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# Social determinants of health among people working on informal gold mines in French Guiana: a multicentre cross-sectional survey

Maylis Douine <sup>1</sup>, Yann Lambert,<sup>1</sup> Lorraine Plessis,<sup>1</sup> Irène Jimeno,<sup>1</sup> Muriel Galindo,<sup>1</sup> Teddy Bardon,<sup>1</sup> François-Michel Le Tourneau,<sup>2</sup> Perrine Molinié,<sup>1</sup> Alexandre Vié,<sup>1</sup> Antoine Adenis,<sup>1</sup> Mathieu Nacher,<sup>1</sup> Amanda Figueira da Silva,<sup>3</sup> Stephen Vreden,<sup>4</sup> Martha Cécilia Suarez-Mutis,<sup>5</sup> Alice Sanna<sup>1</sup>

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For numbered affiliations see end of article.

**Correspondence to**

Dr Maylis Douine;  
mdouine@yahoo.fr

## ABSTRACT

**Introduction** Social determinants of health, such as living and working conditions, economical and environmental context and access to care, combine to impact the health of individuals and communities. In French Guiana (FG), the persons working in informal artisanal and small-scale gold mining in the rainforest are a particularly vulnerable population which lives in precarious conditions and far from the health system. Previous studies have demonstrated their high morbidity due to infectious diseases. This study aims to describe the social determinants of health in this specific population.

**Methods** This international multicentre cross-sectional survey included people working on the informal FG gold mines at the crossing points located at both borders with Suriname and Brazil. After collecting written informed consent, a structured questionnaire was administered.

**Results** From September to December 2022, 539 gold miners were included. These poorly educated migrants, mainly from Brazil (99.1%) did not have access to drinkable water (95.4%), lived in close contact with wild fauna by hunting, eating bushmeat or being bitten and were exposed to mercury by inhalation (58.8%) or ingestion (80.5%). They report frequent accidents (13.5%) and chronic treatment interruptions (26.6% of the 11.9% reporting chronic treatment). Half of them considered themselves in good health (56.4%).

**Conclusion** This study shows a singular combination of adverse exposures of gold miners working in FG such as zoonoses, heavy metal poisoning, aggression of wild fauna. For ethical as well as public health reasons, actions towards health equity must be considered at different levels: individual, community, environmental, systemic and global level. As end users of minerals, we must assume our responsibilities for the well-being of the extractors by including health in political decisions to engage together in global health.

**Trial registration number** NCT05540470.

## WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Artisanal and small-scale gold mining (ASGM), frequently related to illegal activity, has important environmental and health consequences.
- ⇒ The international literature mainly focuses on issues related to mercury pollution and poisoning.
- ⇒ In the specific context of ASGM in French Guiana, a French territory located in the Amazon, several health problems have already been described such as high malaria transmission, sexually transmitted infection burden and exposition to zoonoses.

## WHAT THIS STUDY ADDS

- ⇒ This study provides insights in lifestyle, working conditions and environmental challenges that expose gold miners to health disorders in this Amazon region.
- ⇒ Describing the social determinants of health provides a comprehensive understanding of what makes this population vulnerable from a global health perspective.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ These scientific evidences highlight the complex and interconnected relationship between regulation, political response to ASGM, the right to health and public health challenges.
- ⇒ This could broaden the vision of policy makers when addressing ASGM, specifically in a high-income country like France.
- ⇒ This study demonstrates the need for ethical and pragmatic thinking to ensure healthy and fair extraction of minerals, as we are all end-users.

## INTRODUCTION

Gold mining is a multifaceted industry, encompassing the extraction, processing and trading of gold from the earth's crust. It encompasses both legal and informal activities, with significant repercussions on

sociodemographic aspects. All over the world, it attracts people to mining areas, altering local demographics and causing social and environmental problems, particularly in the case of informal activities.

Social determinants of health, such as education, income, working conditions and the environment, have a major impact on individual health.<sup>1</sup> Taking them into account is therefore essential for improving health and reducing inequities, in particular among the most vulnerable populations. The informal artisanal and small-scale gold mining (ASGM) and its socio-economic environment are known to be associated with unfavourable health conditions.<sup>2-5</sup> The international literature shows a high risk of mercury poisoning, HIV infection, silicosis and occupational injuries for this population.<sup>2-5</sup> In French Guiana, a French overseas territory located in the Amazon region, people active in informal ASGM constitute a specific population living apart from the general population and far from health structures. Most of them are of Brazilian origin and migrate clandestinely from the poorest states of Brazil in search of the wealth that the gold sector seems to offer.<sup>6</sup> Previous surveys have described that this population is exposed to vectorborne diseases, especially malaria (PCR-*Plasmodium* prevalence from 2.5% to 5.3% in 2019), zoonoses such as leptospirosis (28.1% (95% CI 23.5 to 32.7) in 2019), sexually transmitted diseases (prevalence of HIV, hepatitis C virus, hepatitis B virus and syphilis in 2019 were respectively 0.5% (95% CI 0.1 to 2.1), 2.1% (0.7 to 3.6), 1.6% (0.3 to 2.8) and 12.4% (9.0 to 15.7)), tobacco or alcohol addiction (41.2% and 57.3%, respectively in 2019) or heavy metal hypersensitivity pneumonia.<sup>7-10</sup> In 2013, a large outbreak of beriberi, a thiamine deficiency causing severe cardiac failure and neuropathies, was documented among gold miners, a disease that had disappeared from the territory since the end of the penal colony in the middle of the 20th century.<sup>11</sup>

The question of gold mining in French Guiana is complex and poses many ecological, sanitary, societal and economic challenges.<sup>12 13</sup> However, the Universal Declaration of Human Rights states that “everyone has the right to a standard of living adequate for the health and well-being of himself and of his family”.<sup>14</sup> The United Nations promotes the Sustainable Development Goals (SDGs) for 2030 in which health occupies a large place, notably in SDG 3 which aims to ensure a healthy life and to promote the well-being of all at all ages.<sup>15</sup> France is also committed to these SDGs with indicators adapted to its territory. It is therefore essential to assess and address the social determinants of health in the gold-mining population.

Given the variety and often peculiarity of the health problems experienced by gold miners, we assume that the context of their mining activity exposes these precarious economic migrants to specific factors detrimental to their health. The present study therefore aims to describe the social health determinants—socio-economic, behavioural and environmental determinants, access to

healthcare—of this hard-to-reach population working in informal gold mines in French Guiana.

## METHODS

### Study design

The study took place in Brazil and Suriname, at their border with French Guiana, a French overseas department located in South America. Its 83 000 km<sup>2</sup> area is mainly covered by rainforest and the gold-rich soils attract poor workers particularly from Brazil, who work on several hundred clandestine sites (without regulatory authorisation and often in protected areas) spread out in the heart of the rainforest. Theoretically, access to healthcare is free in Health Center, irrespective of social and migratory status of the individual.<sup>16</sup> Nevertheless, the remoteness of the mines and the repression of undocumented migration and clandestine mining activity (through police interventions called ‘Harpie operation’) represent significant obstacles for an effective access to care of this population.<sup>7</sup> Following on from previous interventions, the Harpie operations set up in 2008 intends to eliminate illegal gold-mining zones and destabilise the underground economy, notably by destroying logistical circuits.<sup>17</sup>

This cross-sectional multicentric cross-border survey was initially implemented to measure malaria prevalence in the ASGM population working in French Guiana, as a pre-intervention survey in a larger public health intervention study (Curema project, ClinicalTrials ID: NCT05540470).<sup>18</sup> Secondary objectives of this survey include a broader assessment of the health of this hard-to-reach population and of its health determinants. Participants were enrolled in the study on staging areas where they come to trade their gold, purchase goods, get some rest or visit their families. These areas are located on the Brazilian bank of the Oyapock river and on the Surinamese bank of the Maroni river. The study team, composed of a health mediator, a nurse and a physician, collected written informed consent statement after explaining the context of the study, the objectives and the content of the protocol, orally and by means of an information note in Portuguese (participants were originally from Brazil). Participants could ask any questions they wished before giving their consent. A questionnaire was then administered, and blood and hair samples (with specific consent for hair, as it was only used for a secondary objective) were taken, along with a medical examination. The sample size was calculated to evaluate a malaria elimination intervention in this population (n=860) (comparison of PCR-*Plasmodium* prevalence before/after an intervention, to be able to identify a 75% reduction, assuming a 2% baseline). Inclusion criteria were: to be over 18 years of age, to have left an informal gold-mining site in French Guiana within the last 7 days and to have agreed to participate in the study. In the absence of an available sampling frame for the source population, the

sampling method relied on opportunistic encounters and the 'snowball effect'.

### Data collection and analyses

A questionnaire collected social determinants of health, specific to the gold-mining population. These determinants were classified in sociodemographic (age, sex, education, income, occupational activity, time spend in gold-mining activity), behavioural and environmental (access to drinkable water and sanitation, exposure to mercury, waste management, contact with wildlife: hunting, bushmeat consumption, bites, etc) and healthcare access (chronic treatment, accidents, loss of follow-up, etc (online supplemental material)). Reported income was assessed by comparison with the Brazilian minimum wage (BMW), which was 1212 Brazilian real (US\$226) per month at the time of the survey. The distance from the mining site to the primary care health facilities was approximated as the distance from the mines to the study inclusion sites, the latter being close to a formal health facility (1 hour maximum by boat). Most of the questions referred to the last mining site where the participants worked in order to limit memory bias. Digestive exposure to mercury was assessed by showing pictures of the four fish species known to be the most heavily contaminated by organic methylmercury in the area (piscivorous fish at the top of the food chain). Self-perceived health was assessed with the question "Would you say your health is good, medium or poor?" then classified as good or medium/poor.<sup>19</sup> Chronic treatments were considered only as the treatment of a chronic pathology (eg, excluding contraceptives). The questionnaire was conducted in Portuguese and was recorded on a digital tablet.

The characteristics of the study population were described using the median and IQR (quantitative variables) and frequencies (qualitative variables). Bivariate analyses assessed the association between social determinants of health with gender and perception of health using  $\chi^2$  tests and logistic regression. A multivariable unconditional logistic regression model including variables with a p value <0.20 assessed independent factors associated with the perception of health by the respondents. Statistical analyses were performed using Stata V.16 (College Station, Texas, USA), a standard statistical data analysis software.

### Patient and public involvement

The study population was involved in the development of the questionnaire (with the definition of meaningful questions and appropriate wording), and pretesting of the questionnaire (comprehension, acceptability, duration). Recruitment of participants was done by opportunistic meeting and then by snowball sampling, thus involving the participants themselves. The socio-economic and behavioural questionnaire was administered by a health mediator, who is a pair issued from the target community.

## RESULTS

From September 2022 to December 2022, 539 persons were included in the study, 211 at the Brazilian border and 328 at the Surinamese border.

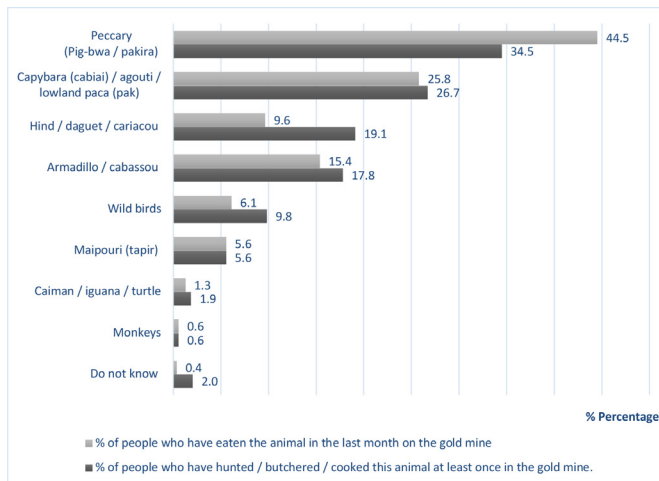
### Socio-economical determinants of health

The study population had a median age of 38 years (IQR 30–48). The male/female sex ratio was 2.7 and participants were mainly of Brazilian origin (534/539, 99.1%). A large proportion (222/539, 41.2%) had a primary education level or had never been to school, while 21.1% (114/539) attended postsecondary education. The median time already spent in gold-mining activity at the time of the survey was 8 years (IQR 2–16). The three main professions among men were gold miner, itinerant salesman and goods carrier; among women the main occupations were cook, itinerant saleswoman and shopkeeper. Regarding their income, 65.7% (354/539) considered having earned the equivalent of two to three BMW during the past month (US\$452–678), 11.2% (64/539) four or more ( $\geq$ US\$904) and 17.2% (93/539) one or less ( $\leq$ US\$226), with a higher proportion of low incomes ( $\leq$ 1 BMW) among women than among men (24.5% vs 14.5%,  $p=0.034$ ).

### Behavioural determinants of health

On the last mining site, the main sources of drinking water were wells (63.5%, 342/539), rivers (53.0%, 302/539), rainwater collection (4.6%, 25/539) and rarely bottled mineral water (2.0%, 11/539). Only 25 participants (4.6%) reported always purifying water before drinking, 141 (26.2%) did so occasionally and 363 (67.4%) never treated the water. Among those who used to treat water, it was done using purification tablets (81.9%, 136/166), filtration (12.1%, 20/166), hydrochloric acid (0.6%, 10/166) or boiling it (5.4%, 9/166) (alternatively or combined), and three declared just letting water settle. Almost all participants reported open defecation in the forest (91.6%, 494/539). Only 25 (4.6%) used wooden latrines and 17 (3.2%) a hole in the ground. Two participants declared defecating directly in the river. Regarding inhalation exposure to mercury in the past month, 118 participants (21.9%) declared having used this metal themselves to amalgamate gold particles and 199 (36.9%) reported witnessing the process. Among the former, 21.2% used protection (25/118) compared with 9.5% among the latter (19/199,  $p=0.012$ ). The main means of protection were covering one's nose and mouth with a mask or fabric (33), staying away (5), washing hands after manipulation (5) and one plugs his nose. The second source of mercury exposure, consumption of piscivorous fish, was widely practised by participants: 80.5% had eaten some in the past month on the mining site, at a median of eight times (IQR 3–15). Only 19 participants (3.5%) reported bringing back electronic or mechanical waste while most (80.7%) left it directly in the forest (burnt, buried or just left on the ground) (15.8% did not know), thus contributing to environmental pollution.





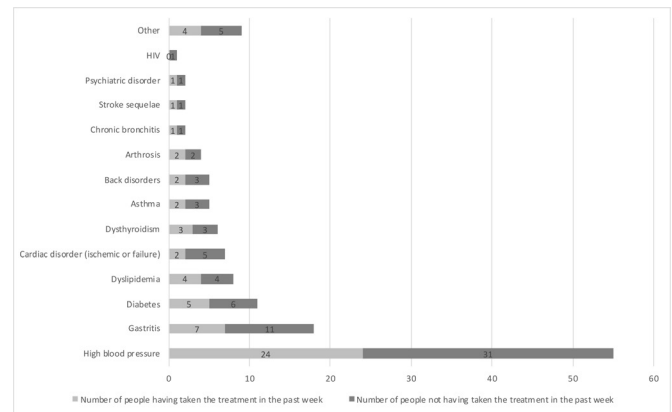
**Figure 1** Animal species hunted/butchered/cooked or eaten on gold mines in French Guiana (n=539).

### Environmental health determinants

One-quarter (23.8%) of the participants reported hunting during their stays on gold mines: 13.2% used to do it several times a month or a week, and 10.1% only a few times a year. Among the study population, 34.5% reported having ever butchered or cooked the meat, half of whom were not hunters. Two-third (65.1%) had eaten bushmeat in the past month, at a median of five times (IQR 2–12). The animal species hunted/prepared and consumed are detailed in figure 1. Three hundred and thirty-six participants (62.7%) reported the presence of ‘domestic’ animals on the gold mine. These animals were mainly dogs (322/539, 59.7%), coming from French Guiana (43.2%), Suriname (27.3%) or Brazil (14.9%). The other domestic animals were cats (94/539, 17.4%), chickens (22/539, 4.1%), pigs (20/539, 3.7%) and more anecdotally monkeys, pacas, cows, birds or sloths. Two-third of the participants reported having suffered an injury associated with wild fauna aggression in the past year (360/539=66.8%). These were mainly related to bat bites (308), scorpion stings (122), snake bites (19), spider (17) or centipede (10) stings, dog bites (7), caterpillar (6) or stingray (4). The presence of bats in the last gold mine was reported by 96.9% of the respondents. Finally, 73.8% reported having suffered tick bites and 73.1% mosquito bites.

### Access to the healthcare system

The main health problems on the gold mines according to the participants were malaria (317), cutaneous leishmaniasis (256), digestive disorders (216), influenza-like syndromes (168), musculoskeletal disorders (160), headache (133) or other cutaneous disorders (52). During the previous year, 13.5% (69/512) of respondents reported having had at least one accident on the gold mine (27 did not want to answer), declaring in total 74 accidents. These accidents occurred during work (56.8%, 42/74), while travelling (24.3%, 18/74), during domestic time (14.9%, 11/74); three were related to intentional



**Figure 2** Number of participants declaring having a chronic treatment and those who have followed this treatment in the past week (n=539).

violence (fight, stab wound). They led to hospitalisation for 11 people, outpatient care for 18, 37 were self-cared for and 4 were about to seek care. The median travel time from the mine site to the nearest healthcare facility was 1 day (IQR 0.4–2), with 37.4% (201/537) of study participants working more than >1 day away. Sixty-four people (11.9%) declared following a chronic medical treatment. Of these, 17 reported not having taken their medication in the last week (26.6%, 17/64), 8 because they had stopped their follow-up, 8 because of distance to health facilities, 3 forgot, 3 because they preferred to take the medication on the basis of symptoms instead of permanently and 1 because of the cost. Figure 2 represents the treatment indication and the intake during the previous week (more than one answer possible).

### Factors associated with self-perceived health

Concerning their own perception of their health, 304 respondents (304/539, 56.4%) considered having a good health, 186 (34.5%) a medium and 49 (9.1%) a poor health status (43.6% for both). After multivariate analysis, the main factors associated with a self-perception of good health were male gender (OR 1.9 (95% CI 1.3 to 2.9)), no injury by wild fauna in the past year (OR 1.6 (95% CI 1.0 to 2.3)), no chronic treatment (OR 2.9 (95% CI 1.6 to 5.3)) and access to drinkable water and latrines (OR 3.9 (95% CI 1.5 to 10.3) and 3.7 (95% CI 1.3 to 10.5)) (table 1).

### Health determinants by gender

As the characteristics and the behaviour of men and women involved in the ASGM seem to be different, we described the health determinants according to the gender.<sup>6</sup> Women were more educated than men but reported more frequently a low income. They consumed less piscivorous fish and less bushmeat, hunted very rarely, were less exposed to inhaled mercury and were less injured by wild fauna; on the other side, they butchered and cooked bushmeat more often. Women had a worse perception of their own health than men, declared having a chronic treatment more frequently, without

**Table 1** Factors associated with self-perception of good health among participants working on informal gold mines in French Guiana (univariate and multivariate analyses)

	Perception of health status		Univariate analysis		Multivariate analysis*	
	Poor/Medium	Good	P value	OR (95% CI)	P value	OR (95% CI)†
	N (%)	N (%)				N=537
<b>Sociodemographic determinants</b>						
<b>Sex</b>						
Women	80 (34.0)	63 (20.7)	0.001‡	1	0.002	1
Men	155 (66.0)	241 (79.3)		1.9 (1.3 to 2.9)		1.9 (1.3 to 2.9)
<b>Age (years)</b>						
≤38	100 (42.6)	177 (58.2)	<0.001	1	0.003	1
>38	135 (57.5)	127 (41.8)		0.5 (0.4 to 0.7)		0.6 (0.4 to 0.8)
<b>Time spent in gold-mining activity (years)</b>						
≤8	108 (46.0)	167 (55.3)	<b>0.032</b>	1		
>8	127 (54.0)	135 (44.7)		0.7 (0.5 to 1.0)		
<b>Education</b>						
Primary or none	89 (37.9)	133 (43.8)	<b>0.169</b>	1		
Secondary or superior	146 (62.1)	171 (56.3)		0.8 (0.6 to 1.1)		
<b>Income (in number of Brazilian minimum wages)</b>						
≤1	49 (20.9)	44 (14.5)	0.233	1		
2–3	150 (63.8)	204 (67.1)		1.5 (0.9 to 2.4)		
≥4	26 (11.1)	38 (12.5)		1.6 (0.8 to 3.1)		
dnk or variable income	10 (4.3)	18 (5.9)		2.0 (0.8 to 4.8)		
<b>Behavioural determinants</b>						
<b>Access to drinkable water</b>						
No	229 (97.5)	279 (91.8)	<b>0.005</b>	1	0.005	1
Yes	6 (2.6)	25 (8.2)		3.4 (1.4 to 8.5)		3.9 (1.5 to 10.3)
<b>Access to latrines</b>						
No	230 (97.9)	284 (93.4)	<b>0.015</b>	1	0.016	1
Yes	5 (2.1)	20 (6.6)		3.2 (1.2 to 8.8)		3.7 (1.3 to 10.5)
<b>Consumption of piscivorous fish</b>						
No	39 (16.6)	56 (18.4)	0.567	1		
Yes	193 (82.1)	241 (79.3)		0.9 (0.6 to 1.4)		
dnk	3 (1.3)	7 (2.3)		0.16 (0.4 to 6.7)		
<b>Contact with mercury (two dnk)</b>						
No	96 (40.9)	124 (41.1)	0.961	1		
Yes	139 (59.2)	178 (58.9)		1.0 (0.7 to 1.4)		
<b>Electronic/Mechanical waste left in the forest</b>						
Yes	181 (77.0)	254 (83.6)	<b>0.007§</b>	1		
No	5 (2.1)	14 (4.6)		2.0 (0.7 to 5.6)		
dnk	49 (20.9)	36 (11.8)		0.5 (0.3 to 0.8)		
<b>Environmental determinants</b>						
<b>Hunting on the gold mines (one dnk)</b>						
No	182 (77.5)	228 (75.3)	0.552	1		
Yes	53 (22.6)	75 (24.8)		1.1 (0.7 to 1.7)		
<b>Bushmeat consumption</b>						
No	82 (35.5)	96 (32.2)	0.428	1		

Continued

Table 1 Continued

	Perception of health status		Univariate analysis		Multivariate analysis*	
	Poor/Medium	Good	P value	OR (95% CI)	P value	OR (95% CI)†
	N (%)	N (%)				
Yes	149 (64.5)	202 (67.8)		1.1 (0.8 to 1.6)		
Bite by wild fauna in the past year						
Yes	167 (71.1)	193 (63.5)	<b>0.063</b>	1	0.026	1
No	68 (28.9)	111 (36.5)		1.4 (1.0 to 2.0)		1.6 (1.0 to 2.3)
Access to healthcare						
Accident in the past year on the gold mine						
No	191 (81.3)	252 (82.9)	0.875	1		
Yes	32 (13.6)	37 (12.2)		0.9 (0.7 to 1.3)		
dnk or dnwa	12 (5.1)	15 (4.9)		0.9 (0.4 to 2.1)		
Declaring chronic treatment						
Yes	46 (19.6)	18 (5.9)	<b>&lt;0.001</b>	1	0.001	1
No	189 (80.4)	286 (94.1)		3.9 (2.2 to 6.9)		2.9 (1.6 to 5.3)
Distance to health facilities (day)						
≤1	144 (61.5)	192 (63.4)	0.664	1		
>1	90 (38.5)	111 (36.6)		0.9 (0.7 to 1.3)		

\*Goodness-of-fit of the model (Hosmer-Lemeshow)=0.912.  
†Adjusted OR after logistic regression.  
‡Bold: variables included in the multivariate analysis.  
§Not introduced in the final model because significance related to 'dnk' answer.  
dnk, does not know; dnwa, does not want to answer.

difference in having taken their medication the past week (55.4% among women vs 44.6% among men,  $p=0.224$ ) (table 2).

## DISCUSSION

This study provides new insights on several health determinants of the population working in informal ASGM in French Guiana. These poorly educated migrants from Brazil have no access to drinkable water or to latrines, live in close contact with wild fauna by hunting or eating bushmeat or being bitten/stung and were exposed to mercury by inhalation and ingestion. They report frequent accidents and chronic treatments' interruptions. Half of them consider themselves in good health, which is associated with male gender, absence of chronic treatment and of aggression from wild fauna as well as access to drinkable water and latrines.

## Limitations

The study was questionnaire-based and therefore data relied on subjective, self-reported information. The recruitment through opportunistic meeting and snowball sampling limits the representativity of the sample. The enrolment process was conducted in staging areas, thus gold miners who never or rarely leave the camp were under-represented. Also, more health-conscious persons

may have been more likely to participate. Chronic diseases might have been under-reported due to participants' lack of awareness of the problem. Because the study was conducted by a medical team, the participants may have given the more socially desirable answers.

## A suitable combination for poor health

The present study showed that this population of economic migrants encounter a peculiar profile of health determinants (socio-economical and behavioural characteristics, environmental determinants or access to healthcare) that can impact their health (figure 3). First, they are exposed to vectorborne diseases due to highly frequent insect stings and delayed access to care. Thus, the link between malaria and gold mining is well documented<sup>20–22</sup> and led to the implementation of specific interventions in the Guiana Shield.<sup>23 24</sup> According to the participants, malaria remains one of the first health problems encountered on mining sites, followed by cutaneous leishmaniasis, transmitted from sloths through sandflies causing a high morbidity (prevalence of suspected active mucocutaneous leishmaniasis of 2.4% (95% CI 0.8 to 3.9) in 2019<sup>9</sup>). Second is the risk related to zoonoses due to close contact with wildlife, which favours pathogen transmission and/or spillover.<sup>25</sup> Previous surveys have shown a high exposure to leptospirosis (prevalence of 28.1% (95% CI 23.5 to 32.7) in 2019), and the discovery of a new species of *Anaplasma* and of *Brucella* in patients

**Table 2** Social determinants of health according to gender among people working on informal gold mines in French Guiana

	Gender		Univariate analysis	
	Women	Men	P value	OR (95% CI)
	N (%)	N (%)		
<b>Sociodemographic determinants</b>				
Age (years)				
≤38	69 (48.3)	208 (52.5)	<b>0.381</b>	1
>38	74 (51.8)	188 (47.5)		0.8 (0.6 to 1.2)
Time spent in gold-mining activity				
≤8 years	86 (60.1)	189 (48.0)	<b>0.013</b>	1
>8 years	57 (39.9)	205 (52.0)		1.6 (1.1 to 2.4)
Education				
Primary or none	32 (22.4)	190 (48.0)	<b>&lt;0.001</b>	1
Secondary or superior	111 (77.6)	206 (52.0)		0.3 (0.2 to 0.4)
Income (in number of Brazilian minimum wages)				
≤1	35 (24.5)	58 (14.7)	0.034	1
2–3	81 (56.6)	273 (68.9)		2.0 (1.2 to 3.3)
≥4	19 (13.3)	45 (11.4)		1.4 (0.7 to 2.8)
dnk or variable income	8 (5.6)	20 (5.1)		1.5 (0.6 to 3.8)
<b>Behavioural determinants</b>				
Access to drinkable water				
No	135 (94.4)	373 (94.2)	0.925	1
Yes	8 (5.6)	23 (5.8)		1.0 (0.5 to 2.4)
Access to latrines				
No	136 (95.1)	378 (95.5)	0.865	1
Yes	7 (4.9)	18 (4.6)		0.9 (0.4 to 2.3)
Consumption of piscivorous fish				
No	37 (25.9)	58 (14.7)	<b>0.01</b>	1
Yes	104 (72.7)	330 (83.3)		2.0 (1.3 to 3.2)
dnk	2 (1.4)	8 (2.0)		2.6 (0.5 to 12.7)
Contact with mercury (two dnk)				
No	88 (61.5)	132 (33.5)	<b>&lt;0.001</b>	1
Yes	55 (38.5)	262 (66.5)		3.2 (2.1 to 4.7)
Electronic/Mechanical waste left in the forest				
Yes	111 (77.6)	324 (81.8)	0.314	1
No	4 (2.8)	15 (3.8)		1.3 (0.4 to 4.0)
dnk	28 (19.6)	57 (14.4)		0.7 (0.4 to 1.2)
<b>Environmental determinants</b>				
Hunting on the gold mines (one dnk)				
No	129 (90.9)	281 (71.0)	<b>&lt;0.001</b>	1
Yes	13 (9.2)	115 (29.0)		4.1 (2.2 to 7.5)
Butchering bushmeat				
No	55 (38.5)	297 (75.2)	<b>&lt;0.001</b>	1
Yes	88 (61.5)	98 (24.8)		0.2 (0.1 to 0.3)
Cooking bushmeat				
No	38 (26.6)	297 (75.8)	<b>&lt;0.001</b>	1
Yes	105 (73.4)	95 (24.2)		0.1 (0.1 to 0.2)

Continued



Table 2 Continued

	Gender		Univariate analysis	
	Women	Men	P value	OR (95% CI)
	N (%)	N (%)		
Bushmeat consumption				
No	58 (40.9)	120 (31.0)	<b>0.034</b>	1
Yes	84 (59.2)	267 (69.0)		1.5 (1.0 to 2.3)
Bite by wild fauna in the past year				
No	62 (43.4)	117 (29.6)	<b>0.003</b>	1
Yes	81 (56.6)	279 (70.5)		1.8 (1.2 to 2.7)
Access to healthcare				
Perception of health				
Poor/Medium	80 (55.9)	155 (39.1)	<b>0.001</b>	1
Good	63 (44.1)	241 (60.9)		1.9 (1.3 to 2.9)
Accident in the past year on the gold mine				
No	124 (86.7)	319 (80.6)	0.178	1
Yes	12 (8.4)	57 (14.4)		1.8 (0.9 to 3.6)
dnk or dnwa	7 (4.9)	20 (5.1)		1.1 (0.5 to 2.7)
Declaring chronic treatment				
No	114 (79.7)	361 (91.2)	<b>&lt;0.001</b>	1
Yes	29 (20.3)	35 (8.8)		0.4 (0.2 to 0.6)
Distance to health facilities				
≤1 day	86 (61.0)	250 (63.1)	0.652	1
>1 day	55 (39.0)	146 (36.9)		0.9 (0.6 to 1.4)

Values in bold are variables included in the multivariate analysis.  
dnk, does not know; dnwa, does not want to answer.

working in gold mining.<sup>9 26 27</sup> The very high exposure to bat bites exposes them to rabies and potentially to other known or unknown pathogens.<sup>28</sup> Third is the risk of gastrointestinal infections and digestive parasitosis due to extremely poor sanitation and limited access to clean drinking water. Digestive disorders were the third main health issue on gold mines mentioned by participants. There are no data about intestinal infections among the gold miners, but military returning from mining sites were frequently infected by hookworm, ascariasis or giardiasis.<sup>29</sup> Access to clean drinking water, one of WHO's SDGs, is also a major public health issue in other areas of French Guiana, contributing to a high incidence of intestinal infections in this region.<sup>30-33</sup>

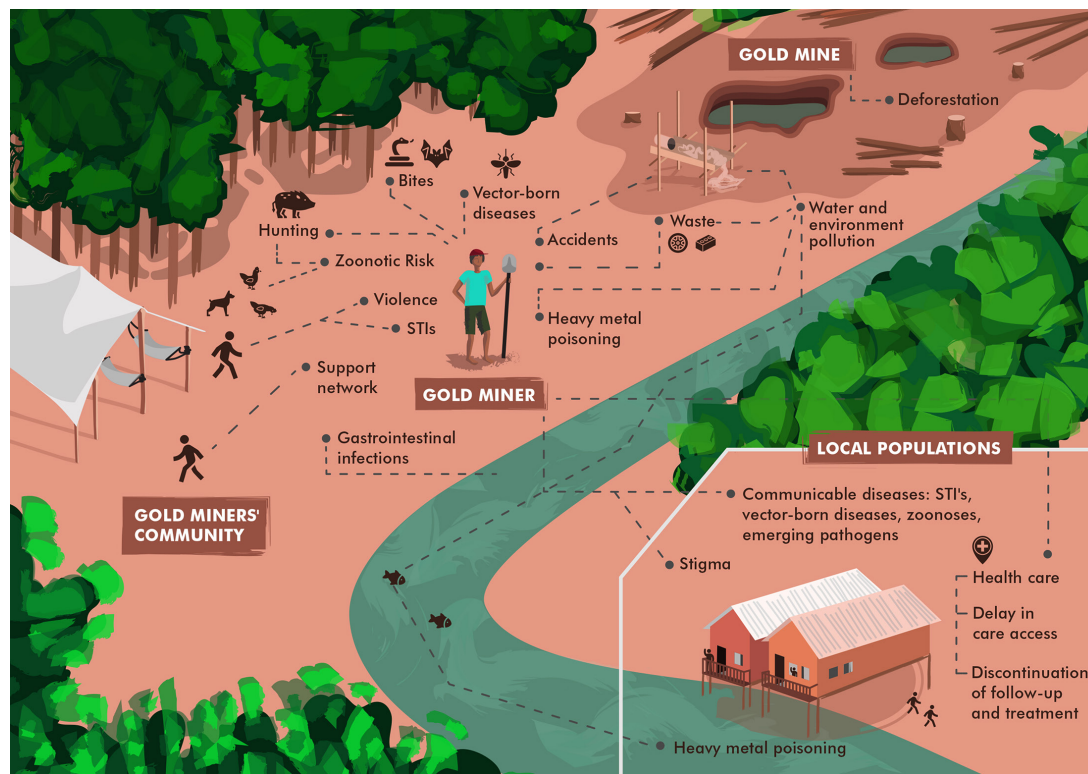
Chronic diseases were likely to be underdiagnosed, and follow-up and treatment seemed to be frequently interrupted, which can lead to complications. Women described a poorer perception of their health status and reported more often following a chronic treatment, probably because women attend health centres more often.<sup>34 35</sup>

Occupational injuries were frequent, such as all-terrain vehicle (ATV) accidents, falling trees, collapse of a primary mine shaft, etc. Almost half (44%) of the

emergency calls from informal gold mines until 2010 in French Guiana (which represents 0.5% of the emergency calls (340/71 932)) were related to trauma.<sup>36</sup> As observed in other ASGM, personal protective equipment kits were virtually absent.<sup>5 6</sup> Deaths due to undocumented fever or trauma in the gold mines were reported. Deceased persons are most of the time buried near the camp, localising the grave with a handmade wooden cross (personal observation<sup>6</sup>).

Pollution of the immediate environment of gold miners is detrimental to the forest, and in turn may harm the polluters' health. Inhalation of mercury affects the respiratory tract and consumption of methylmercury contaminated fish may result in severe neurological and psychomotor disorders.<sup>37</sup> Electronic and mechanical waste left abandoned in the forest releases numerous toxic compounds including heavy metals (such as lead) or toxic gases when burned.<sup>38</sup> It is also worth mentioning that the destruction of batteries, ATV, petrol drums, etc, by Police Operation has the same effect. Further analyses are in progress to assess heavy metal poisoning among gold miners in French Guiana.

Several studies have shown a correlation between perceived health and morbimortality.<sup>39</sup> In our study,



**Figure 3** The gold miner, his environment, his community and local populations in French Guiana: individual and collective health issues in 2022.

56.4% of the respondents considered themselves to be in good health, which is comparable to the rates reported about the general population of Brazil (53%)<sup>40</sup> and higher than in people with low economic status in southern Brazil (49.5%). This could indicate that our predominantly male population generally has a perception of better health or that they are indeed physically fit adults who migrate for work ('healthy worker bias').

### Other health determinants to explore

Several other health determinants specific to the population working in ASGM have been described elsewhere in the literature and could be the subject of further studies. One of those is food insecurity (inaccessibility or limited diversity) due to the exorbitant cost of food due to the isolation and the hazards of supply (eg, interception by military operations) can cause profound deficiencies.<sup>11 41 42</sup> Another determinant is the violence which can occur in these communities outside the framework of the social rules of the countries or through exogenous sources of violence such as the recent phenomenon of the control of gold mines by Primeiro Comando da Capital, the largest drug trafficking factions ('facções') in Brazil, or by itinerant organised crime groups robbing the camps.<sup>43 44</sup>

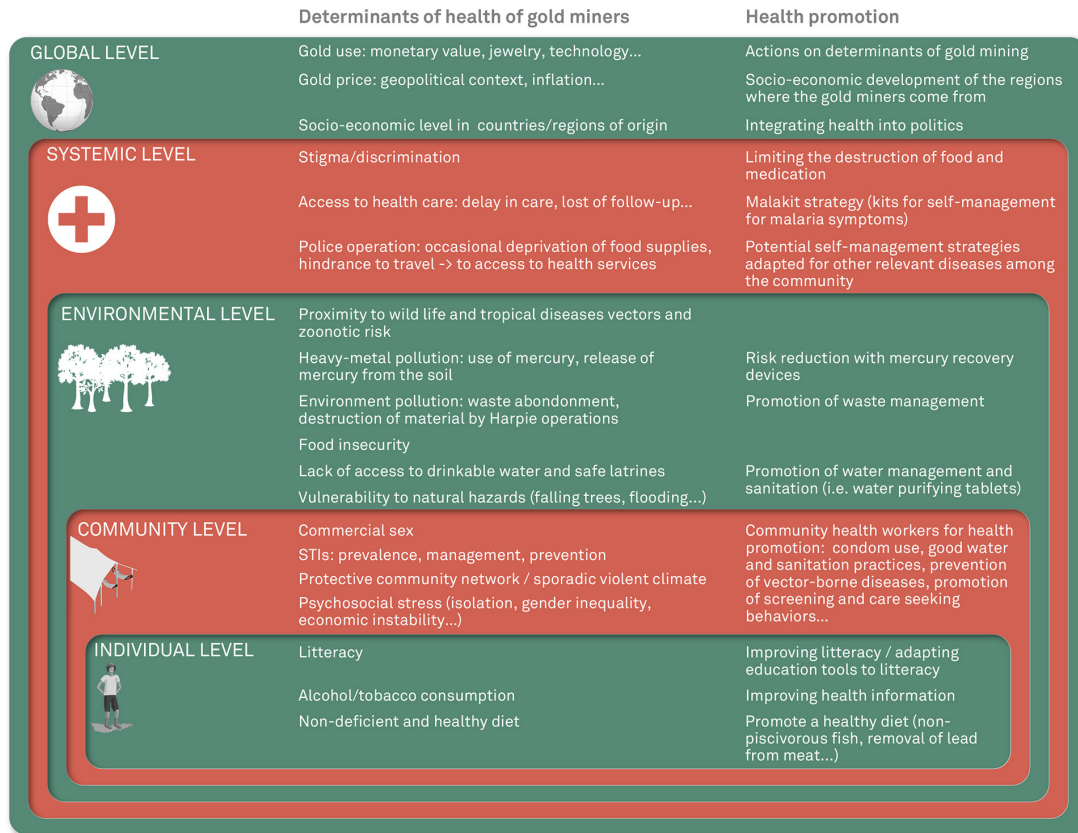
The question of gender inequality should be deeper explored. Indeed, surveys have shown that women on gold mines face specific issues such as commercial sex or lower incomes (however the proportion of men and women reporting high incomes (>4 BMW) is the same,

and female camp leaders or mine owners do occur).<sup>45 46</sup> Finally, mental health has been identified as a health issue in other studies in ASGM communities.<sup>5</sup> Isolation from society in general and from family in particular, precarious health conditions, instability of income, stigmatisation and tensions that may arise within the community or with other local communities can lead to significant psychosocial stress, which could be assessed in further studies.

However, some protective health determinants from previous studies can be put forward. The population was quite young (median age of 38 years), with a frequent—although likely overestimated—use of condoms (93.4% in commercial sex), a reported low consumption of crack or cocaine (1.2%) and an obesity ratio far below that of French Guiana or Brazil (7.7% >30 body mass index compared with 18.8% in French Guiana and 26% in Brazil)<sup>8 47 48</sup> (unpublished data). The strong social link between people working in informal mining camps might also be a positive determinant for health: social support networks (support from families, friends and communities) are linked to better health.<sup>49</sup>

### Human rights, regulation, ecology... a thorny issue

The subject of health of clandestine workers involved in informal ASGM is delicate and raises many operational, political, legal and ethical questions: should health authorities be directly involved in the provision of health-care and prevention for illegal migrants who moreover



**Figure 4** Health determinants of gold miners at individual, community, environmental, systemic and global level in French Guiana in 2022. STI, sexually transmitted infection.

are involved in informal activities.<sup>50</sup> The approach to reduce this scourge in France is essentially repressive.

Weighing the intended benefits of the country's actions (eg, preserving the forest through prevention of deforestation and environmental pollution) need to be weighed against the negative consequences for health of the migrants and for the general population. For example, hindrance to travel leads to poor access to malaria diagnosis and treatment for the gold miners population, which may hinder the country's aspirations towards malaria elimination.<sup>51</sup> Other example, the burning of chemicals during police interventions and the pressure on miners limiting their involvement in protecting their environment worsens pollution. The Ottawa Charter states that "our societies are complex and interconnected and health cannot be separated from other objectives".<sup>52</sup> Also, the right to health is well enshrined in the Declaration of Human Rights and the Geneva Charter emphasises the responsibility of decision makers: 'well-being is a political choice'.<sup>53</sup> These statements demonstrate the relevance and our duty to incorporate health into all aspects of our societies, including the ASGM issue.

The global drivers of gold mining include the precarious socio-economic conditions in the migrant's country of origin (here the poorest states of Brazil<sup>7</sup>) and the ever-increasing price of gold (figure 4). The health issues related to gold mining must necessarily be considered on this global scale. At the systemic level, strategies are proposed such as

implementing the Malakit intervention for self-diagnosis and self-treatment of malaria to strengthen access to quality care adapted to the remoteness of the population.<sup>23</sup> At the environmental level, risk-reduction approaches such as mercury use recovery devices or alternative methods or a better waste management could be promoted.<sup>54</sup> At the community level, health workers could promote healthy behaviours such as condom use, good water and sanitation practices, prevention of vectorborne disease, etc. Finally, providing adapted health messages and tools such as water treatment tablets could improve health at the individual level.

For millennia, throughout the world, our societies have valued gold through symbolism, jewellery or monetary value. Today, only 8% of gold is used for technology.<sup>55</sup> But more broadly, we all are end users of minerals in our daily lives. We need to take a collective responsibility for our way of life and be concerned about the first ring of this gold chain: those who work hard to extract it. An international reflection on the concept of fair, clean and responsible mining, both for the protection of the environment and the respect of human rights, starting with health promotion, is essential. This is particularly true in France, which has significant resources and a long commitment of defending human rights.

### CONCLUSION

This study provides the first comprehensive description of the determinants of health among gold miners in the



Amazon region. We have shown that this population is subject to a peculiar combination of adverse exposures. Several of these factors could be mitigated by actions with and for the population to improve their health. Transdisciplinary reflection involving social, medical and environmental sciences as well as policy makers and the ASGM population would be beneficial to engage together in enhancing population health. This vision meets the core principles of the 2030 agenda of the United Nations, in particular SDG 3 aimed at achieving universal health coverage and providing access to safe and affordable medicines and vaccines for all and reducing health inequalities: ‘No one left behind’. That should be a commitment of humanity.

#### Author affiliations

<sup>1</sup>Centre d'Investigation Clinique Antilles-Guyane, CIC Inserm 1424, Centre Hospitalier de Cayenne, Cayenne, French Guiana

<sup>2</sup>CNRS, UMR 8586, PRODIG, Paris, France

<sup>3</sup>Laboratory of Parasitic Diseases, Oswaldo Cruz Foundation, Rio de Janeiro, Brazil

<sup>4</sup>Foundation for the Advancement of Scientific Research in Suriname, Paramaribo, Suriname

<sup>5</sup>Laboratory of Parasitic Diseases, Institute Oswaldo Cruz, Foundation Oswaldo Cruz, Rio de Janeiro, Brazil

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**Patient consent for publication** Consent obtained directly from patient(s).

**Ethics approval** The protocol was approved by the National Ethics Board of Suriname (CMWO (Commissie voor Mensgebonden Wetenschappelijk Onderzoek), N°005/22) and of Brazil (CONEP (Comissão Nacional de Ética em Pesquisa), N° 5.507.241). The database was pseudonymized and registered according to the European General Data Protection Regulation (GDPR). This study was conducted in accordance with the principles set forth in the Declaration of Helsinki. Participants gave informed consent to participate in the study before taking part.

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#### ORCID iD

Maylis Douine <http://orcid.org/0000-0003-4616-6690>

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