisoning. Geographic isolation and lack of health resources are problems faced by riverside communities in the Amazon region.

The traditional subsistence populations of the Amazon region are described as a unique profile of human mercury exposure, due to high fish consumption (406 g/day)[12]. Despite changes in the economic development of riverside communities[22], with the implementation of government programs such as *Bolsa Família*[23], fish is still the main source of protein for families and the main means of exposure to MeHg for riverside residents[7]. The results indicate that consuming fish more than twice a week is associated ($_{a}$OR=1.84; $_{95\%}$CI: 1.56-2.16) with greater mercury exposure in riverside communities in the Amazon region[14,24].

In the Amazon, natural mercury in the soil is transported to the basins of the region's great rivers. Mercury bioaccumulates in the muscle tissue of fish[23], so that the concentration of methylmercury increases according to the highest position in the food chain[5]. In the study carried out on the *Madeira* River, with 84 species studied, it was found that methylmercury levels were found in high concentrations in carnivorous and piscivorous fish[8]. Therefore, understanding fish consumption in these traditional populations is of great relevance for understanding mercury contamination and its possible adverse health effects[25].

Fish is one of the main subsistence of family consumption. Fish consumption should not be discouraged for the riverside diet[24], but it is suggested to substitute carnivorous fish, with higher concentrations of mercury, for non-carnivorous fish, which have levels of concentrations that cause less damage to health[8].

Eating fish is less of a problem when compared to lack of health care and endemic diseases, characteristics of the Amazon region[24].

Concerning age cycle, adolescents showed a higher prevalence of mercury exposure of 57.4% and Odds Ratio ($_{a}$OR=2.50; $_{95\%}$CI: 1.09-5.75). Hacon et al.[7] organized individuals into three groups, being preschoolers (0 to 5 years old), children (6 to 15 years old), adults of both sexes (> 16 years old). The group of adolescents also presented concentrations higher mercury averages than children.

Perhaps one of the possible explanations is the food transition that has been taking place in the riverside communities of the region[26]. Change in eating habits is more noticeable in children favored by government programs (*Bolsa Família*) that favor acquisition of other types of food[23], decreasing the daily fish consumption. Meanwhile, adolescents are more exposed to fish consumption due to autonomy with their own food, fishing as a means of survival, and greater contact with gold mining areas.

Parasites in riverside communities showed a significant association with mercury exposure around 22%. The result was lower than in the study carried out on riverside residents in Xieng Khouang province, which found a prevalence of 41.2%[27]. The result was greater when compared to national studies carried out in the Northeast, with a prevalence rate of 15.73%[28] and 18% in the South[29].

Enteropathogens in a riverside population in the Amazon is very common. They are commonly associated with factors such as irregular personal hygiene habits, care in preparation and form of food consumption[30], lack of basic sanitation[17]. The transmission of these agents takes place via the oral-fecal route, with food or water contaminated with parasites' eggs and cysts[30]. Such exposure leaves riverside children and adolescents more vulnerable to having serious impairments in cognitive and physical developments[31] due to gastrointestinal disorders of nutrient malabsorption[30].

These factors are highlighted[32] as important so that children do not achieve satisfactory growth, since they live with limited access to health care.

Concerning short stature, riverine youths had a 32% risk for short stature with mercury exposure, classified as serious by the WHO[33]. This result is similar to that found (35.8%) in children under 5 years old in the city of Jordão, state of Acre[34], and much higher than the prevalence (9.6%) found in children under 5 years old in the state of Maranhão[35].

Short stature prevalence in northern Brazil is also higher when compared to the international literature. A study conducted in Jordan[36] found a prevalence of 4.9%. These findings may have been due to a long history of food shortages, lack of prenatal care, inadequate vaccination schedule. Moreover, mothers are typically of short stature and presented ≤146.4 cm, which would explain the short stature of children and adolescents. Furthermore, children are benefited by *Bolsa Família*, which conditions greater attention to immunization, monitoring of children's weight, in addition to subsidizing the purchase of more products for consumption[37].

A study of the lifestyle of riverside communities also describes that there is a family protection network aimed at children, which are prioritized for protein consumption[26].

The significant value of short stature is explained by only 20%. Some studies carried out in the Amazon[32,37] have already investigated the relationship between z scores and mercury concentrations, but there was no significant association between them. Factors were influenced by socioeconomic and maternal and child factors rather than by mercury exposure through fish[32].

The results of this research contribute to monitoring mercury exposure of these isolated communities, which, due to difficulty of access, has important aspects that need to be identified so that building control and prevention strategies are improved for these traditional populations.

Study limitations

The limitations of this research are related to reverse causality because it is a cross-sectional study. The frequency questionnaire applied to mothers on fish consumption demanded that they remember their previous week consumption, which may underestimate or not reflect, in fact, the habit of eating fish.

Contributions to nursing, health, and public policy

Mercury in Amazonian ecosystems is widely discussed in the scientific community. The findings of this study provide support for identifying important characteristics such as lifestyle, food and exposure to contaminants (Hg) at risk to the health of the region's riverside population. Its results are important to identify and implement strategies that can improve health care, prevent poisoning and improve quality of life.

CONCLUSION

Mercury exposure prevalence among children and adolescents in riverside communities was considered a cause for concern (46.3%). Fish consumption greater than or equal to twice a week, being adolescents, presence of parasites and risk for short stature were consolidated as factors associated with mercury exposure.

The associated factors denote the vulnerability and difficulties experienced by riverside communities in the Brazilian Amazon. It is necessary to implement public policies with a focus on socio-environmental sustainability, with control of monitoring the levels of mercury exposure, especially in children and adolescents, respecting their right to remain in their territories with socio-cultural and political autonomy.

PROMOTION

National Council for Scientific and Technological Development.

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