Environmental pollution challenges public health surveillance: the case of mercury exposure and intoxication in Brazil

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Summary

Pollution, causing millions of deaths annually, disproportionally affects low- and middle-income countries (LMICs). Mercury ranks among the three main chemicals of major public health concern, and even low levels can cause cardiovascular and nervous outcomes, with children and indigenous populations being especially vulnerable. Nearly 80% of all emissions in South America originate from the Amazon. Brazil, the fifth-largest contributor to global mercury emissions, exemplifies the challenges faced by LMICs in effectively monitoring and addressing mercury exposure/intoxication. Despite having powerful tools such as SINAN (a digital platform for compulsory disease reporting), and Community Health Agents, data reveals significant underreporting, especially in the Amazon. Furthermore, SINAN has important delays in its update: for instance, 196 cases of Munduruku Indigenous people in 2019 have only been included in 2023. In this Personal View, we outline insightful recommendations to enhance public health surveillance and implement enduring, effective strategies to monitor, report and address mercury exposure/intoxication, focusing on the Brazilian Amazon. Although these recommendations are tailored to the challenges of this country, they hold potential for adaptation by other Amazonian countries facing similar issues (high mercury emissions and the presence of vulnerable populations, among others).

Keywords: Amazon; Mercury; Environmental health; Contamination; Public health; Surveillance; Indigenous people; Methylmercury

Introduction

Pollution is currently the cause of over nine million deaths annually worldwide, equivalent to one in every six global deaths.[1] The impact of this problem is unevenly distributed, with low- and middle-income countries (LMICs) accounting for more than 90% of these deaths. Toxic chemical pollution and ambient air pollution have been identified as the main drivers of this mortality rate.[1] Hence, it is imperative to examine the efforts made by nations in tackling this issue and identify ways to improve existing strategies.

Among the worst global pollutants, mercury has gained attention due to its omnipresence in the environment.[2] It is currently ranked among the top three main chemicals or group of chemicals of major public health concern.[3,4] This metal's impact on global health spurred the establishment of the Minamata Convention on Mercury, an international treaty on environment and health (https://minamataconvention.org/en/about). The treaty came into effect in 2017 and focuses on key actions to globally reduce mercury pollution and their impacts. It proposes to ban new mercury mines, phase out existing ones, reduce mercury use in various products and processes, and implement controls on air, land, and water emissions. The Convention also regulates artisanal and small-scale gold mining and addresses issues related to mercury storage, disposal, contaminated sites, and health concerns.

Mercury is a liquid metal that serves no biological function but finds widespread use in modern-day human activities. Its applications range from dentistry to the production of electrical components such as batteries and switches, as well as industrial compounds including chlorine gas and caustic soda. Nevertheless, the use of mercury carries a significant environmental cost, with thousands of tons of toxic waste being released into the environment each year.[2] According to the United Nations, artisanal and small-scale gold mining is the primary anthropogenic activity

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Portuguese and Spanish versions of this summary are available in the Supplementary Material.

contributing to mercury emissions into the air globally (Figs. 1 and 2). Indonesia, Peru and Brazil are the leading countries responsible for gold mining emissions (Fig. 2).[2] Worryingly, around 80% of all emissions in South America originate from the Amazon, where gold mining is currently a large-scale activity of high impact.[5]

In mining activities, mercury is used to capture small particles of gold, especially when it is in alluvial deposits, such as found in the Amazon. Subsequently, to separate mercury from gold, the mixture is heated until the mercury turns into a gas. During this process, some of the mercury is released into the air as vapour, capable of travelling long distances.[2] Indeed, recent evidence has demonstrated that intact forests accumulate more mercury than gold mining regions because the metal is fixed in the leaves of trees.[6] Therefore, fires and deforestation also contribute to the mobilisation of *legacy mercury* (i.e., mercury emitted from human sources in the past which is still circulating in the biosphere),[2] returning fixed mercury to the air (Fig. 3). Mercury vapour can be partially transformed into inorganic mercury, which falls with the rain, contaminating the soil and water bodies. There, methanogenic bacteria transform inorganic mercury into methylmercury, which can enter and suffer biomagnification through the food chain, ultimately reaching humans (Fig. 3). Even in the absence of mining, anthropogenic alterations of the environment, such as hydroelectric power plants (HPPs), can favour human exposure by creating the conditions for bacteria proliferation and the entry of the metal into the food chain reaching human populations.[7,8]

All mercury forms are toxic to humans and can harm multiple organs, mainly the central nervous system (Fig. 4). Neurological consequences of intoxication can include more than 250 different symptoms,[11,12] however, visual and auditory disorders and those related to motor control—such as tremors, lack of coordination, muscle weakness, lack of balance, limb numbness and paralysis, among others—are usually the most frequently reported.[13] Although chronic mercury intoxication is one of the oldest occupational diseases in humans (described by Pope in 1665), the clinical diagnosis of mercury poisoning was only consolidated in the late 1950s with the outbreak at Minamata Bay (Japan).[14] Thousands of people were exposed through the consumption of contaminated fish after the Chisso

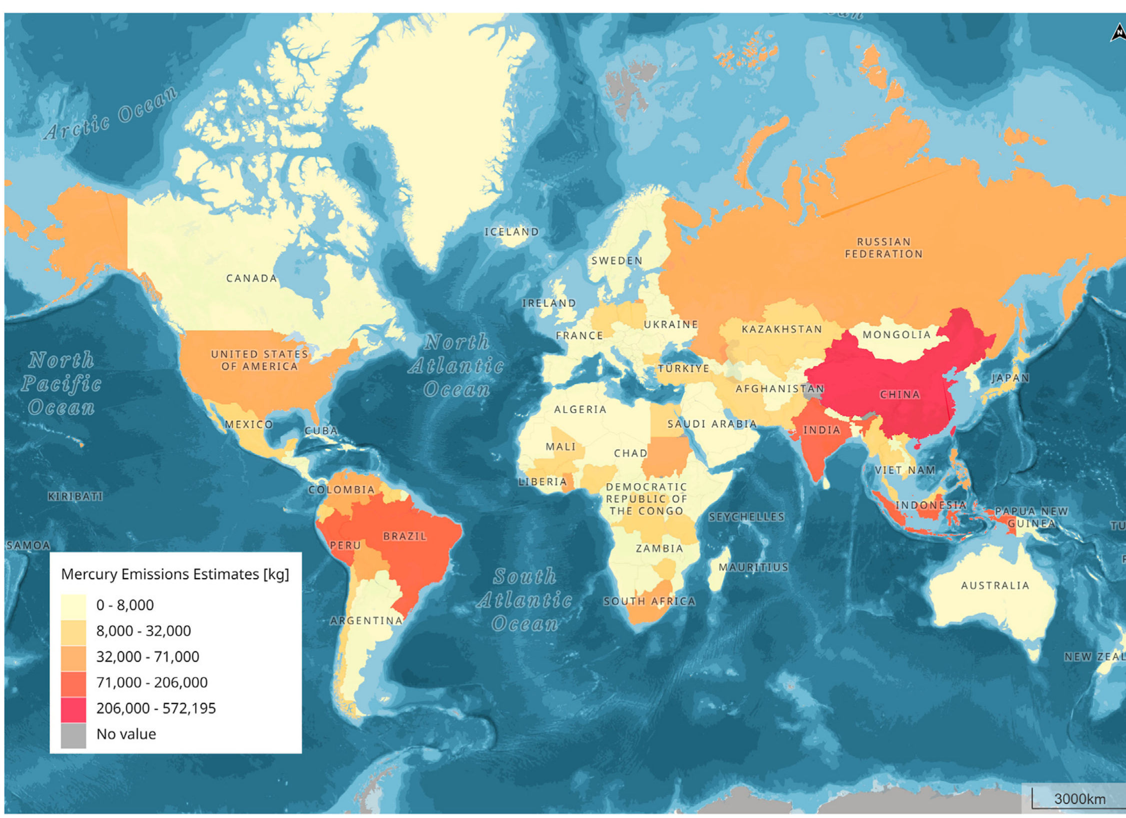

Fig. 1: Mercury emissions (Kg), according to economic sector. Data were estimated by the United Nations Environment Programme (available from: https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-assessment).

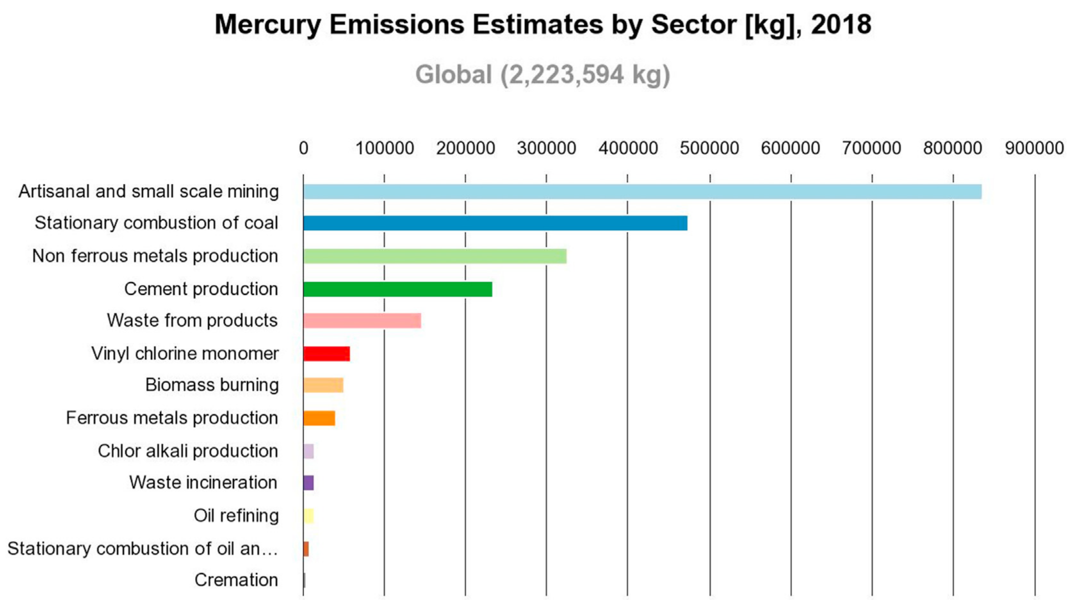

Fig. 2: Mercury emissions (Kg) estimated for each country by the United Nations Environment Programme (available from: https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-assessment). Interactive map in the webpage allows to check that, in the leading countries, the primary activity responsible for these emissions is the gold mining (in Indonesia, Peru, and Brazil) and stationary coal combustion (in China and India).

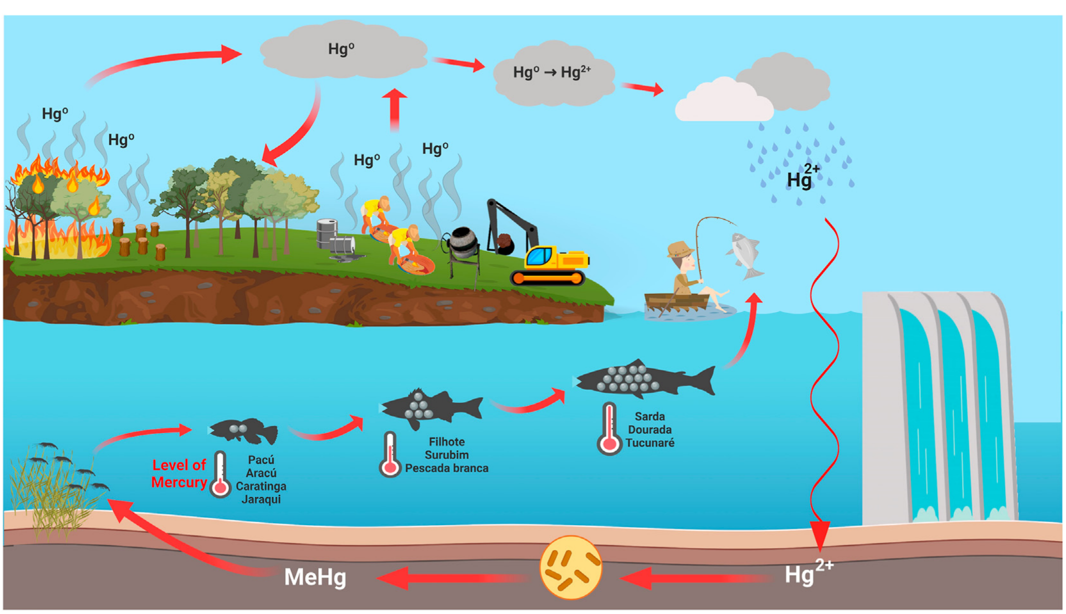

Fig. 3: **Biogeochemical cycle of mercury in the Amazon.** Mercury emissions into the air from gold mining can be partially captured by the leaves of the trees. With deforestation and fires, mercury in leaves is emitted into the air. In the clouds, mercury can be partially transformed into inorganic mercury (Hg^{2+}) that falls with the rain, contaminating rivers and soils. Inorganic mercury can be then methylated by bacteria, producing methylmercury (MeHg), the most toxic species of mercury, which easily enters the food chain. Mercury bioaccumulation and biomagnification throughout the food chain reach the traditional communities, who consume contaminated piscivorous fish (*sarda, dourada, tucunaré,* etc.). Additionally, large-scale projects in the Amazon, such as the hydroelectric power plants, mobilize high quantities of mercury due to two main features: i) producing the physical-chemical conditions that induces bacteria proliferation and, consequently, higher rates of mercury methylation; and ii) closing ecosystems and avoiding the migration of the large Amazonian fish.

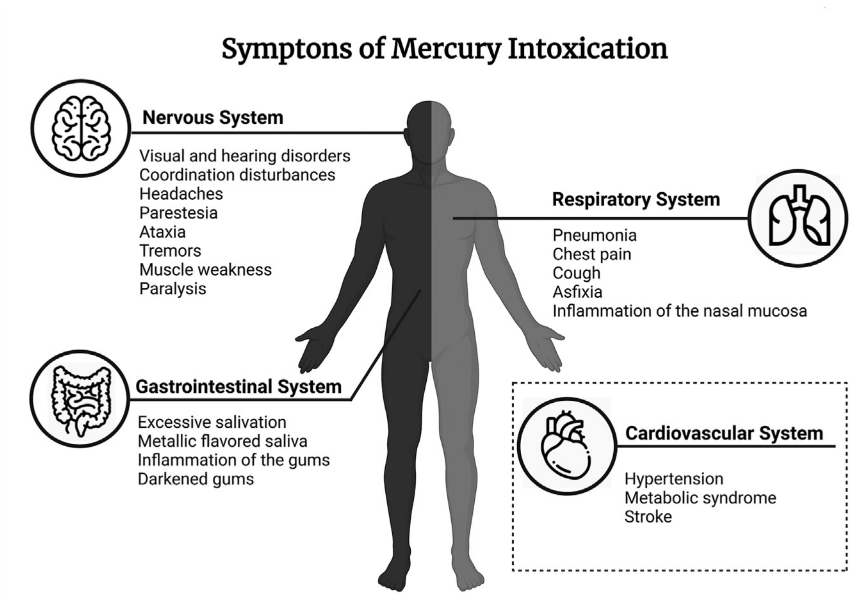

Fig. 4: Some of the main symptoms of mercury intoxication; classical symptomatology has been related to nervous, respiratory, and gastrointestinal systems, among others. However, recent meta-analyses have associated the presence of relatively low levels of mercury with increased risk of cardiovascular outcomes.[9,10] Adapted from Crespo-Lopez et al. (2023).[11]

Corporation had spilled waste into the water. About 900 people died because of mercury contamination and many others remained with sequelae, naming the pathology as Minamata Disease. Especially painful was the high number of children who were born with deformities and neurological diseases because methylmercury can easily cross any biological barrier, including the blood–brain barrier and the placental barrier. In fact, the central nervous system development is particularly sensitive to the effects of this metal.[15] Recent evidence shows that an increase of 1 ppm in total mercury in children's hair can be associated with a one-point decrease in the Intelligence Quotient, used as a marker for cognition and neurological activity.[16] In adults, systematic reviews and meta-analyses have demonstrated that even low concentrations of mercury are associated with a significant increase in cardiovascular outcomes and deaths,[9,10] and hair mercury concentration correlates to dyslipidemia and cardiovascular risk.[17] In this context, health surveillance plays a crucial role as a public health strategy to address this issue.

Given the significant role of mercury as a major global pollutant, the vast emissions from the Amazon, and the severe impacts on human health, this Personal View aims to analyze Brazil's approach to public health surveillance concerning mercury. Brazil serves as a key example of the challenges faced by Global South nations in tackling contamination. This analysis will offer insights and recommendations to enhance resource allocation and healthcare strategies. Additionally, some of these recommendations may be adaptable for other Amazonian countries, with consideration for their unique contexts.

Brazil and the health surveillance of mercury exposure and intoxication

Brazil is an interesting case in public health and mercury exposure/intoxication (exposure is defined as the metal body burden, and intoxication is defined as the presence of signs/symptoms caused by the exposure). Despite ratifying the Minamata Convention on Mercury in 2018,[18] Brazil remains one of the top mercury-emitting countries in the world.[2] At the same time, the country has powerful resources to serve as a model for health surveillance. The Brazilian Ministry of Health developed the national Notifiable Diseases Information System, SINAN (*Sistema de Informação de Agravos de Notificação* in Portuguese), a digital platform of public health surveillance to monitor and control the incidence of notifiable diseases (https://portalsinan.saude.gov.br/). The system gathers data from health facilities and laboratories across the country, collecting and combining information on several notifiable diseases (such as dengue fever, yellow fever, tuberculosis, HIV/AIDS, among others), number of cases, geographic distribution, and demographic characteristics (including age and sex) of the affected population. By monitoring the incidence of notifiable diseases, SINAN helps health authorities identify disease outbreaks, implement control measures, and allocate resources efficiently.

In a continental-sized country such as Brazil, the health system needs significant adaptation to be able to reach isolated populations, such as some remote-living Indigenous peoples and traditional communities. The community health workers, ACS (*Agentes Comunitários de Saúde* in Portuguese), are essential components of the health provision cascade. ACSs are members of the community who are trained to work in primary healthcare (no previous formal degree other than High School is required to be an ACS), becoming responsible for promoting health, preventing diseases, and improving the overall health status of their communities. They are usually residents of the communities they serve and therefore understand the local culture, beliefs, and customs. This helps them establish trust with community members and improve the effectiveness of health surveillance and interventions. According to the Brazilian Law nº 13.595 of 2018,[19] among other responsibilities, ACSs must: *i*) conduct home visits to monitor the health status of community members, identify health problems, and provide health education and advice; *ii*) provide basic health services such as measuring blood pressure and sugar levels; *iii*) refer patients to health services when necessary; *iv*) participate in health promotion and disease prevention activities; and *v*) collect health data and provide reports to health authorities. Consequently, the role of ACSs in Brazil is critical in health surveillance and improving health outcomes, particularly in isolated/remote areas where access to healthcare can be challenging, such as in the Amazon.

The SINAN digital platform and the presence of ACS are two innovative features that contribute to make the Brazilian public healthcare system a potential model of health surveillance to be followed by other countries sharing similar characteristics (high mercury emissions, vulnerable populations in remote/isolated regions, and limited resources, among others). Nevertheless, despite possessing the tools and potential to establish public health strategies based on evidence, Brazil must address the challenges these tools face to ensure effectiveness. Of note, it is of particular importance to understand and overcome the obstacles to improving public health monitoring related to environmental pollution.

In Brazil, "*the notification of suspected and confirmed cases of mercury poisoning is compulsory, provided every week, and must be recorded in the SINAN platform using the investigation form for exogenous intoxication. Compulsory reporting is mandatory for physicians, other health professionals or those responsible for public services and private healthcare providers for patient care*".[20] To report a mercury-related case, a form must be completed within the system.[21] These cases are recorded using the same form and main code (T65.9, which is the code of the International Classification of Diseases—ICD—of the World Health Organisation (WHO) for the toxic effect of unspecified substance) as those used for all exogenous intoxications, including pesticide exposure and drug overdose. Consequently, it is not possible to retrieve mercury-related cases from the SINAN historical database with a simple code-specific search. The ICD T56.1 code, internationally recognized for mercury intoxication, can be added as supplementary information in the SINAN form, however, this is neither mandatory nor recommended.[20] As a result, obtaining accurate data from the SINAN database to develop effective public health strategies for mercury-related issues is challenging.

To assess the current scenario of health surveillance on mercury exposure and intoxication, we carefully reviewed each record coded with the ICD T65.9, from 2007 (the first year of SINAN) to 2022, to identify all suspected/confirmed cases of mercury exposure/intoxication. Individual files (excluding personal data) were obtained from the Brazilian Ministry of Health resources (available online at https://datasus.saude.gov.br/transferencia-de-arquivos/), following the recommended guidelines.[22] Of note, data from 2019 to 2022 had not yet been fully consolidated on July 2023, when this analysis was conducted, and additional cases may have been reported since then.

Two co-authors independently analyzed and selected the cases using the same standardized protocol. The search strategy began with finding records clearly identified as mercury exposure/intoxication. Then, the Excel search tool was used to find other cases using related keywords in Portuguese both with and without accents (translation in English is shown in parentheses): *amálgama* (amalgam), *azougue* (quicksilver), *barômetro* (barometer), *bateria* (battery), *calomelano* (ancient name for mercury), *cinábrio* (cinnabar), *esfigmomanômetro* (sphygmomanometer), *Hg*, *lâmpada* (lamp), *metal* (metal), *mercúrio* (mercury), *pilha* (battery), and *termômetro* (thermometer). Notably, all cases related to fluorescent lamps were included. However, records related to lamps without any indication of the mercury's presence were excluded. Similarly, records of intoxication by batteries (*bateria* and *pilha*) that did not identify mercury as an active principle or toxic agent were excluded, as mercury-free batteries are commercially available in Brazil. An additional analysis that includes all battery-related cases, regardless of whether mercury was explicitly mentioned, is provided in the Supplementary Material.

After selecting the records, the authors compared their results, which were also reviewed by a third co-author to reach a consensus when necessary. Records were included if they indicated the presence of mercury as a toxic agent, active ingredient, or in any other form. Furthermore, cases containing writing or typing errors such as *macurio, marcurio, mercurio, mercuirio, mercuro, mercuruo, mercurios,* and *mercury* were also included.

Cases that did not mention mercury or mercury-containing products, as well as those referring to common names of plants (such as *pinhão mercúrio* or *caroço/semente de mercúrio*, which refer to parts of the plant *Jatropha multifida*), were excluded.

Despite the comprehensive selection process, only 668 suspected/confirmed cases of mercury exposure/intoxication were recorded over the past sixteen years (Fig. 5). This is a very low number considering a population of over 200 million people and the Brazil's significant mercury emissions. Even when applying less stringent selection criteria (Supplementary Material), the total number of cases from 2007 to 2022 was only 1348; this analysis yielded conclusions consistent with those found in the initial analysis, as detailed below.

Some aspects of the SINAN data raised concerns. Only 22.6% (151 cases) included the ICD T56.1 code; in 65.7% of all cases, this specific field was not filled, even when mercury was clearly identified as the toxic agent in the record. Notably, only one case involving a pregnant woman was reported (Fig. 5), despite there being 180 cases involving women of childbearing age (16–55 years). Even more alarming, for 30 cases (16,7%), the pregnancy status was recorded as unknown. This is especially worrisome, considering that even low mercury levels can cause fetal malformations and developmental impairments, according to the WHO.[23,24] Furthermore, a high number of recorded cases (320) were in children/adolescents (0–17 years); the majority (79.4%) of those recorded as "accidental", mainly due to exposure to broken thermometers, fluorescent lamps or other devices containing mercury. Importantly, in children/adolescents, all cases recorded as "environmental" presented "*azougue*" (the common name used in Brazil for liquid mercury) as the main toxic agent, suggesting these children could be living near mining areas, having contact with the liquid metal at their homes or the surrounding environment.

Almost all Brazilian states have registered cases, demonstrating the ubiquity of human exposure to this metal in the country (Fig. 5). However, it is somewhat surprising that only 15.6% of all cases were detected in the Brazilian Amazon, a region where approximately 14% of the Brazilian population lives[25] and from where most of South America's emissions originate. In Brazil, 92% of the country's gold mining (approximately

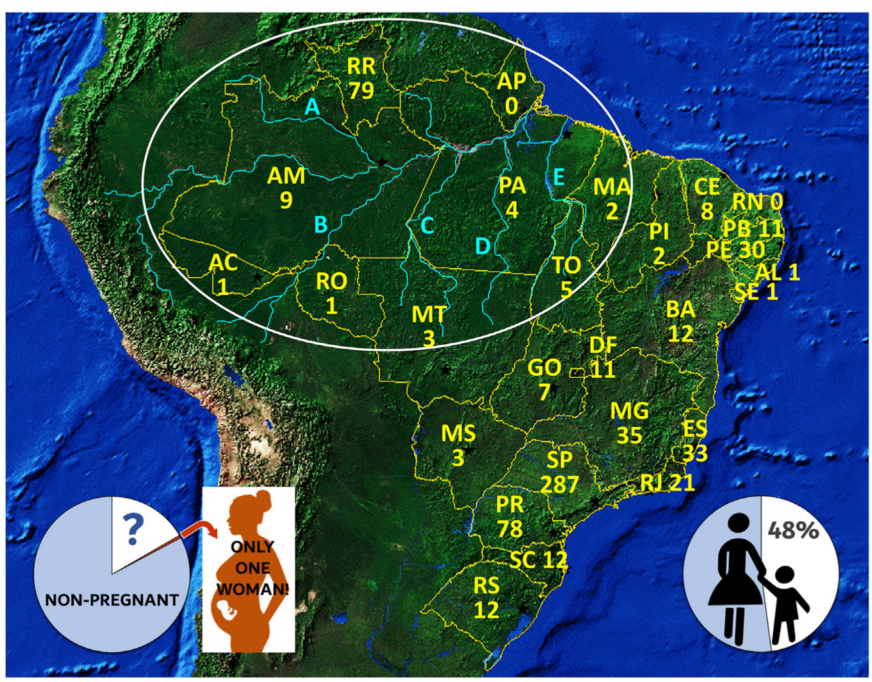

Fig. 5: Map of Brazil showing: i) **in yellow**, the Brazilian states and the number of suspected/confirmed cases of mercury exposure/intoxication recorded in the *SINAN* platform from 2007 to 2022 per Brazilian state, ii) **in blue lines**, the main tributaries of the Amazon River basin, iii) **in the white circle**, the approximate extension of the Brazilian Amazon, iv) **in the left bottom**, the proportions of pregnant status in women of childbearing age (16–55 years) in the records (the symbol "?" means that pregnant status was recorded as unknown), and v) **in the right bottom**, the proportion of children/adolescents (0–17 years) in the total number of cases. **Brazilian states (in yellow):** Acre (AC), Amazonas (AM), Roraima (RR), Rondônia (RO), Amapá (AP), Pará (PA), Mato Grosso (MT), Maranhão (MA), Tocantins (TO), Goiânia (GO), Mato Grosso do Sul (MS), Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE), Bahia (BA), Distrito Federal (DF), Minas Gerais (MG), Espírito Santo (ES), Rio de Janeiro (RJ), São Paulo (SP), Paraná (PR), Santa Catarina (SC), and Rio Grande do Sul (RS). **Main tributaries of the Amazon River (in blue):** Negro River (A), Madeira River (B), Tapajós River (C), Xingú River (D), and Tocantins River (E).

242,000 ha) takes place in the Amazon, with nearly 25% of these operations being illegal as they are situated in protected lands.[26] Worth mentioning, one of the Brazilian states in the Amazon region, Amapá (AP), has never reported a single suspected/confirmed case of mercury exposure/intoxication (Fig. 5), despite being home to one of the oldest active mining fronts in Brazil, *Garimpo do Lourenço*.[27] The significant underreporting of human intoxication in the Amazon is further supported by numerous studies in the scientific literature that consistently show a high prevalence of signs and symptoms of mercury intoxication in the Amazonian population.[13] This illustrates the severe underreporting in this region, which is especially concerning given the Brazilian Ministry of Health's reliance on SINAN for efficient resource allocation.

Particularly noteworthy is the case of the state of Pará (PA), which is not only the most populated state of the Brazilian Amazon region but also the second-largest in size. This Brazilian state encompasses the largest and most historically significant regions of gold mining,[26] such as those in the Tapajós River basin (identified as tributary river C, in blue in Fig. 5), and some of the world's largest HPPs, including the Tucuruí HPP (located on the Tocantins River—identified as tributary river E, in blue in Fig. 5) and the Belo Monte HPP (in the Xingú River—identified as tributary river D, in blue in Fig. 5).[7,8,28] Furthermore, among all Amazonian states, the State of Pará suffered from the most alarming records of fires and deforestation in recent years.[29,30] Therefore, this State exhibits many factors contributing to mercury mobilisation and human exposure. Despite all these conditions, only four suspected/confirmed cases of mercury intoxication have been reported in this state from 2007 to 2022. Of note, since data from 2019 to 2022 are not yet consolidated and cases of those years are being added, these numbers should increase. As for example, the cases detected in the Indigenous Munduruku people in 2019 which are still being included in the database.

The notifications of mercury intoxication in the Indigenous Munduruku population

The first records of contact of the Indigenous Munduruku people with the colonizing fronts date from the second half of the 18th century, with the first written reference in 1768.[31] The Munduruku people speak Tupi language and live in different territories of the State of Pará (mainly in the Tapajós River basin). Currently, the Munduruku population numbers around 12,000 people, mainly concentrated in the Sai Cinza, Sawré Muybu, and Munduruku indigenous lands. Due to the historical presence of illegal gold mining in these lands and the increased rates of congenital malformations in newborns reported over the last decade, the Pariri Indigenous Association sent a letter to the Oswaldo Cruz Foundation asking for support to understand the main problems related to mercury contamination in the region. Between October–November 2019, an interdisciplinary research team visited the Sawré Muybu, Sawré Aboy, and Poxo Muybu indigenous villages in the Sawré Muybu indigenous land (an area of 178.173 ha, where approximately 1000 people live). The team conducted interviews, clinical assessments, and collected hair samples from 200 people for analysis. The laboratory analysis revealed high mercury exposure, with levels as high as 23.9 μg/g in their hair (median of 6.6 μg/g).[32] Various health issues were identified in the Munduruku population, including motor, sensory, and cognitive abnormalities in adults.[33] However, these issues were especially concerning in 0–2 years-old children, who are more vulnerable to the adverse effects. The clinical assessment identified gross motor delay, stunt, and anaemia in the young children.[34] Moreover, mercury contamination was demonstrated in different species of fish, a primary source of protein and sustenance for these communities (averaging 0.10 μg/g and 0.44 μg/g of total mercury for non-piscivorous and piscivorous fish, respectively).[32] This contamination poses a severe risk to their health and traditional ways of life.

After persistent negotiations and advocacy efforts with local health authorities, supported by the public defender's office of the Union, a significant breakthrough was achieved in June 2023 that led to the notification of the 196 cases of mercury exposure detected in the Munduruku people in 2019. Those cases are being retrospectively included in the SINAN database.

The evidence of mercury intoxication among the Munduruku people is just an example of what is likely to be found across the entire Amazon region. Here, anthropogenic activities such as mining, HPPs, fires, and deforestation, contaminate water, soil, and fish, resources that are essential to the diet and subsistence of many of the over 180 indigenous ethnic groups living in the region, which includes approximately 870,000 people.[35]

Insights and recommendations

The information presented and discussed here underscores the urgent need for immediate action to address indiscriminate mercury exposure and safeguard the health and well-being of the population. Especially in the Amazon, this is necessary to preserve the cultural heritage and sustain the ecological balance of this region. Long-term solutions should involve collaborative efforts between the Amazonian society, governmental agencies, researchers, legal entities, and advocacy groups to mitigate the devastating effects of mercury exposure and the anthropogenic impact on the Amazonian environment.

In a previous work, we provided insights and proposals to reduce mercury emissions in the Amazon,[30] including recommendations for specific actions to control and improve gold mining practices, as well as other measures related to mercury emissions. Notably, many Amazonian rivers used for mining are shared by the countries that make up the Amazon rainforest. Therefore, mining regulations and controls must be collaboratively defined, enforced, and implemented simultaneously across these nations. Without coordinated efforts, pollution in one country will continue to harm the health of all communities that depend on those waters and animals.

However, as highlighted by the Environmental European Agency and the United Nations, even in the case of zero emissions, legacy mercury will continue to be responsible for human exposure for centuries.[2,36] Therefore, governments must join efforts to manage human exposure and intoxication effectively. Based on our experience with vulnerable populations in Brazil, we propose some recommendations (Panel 1).

Ubiquitous and perdurable contaminants such as mercury pose huge challenges for public health surveillance. The combination of different susceptibilities[28] and situations of vulnerability of some populational groups make environmental monitoring of mercury (in water, soil, air, plants, and animals) insufficient as a prevention strategy for human health and environmental protection. For example, recent data on piscivorous fish in Amazonian markets for human consumption shows average levels of mercury at 0.603 ppm,[37] which is adequate for human consumption according to the Brazilian legislation (up to 1 ppm for piscivorous fish).[38] However, this means that a single meal of 200 g of piscivorous fish is sufficient to exceed the provisional tolerable weekly intake of methylmercury (PTWI) recommended by both the United States Environmental Protection Agency and the WHO (approximately 42 and 96 μg for a 60 kg-person, respectively).[11,23,24,29] Of note, these consumption advisories are primarily based on the neurodevelopmental impacts of mercury on children, particularly during prenatal development. Further research is needed to fully understand the effects or symptoms in adults. Recent studies have demonstrated, for instance, that hair mercury levels around 2 μg/g (which would be approximately the levels found in a person consuming the PTWI recommended by WHO)[11,29] are associated with an increased relative risk of hypertension, stroke, and all cardiovascular diseases.[9,10,17]

It is important to note that the Brazilian legislation overlooks the culture and dietary patterns of traditional Amazonian communities, which include three main groups: i) Indigenous people, descendants of the Native populations of the Amazon; ii) *Quilombolas*, descendants of African people who arrived in Brazil in the mid-16th century as enslaved workers; and iii) riverine people, descendants of migrants from various regions and countries since the early 20th century. All these communities maintain a close connection with the surrounding environment, making them the first to experience the impacts of environmental pollution. For instance, riverine populations typically consume around 10 meals per week containing 160–430 g of fish each,[39] while the Munduruku indigenous people also rely heavily on fish for their diet and cultural practices.[31]

Given this context, establishing Brazilian recommendations on the PTWI and body burden of mercury is essential. These guidelines would aid health professionals in detecting human exposure and preventing intoxication. Furthermore, Brazil could leverage the presence of ACS among vulnerable populations to: i) adapt these recommendations to respect community's cultural practices, thus improving adherence, and ii) facilitate early identification of high-risk individuals by evaluating fish intake using standardized forms.

Our analysis of SINAN data highlights the importance of training health professionals and reinforcing the presence of neurologists and cardiologists in the Amazon, as implemented during the COVID-19 pandemic.[40] Additionally, we highly recommend developing educational

Panel 1: Highlights of recommendations to improve monitoring of human exposure to mercury, and enhance the long-term effectiveness of public health strategies in Brazil

- Establish recommendations for the provisional tolerable weekly intake and body burden of mercury
- Adapt ACS program to reflect the reality and culture of communities in vulnerable situations and enable early identification of high-risk individuals
- Train health professionals, especially Indigenous Health Agents (AIS) and Indigenous Sanitation Agents (AISAN)
- Increase the local presence of neurologists and cardiologists
- Develop educational material tailored to specific vulnerable groups
- Develop a specific form in SINAN with the ICD T56.1 code to record mercury exposure/intoxication cases, including specific fields for relevant information (fish intake, working in mining activities, etc.)
- Improve local infrastructure in the Amazon to detect human exposure, by allocating mercury analyzers in public laboratories, and implement a human biomonitoring program for regular assesment of exposure levels
- Involve Amazonian society, especially local communities and research teams from public Federal Universities in the Amazon in the decision-making and implementation process

materials tailored to specific vulnerable groups, like the recent example developed by our team in collaboration with the Ministry of Indigenous People.[41]

When dealing specifically with mercury exposure or other forms of exogenous intoxication affecting vulnerable populations, it is essential to ensure that health professionals working in these areas are adequately trained to promptly identify, diagnose, and report cases of poisoning. As seen in the case of the indigenous Munduruku people, the collaboration between health services, indigenous leaders, advocacy and research groups, and governmental agencies played a vital role in ensuring accurate reporting and appropriate governmental-level response.

In addition, developing a specific form in SINAN with ICD T56.1 code for recording mercury exposure/intoxication cases would enhance the visibility of the problem and improve data quality. Furthermore, including specific fields to describe relevant information, such as the fish intake and work in mining sites, is highly recommended. There is an urgent need to develop and validate tailored screening tools to help health professionals prevent and identify mercury-associated health impacts, and make these tools widely available for use among Brazil's diverse populations and cultures.

Alongside training health professionals, frequent biomonitoring of human exposure to mercury in the Amazon is essential. Biomonitoring can help identify sources of exposure, whether occupational, dietary, or form products such as mercury-adulterated skin-lightening creams. Therefore, investments should also focus on improving local infrastructure, such as increasing the number of mercury analyzers in the region.[11] This approach would enable the collection and reporting of data necessary to understand the real scenario and support evidence-based interventions.

In the Brazilian Amazon, research teams with proven experience are mainly based in public Federal Universities.[11] Strengthening these teams in the Amazon region would leverage the existing infrastructure and social influence of these institutions without placing excessive strain on the public health system. Furthermore, the in-depth understanding that these institutions have of the intricate Amazonian context provides them with the expertise needed to effectively implement local, culturally-sensitive prevention strategies.[42]

In a region facing considerable challenges like the Amazon, the Amazonian society (including researchers, traditional communities, health professionals, urban populations, etc.) should take the lead in developing and implementing solutions to ensure the effectiveness of public health strategies concerning mercury exposure. Sustainable change hinges on the awareness, empathy, and active involvement of Amazonian society. By improving reporting mechanisms and aligning them with the objectives of the Minamata Convention, Brazil can better fulfil its commitments to safeguard public health, protect vulnerable populations, and effectively address the challenges posed by mercury contamination. Some of these recommendations could eventually be adapted to other Amazonian countries with similar characteristics (high mercury emissions, presence of vulnerable populations, etc.), while also respecting their unique differences. Furthermore, reliable epidemiological data is crucial in the aftermath of the COVID-19 pandemic, particularly due to key factors: *i*) the potential for harmful interactions between mercury intoxication and COVID-19 infection,[43] *ii*) the high prevalence of both issues in overlapping regions such as East and Southeast Asia, South America and Sub-Saharan Africa,[2] and *iii*) the presence of large groups of systematically minoritised populations (i.e., racial and ethnic minorities and rural populations, among others).

Contributors

Conceptualization, G.P.A., M.A.-O., A.L.-A, and M.E.C.-L.; methodology, formal analysis, and data curation—A.L.-A, and I.S.-S.; validation, L.S.-S., J.L.B., C.G.L.-N., M.A.-O., G.P.A., C.B.A.d.S., and M.E.C.-L.; writing—original draft preparation, P.C.B., and M.E.C.-L.; figures, panel and supplemental material preparation–A.L.-A., C.G.L.-N., and M.E.C.-L.; investigation and writing—review and editing, M.E.C.-L., A.L.-A., P.C.B., I.S.-S., C.B.A.d.S., C.G.L.-N., L.S.-S., J.L.B., M.A.-O., and G.P.A.; supervision, project administration and funding acquisition, M.E.C.-L., M.A.-O., G.P.A., and C.B.A.d.S. All authors have read and agreed to the published version of the manuscript.

Data sharing statement

All data and files included in this manuscript are available upon request to the corresponding authors.

Editor's note

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AI use statement

To improve the readability and language of the text during the revision process, the authors employed ChatGPT-4.0 by Open AI, followed by manual checks and revisions. All the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of interests

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lana.2024.100880.

Personal View

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