Knowledge and awareness of health effects related to the use of mercury in artisanal and small-scale gold mining in Suriname

I.B. Ottenbros⁎, R.Z. Boerleidera, B. Jubitanab, N. Roeleveldb, P.T.J. Scheepersa

a Radboud Institute for Health Sciences, Radboud University Medical Center, P.O. Box 9101, 6500 HB Nijmegen, The Netherlands
b Medische Zending Primary Health Care Suriname, Zonnebloemstraat 45–47, Paramaribo, Suriname

ARTICLE INFO

Editor: Prof. Yong-Guan Zhu
Keywords:
Mercury
Artisanal and small-scale gold mining
Risk communication
Health education
Public health
Human biomonitoring

ABSTRACT

Background: The use of mercury in artisanal and small-scale gold mining has negative effects on human health and the environment. In Suriname, the current gold rush resulted in estimated mercury emissions up to 63t per year. To reduce the use of mercury and the subsequent health impact to gold miners and local inhabitants, knowledge and awareness in the community should be increased.

Methods: This study evaluated the effects of a health education programme (HEP) on the levels of knowledge and awareness among local inhabitants and small-scale gold miners in active gold mining areas in the interior of Suriname, South-America. Baseline knowledge levels were assessed with a survey prior to the implementation of the HEP. Thereafter, the exact same questions were asked to evaluate the effects. A total of 959 local inhabitants and 140 gold miners completed the survey including five topics: general knowledge on mercury, potential routes of exposure, health risks for children versus adults, mercury related health effects, and reproductive risks. Additionally, participants were asked in a separate survey (n = 107) about potential exposure reduction techniques and their willingness to be involved in a future human biomonitoring programme.

Results: The HEP influenced knowledge on exposure routes of mercury (increase from 64% to 78% of respondents who could name the relevant exposure routes) and on health effects attributed to mercury (increase from 48% to 70% of respondents who were able to list the correct health effects). After the HEP, 70% of the respondents affirmed the higher sensitivity of children, while knowledge on reproductive health effects increased from 39% to 63%. Self-estimated levels of knowledge also increased, indicating lower anxiety regarding potential risks of mercury. Gold miners reported to be willing to improve their work procedures (e.g. burning amalgam with a retort), although suitable tools were not always available. Consistent results were found for individuals included in both surveys, before and after the health education programme. Almost all respondents in the separate survey reported to be willing to give consent for participation in a future human biomonitoring programme, for themselves and their children.

Conclusion: The implementation of a health education programme within an existing local healthcare structure proved effective and levels of knowledge and awareness improved. Most improved was the knowledge on health effects attributable to mercury, more specifically reproductive health effects.

1. Introduction

In Suriname, South-America, approximately 17,000 individuals (12% of the total workforce) are officially registered gold miners in the artisanal and small-scale gold mining (ASGM) sector, of which 11,000 are nationals (Duijves and Heemskerk, 2014; Hammond et al., 2007). The total number of people employed in ASGM is unclear due to the informal nature of the work. Rough estimates go as high as 40,000 small-scale miners. The small-scale gold mining industry is firmly embedded across the Guianas (Bulkan and Palmer, 2016; Canterbury, 2016; Tudesque et al., 2012), employing approximately 30% of the Guianas' population and tens of millions more in the developing world (UNEP, 2013). The effects of the current gold rush exceed those of earlier gold rushes in terms of the number of people involved, the amount of gold produced, and the socioeconomic and environmental impacts on Suriname (Heemskerk et al., 2016). Satellite imagery

Abbreviations: ASGM, Artisanal and small-scale gold mining; HEP, Health education programme; GMP, Global mercury project
⁎Corresponding author at: Institute for Risk Assessment Sciences, Division of Environmental Epidemiology, Utrecht University, Yalelaan 2, 3584 CM Utrecht, The Netherlands.
E-mail address: I.B.Ottenbros@uu.nl (I.B. Ottenbros).
https://doi.org/10.1016/j.envint.2018.10.059
Received 23 July 2018; Received in revised form 26 October 2018; Accepted 30 October 2018
Available online 16 November 2018
0160-4120/ © 2018 Elsevier Ltd. All rights reserved.
suggested that deforestation induced by gold mining in Suriname has doubled between 2008 and 2014, as compared to the 2001–2008 period (Rahm et al., 2015). In 2015, the amount of gold produced by ASGM was estimated to be 18.9 t, which is about 68% of the total gold production in Suriname and corresponds to a mercury emission of approximately 63 t (Duijves and Heemskerk, 2014).

ASGM activities are located in the regions Central and East Suriname (the so-called trans-Amazonian Greenstone belt, see Fig. 1). A previous study showed that a large part of ASGM miners are foreigners, mostly of Brazilian origin (Duijves and Heemskerk, 2014). The mobility of the miners is very high and they move frequently from one mining site to another, which makes it challenging to involve this group in follow-up studies. In Suriname, mining sites are only partly registered and although registration systems are in place, there is a lack of controls. Benefits of registration for gold miners are unclear and the proof of registration (a paper slip) does not make one a “legal” gold miner (Duijves and Heemskerk, 2014). The unregulated ASGM sector has a negative impact on the environment and presents severe health risks for the miners and communities in Suriname. While the communities are often dependent on the income from gold mining and related activities. The main environmental risks and health risks are posed by the use of mercury in the ore extraction process, in tailings, and in sitation of rivers (Healy and Heemskerk, 2005). With a case study in 2014, Duijves and Heemskerk found that almost all (97.8%) workers in Suriname used mercury during the mining process (Duijves and Heemskerk, 2014). Various mining techniques are practiced, with different quantities of mercury, dependent on the gold extraction methodology applied. Most commonly used techniques are hydraulic pumps with a sluice box, panning, crushing and grinding, mining by river dredges, or a combination of these. The amount of mercury applied mostly depends on the amount of ore to be processed (more ore requires more mercury), ore grade (lower ore grade requires more mercury), and grain size of the gold (lower grain size requires more mercury) (Heemskerk et al., 2016).

On a worldwide scale, ASGM is seen as one of the major contributors to mercury consumption and emissions into the environment, affecting millions of people, particularly in low- and middle-income countries (Veiga et al., 2006). Growing concerns about gold-mining induced mercury contamination have led to international actions, including the Global Mercury Project (GMP) in 2002 and the Minamata Convention in 2013. The latter aims to reduce the release of mercury to the environment by 2020 (UNEP, 2013) and came officially into force on 16 August 2017. Article 16 of this convention relates to human health and it encourages identifying all possible human populations affected by mercury pollution, adopting health guidelines to regulate mercury exposure, and providing education about the risks of mercury exposure. Although Suriname has a substantial contribution in the global mercury emissions, the Surinamese government was not involved in the GMP. On 8 March 2018, however, the parliament of Suriname approved legislation to ratify the Minamata Convention on mercury. This is an important step towards the reduction and ultimate phasing out of mercury use in the ASGM sector, since Suriname has “more than insignificant” amounts of ASGM within its border, it is now required to develop a National Action Plan. The Minamata Convention signifies the recognition of the mercury pollution from the ASGM sector as an intractable global problem (Clifford, 2014; Sippl, 2015). Formalization and regularization of the sector is a major part, by assigning one environmental ministry as responsible (Hilson et al., 2018). Along with funding community initiatives, the complex political and economic incentives that drive mercury trade and mercury use must be addressed (Spiegel et al., 2018). Baseline information about, for example, knowledge levels and mercury exposures, is key in formulating effective strategies towards tackling mercury emissions (Clifford, 2017).

The global use of mercury in ASGM communities is associated with adverse health effects, including kidney dysfunction and neurological symptoms (WHO, 2013). Gold miners and inhabitants living in ASGM areas are exposed to metallic mercury vapour directly through inhalation when burning amalgam, as well as indirectly via mercury vapour on contaminated skin, clothes or hair (Scheepers et al., 2014). Methylmercury is formed by anaerobic bacteria in the aquatic environment, and bioaccumulation in the food chain can lead to high exposure when consuming contaminated predator fish (Gibb and O’Leary, 2014; US EPA, 1996; Ha et al., 2017). Both mercury species primarily affect the central nervous system, the kidneys, and the cardiovascular system (WHO, 2013; Boerleider et al., 2017). Methylmercury exposure among pregnant women, foetuses, and young children is of special concern, (Counter and Buchanan, 2004; Driscoll et al., 2013), since the foetal brain is very susceptible throughout pregnancy, while further development extends well into childhood (Roelveld et al., 1990). Exposure of the unborn child to methylmercury has also been associated with low birth weight and delayed growth and development in children (Bose-O’Reilly et al., 2010; Grandjean et al., 2010).

High concentrations of mercury in human specimens in ASGM communities have been found in various studies (Baemul et al., 2011; Gibb and O'Leary, 2014; Kristensen et al., 2014). In Suriname, only a few human biomonitoring studies were performed with limited representativeness for the ASGM areas and workers. A recent study found relatively high levels of mercury in hair from women and children of villages partly corresponding to our study area (Ouboter et al., 2012), as compared to US national averages. The mercury levels found were similar to those seen in women from longitudinal studies finding neurological impairments in children exposed pre- and postnatally. In a pilot study around the border with French Guyana, mercury concentrations were determined in blood, urine and hair samples of a group of 76 pregnant women (Quik, 2017). The majority of the participants had mercury levels in blood and urine below the reference level.

Fig. 1. Overview of the selected active mining areas and corresponding villages, located in the so-called Greenstone Belt (green coloured area), extending from North-central to South-East Suriname, South America. Grey areas are the areas contusted between neighbouring countries Guyana and French Guyana and Suriname. The study areas are numbered as follows: 1. Sarakreek (villages: Lebi Dotie and Bakoe), 2. Brokopondo (Brokopondo and Balinguila), 3. Boven Saramacca (Nieuw Jacobkondre and Poesoegroenoe), 4. Beneden Marowijne (Langatabbetje and Nason), 5. Brownsweg (Brownsweg and Nieuw Koffiekamp), 6. Klaaskreek (Klaaskreek and Nieuw Lombe).
study sites were selected based on the presence of mining activities. An
principal investigator ensured equal interpretation of the questions. The
ners) for consistent translations. Training and supervision by the prin-
to the local languages and Portuguese (for Brazilian migrant gold mi-
were performed by trained interviewers who spoke the languages of the
assess the current level of knowledge and awareness of mercury related
mining activities were significantly elevated compared to those from a
control group (de Kom et al., 1998). Another pilot study assessed
mercury concentration in hair from mothers and newborns, among
whom 14 mothers (36%) had elevated levels compared to a US re-
ference value. Moreover, 31 newborns (80%) had higher mercury
levels in hair than their mothers (Mohan et al., 2005). In 2012, Ouboter
et al. reported mercury levels in predator fish, of which 41% were
above the European standard for human consumption (Ouboter et al.,
2012). Unfortunately, mercury exposure related health effects are not
reported systematically in Suriname. In other ASGM areas, the health
effects reported among workers were neurologic effects, including
tremors, ataxia, memory problems, and vision disorders (Gibb and
O'Leary, 2014). These were found to occur not just among those en-
aged in mining activities but also due to fish consumption by in-
dividuals living downstream of areas with mining activities.

It is recommended to develop effective communication aiming at a
reduction of exposure in the ASGM sector, resulting in improvements of
levels of knowledge and awareness (Ha et al., 2017; UNEP, 2013). As
stated in the Minamata convention, small-scale approaches may lead to
less mercury intoxication and lower emissions of mercury into the en-
vIRONMENT (UNEP, 2013). There is only limited insight in the current
level of knowledge about mercury related health effects among gold
miners and local inhabitants. Information in Suriname is scarce, re-
sulting in a need for accessible and objective information on health
effects and possible protective measures that could be taken to reduce
exposures. To this end, a health education programme (HEP) was im-
plemented, and its effectiveness and feasibility were measured to im-
prove the knowledge infrastructure in a community health perspective.
The HEP addressed the general risk of mercury, groups at high risk,
potential routes of exposure (indirectly via diet for inhabitants and
directly for gold miners), related health effects, and possible protective
or avoidance measures. In addition to the HEP, information was gath-
ered about the feasibility of a future biomonitoring programme, be-
cause demonstrating actual values of mercury in the human body (in
blood, urine or hair) will support awareness and increase motivation to
act, leading to a reduction of exposure on family and individual levels.

2. Methods

2.1. Baseline survey

The first round of surveys was performed in April and May 2016 to
assess the current level of knowledge and awareness of mercury related
health effects among gold miners and local inhabitants. All surveys
were performed by trained interviewers who spoke the languages of the
participants using a standardized questionnaire, which was translated
to the local languages and Portuguese (for Brazilian migrant gold mi-
ners) for consistent translations. Training and supervision by the prin-
cipal investigator ensured equal interpretation of the questions. The
study sites were selected based on the presence of mining activities. An
overview of the six selected areas with villages and corresponding
mining fields is presented in Fig. 1. The number of participants included
in the study was proportional to the total number of inhabitants for that
area, as indicated by the local health registration systems. Participants
were recruited if they were 18 years of age or older and lived for more than
one month in a village close to an active mining area (local in-
habits), or were working and living at the mining fields in the ASGM
sector (gold miners). Recruitment of local inhabitants at baseline oc-
curred at different times of the day and at every other house for the
more densely populated areas, and at all houses in the less densely
populated areas. At each location, the family member with the first
birthday coming up was invited to participate. All participants signed
an informed consent form before participating. The study was approved
by the medical ethical committee in Suriname.

The survey consisted of 43 questions and covered five topics (see
Table S1 in the Supplementary Material for an extensive overview of
the content of each topic). The first topic, general knowledge on mer-
curry, was covered by questions about the appearances of metallic
mercury and mercury vapours (colour and odour) and the presence of
mercury in objects inside the house. Next, questions were asked con-
cerning exposure routes through inhalation, diet (fish), and dermal
uptake. Thirdly, participants were asked if they were aware of the fact
that children were more sensitive to mercury when compared to adults,
and if children in active gold mining areas were at higher risk or not. At
the fourth topic, participants were asked if they had knowledge on the
health effects of mercury, and if so, if they were able to name these. At
last, questions were posed about knowledge on reproductive health
risks for both men and women, during pregnancy, for the unborn child,
and regarding breastfeeding. The survey was the same for local in-
habits and gold miners. All questions were scored: “1” for a correct
answer and “0” for an incorrect answer, resulting in average knowledge
indices per topic (Table 1). The correctness of these answers was vali-
dated in a literature review (Boerleider et al., 2017). For comparison
between the different topics, all average indices were expressed on a
scale from 0 to 1. Next to the quantitative answers, participants were
asked for motivation or reasoning for their answers given. These were
written down as completely as possible by the interviewer. Next to the
two main topics of the survey, all respondents were asked to estimate
their own level of knowledge about mercury and its health effects, and
to assess the magnitude of the mercury issue (whether mercury causes
concerns or not), expressed on an ordinal scale from 0 to 1. Further
needs and worries expressed were categorized into “yes” and “no” and
the concerns were referred to the local healthcare organization for re-
response.

2.2. Health education programme (HEP)

The intervention in the form of a health education programme
(HEP) took place in July and August 2016. This programme was de-
veloped based on the outcome of the baseline survey, anticipating on
the needs of specific knowledge. The HEP covered general knowledge
on mercury, potential routes of exposure, health effects, health risks for
children, and reproductive risks. The motivations for this HEP were: the
need for knowledge about potential health risks related to mercury and
actions the villagers and gold miners could take to reduce their own
exposures to mercury. The HEP was conducted within a local healthcare

| Table 1 |
| Total number of respondents included in the different surveys. |
| Local inhabitants | Gold miners | All |
| Health education programme | Baseline | After HEP | Baseline | After HEP | Baseline | After HEP |
| One survey | 747 | 153 | 97 | 39 | 844 | 192 |
| Two surveys (baseline and after HEP) | 59 | 4 | 63 | 107 |
| Exposure reduction & biomonitoring interview | 77 | 30 | 107 |


Note: The survey results are presented in detail in Table S1 in the Supplementary Material.
organization (Medische Zending Primary Health Care Suriname). For all participants, education materials including posters, flyers, and informative videos were made available in different languages. The posters included information on the health effects of mercury, high risk exposure groups, and the potential exposure routes of mercury. Additionally, a mobile application was developed as a reference platform for the healthcare workers. All nurses and healthcare professionals who would provide information were trained. This training included general information about mercury and related health effects, how to work with the education materials, identification of hazardous behaviour at the gold fields, and how to deal with challenging situations/questions. For each area included in the study, both villages and gold fields, the HEP was provided at least two times. In addition, when people visited the local medical clinics they received the information personally.

2.3. Evaluation of the HEP

The effects of the HEP were assessed by a second round of surveys from September to November 2016 in a subgroup of inhabitants and gold miners who participated in the baseline survey and/or took part in the HEP. The survey was equal to the baseline survey and consisted of the same 43 questions. The same study areas, recruitment criterion, and interviewers (or interviewer training for new interviewers) were used as with the baseline survey. Individuals who followed the HEP were actively approached. This back-sampling strategy resulted in a sampling size of approximately 23% of the participants in the baseline survey. The participants followed the HEP themselves (in a group or individually) or received the information via a family member/colleague or through posters or videos. Small-scale gold miners are typically mobile and migrant populations, which made it more difficult to actively approach miners who followed the HEP.

During this second round of surveys, additional questions were asked about which possible protective or exposure reducing measures could be taken and about the willingness to participate in a human biomonitoring programme. For these additional questions, having followed the HEP was not a compulsory criterion. These interviews were also conducted among gold miners visiting the city of Paramaribo, who were asked about potential exposure reducing measures and participation in a potential biomonitoring programme.

An overview of the total number of participants at baseline and after the HEP is given in Table 1, as well as the numbers of persons who participated in the additional interview on what they could do to reduce their personal exposure, as well as their interest to participate in a human biomonitoring study.

2.4. Statistical analyses

The data were analysed using IBM SPSS Statistical Software (IBM, USA, Version 25) after checking for completeness. Descriptive statistics were performed for the characteristics being a miner, age, gender, place of birth, level of education, residential/work area, and the type of the HEP (direct or indirect), which were tested for differences using ANOVA. Also, correlations were tested in a Pearson correlation matrix for both groups of participants (one and two interviews). Student’s t-tests were used to compare the ‘knowledge index’ for each topic of interest based on the surveys before and after introduction of the HEP. The calculations for the knowledge indices are given in Supplementary Table S1, expressed as the sum of all correct answers divided by the maximum number of correct answers for each topic (scaled from 0 to 1). The knowledge indices for the individuals participating before (n = 844) or after (n = 192) the HEP only, were tested with independent Student t-tests. Paired t-testing was performed in the group of respondents who participated both before and after the HEP (n = 63). Gold miners and local inhabitants were treated here as one group since the group of gold miners was too small (n = 4) for separate analysis. Statistical significance was assumed when p-values were < 0.05. Linear regression analyses were performed to assess the associations between the effects of the HEP and being a miner or inhabitant on the average score of the topic of interest. Other variables assessed for possible inclusion in the regression modelling were: gender (male or female), age (< 35 years or ≥ 35 years), place of birth (Surinamese or elsewhere), level of education (no education and only primary school, or high school and higher education), residential/work-area (divided in 6 resorts, as indicated in Fig. 1). For the group of participants before and after the HEP, linear mixed regression models were made, correcting for the inter-individual variation.

3. Results

3.1. Study characteristics

A total of 806 local inhabitants and 101 gold miners completed the survey at baseline, while 212 inhabitants and 40 miners did so after the HEP. Among these, 59 inhabitants and 4 miners participated in both surveys (Table 1). In addition, 107 respondents answered questions about potential exposure reduction measures and participation in a biomonitoring programme. The characteristics of the participants in the surveys at baseline and after the HEP are listed in Table 2, differentiated into local inhabitants and gold miners with one survey and participants in both surveys. No differences were seen among the groups regarding the age of the participants. Compared to gold miners, the local inhabitants were more likely to be female and having the Surinamese nationality. The gold miners surveyed after the introduction of the HEP were higher educated compared to the gold miners at baseline (56.4% vs. 85.6% with no education or only primary school, respectively). A small similar difference was found between the groups of local inhabitants (68.0% vs. 75.1%), albeit not statistically significant. Only relatively small differences were seen in the geographic region of origin. The vast majority of participants surveyed after the HEP took part in the HEP personally. Compared to the groups participating only once, the group that participated at baseline and after the HEP included slightly more women (74.6%). Otherwise, the latter group was largely comparable to the local inhabitants. The statistically significant Pearson correlation coefficients (p < 0.05) between the characteristics are shown in Fig. 2 for both groups of participants (one or two surveys). Being a gold miner was correlated with being male and non-Surinamese, which is in line with the characteristics as described in Table 2.

3.2. Effects of the health education programme on knowledge and awareness

The questions were classified into five main topics (see Table S1): general knowledge on mercury (appearance and presence), exposure routes of mercury (through inhalation, diet and skin), health risks to children and adults (higher sensitivity among children), health effects caused by mercury, and reproductive risks. The knowledge index for each topic was calculated on a scale from 0 to 1 (see Table 3 for all indices); additional qualitative statements and some explanations of the answers given can be found in the discussion section. No statistically significant differences were seen between direct (having followed the HEP themselves, in a group or individually) or indirect (via a family member/colleague, posters or videos) information provision. For this reason, all participants who received information were treated as one group in further analyses.

The general level of knowledge on mercury was moderate (knowledge index of 0.49 on a scale of 0 to 1) and did not change much due to the HEP (Table 3). Regression modelling showed influences of gender (lower index for females in both groups), level of education, and place of birth on the general level of knowledge on mercury (see Supplementary Table S2). Understanding of relevant routes of exposure was
clearly improved by the HEP for both local inhabitants and gold miners, which was confirmed in the group participating in the surveys at baseline and after the HEP. Regression modelling confirmed these results and additionally found a negative effect for female gender and a positive effect for a higher level of education on the knowledge index for exposure routes. The knowledge about the specific influence of mercury on the health of children was estimated to be larger after the HEP (knowledge index increased from 0.57 to 0.70), and even more so for gold miners than for local inhabitants. In addition, regression analysis showed a positive effect for female gender and a negative effect for being born in Suriname. These findings were not confirmed among the participants in both the surveys at baseline and after the HEP, presumably because the knowledge level was already relatively high (index of 0.65). The health effects for adults were evaluated by a single question (“Does mercury cause health effects?”), which was answered affirmatively by almost all respondents, regardless of participation in the HEP. However, the knowledge index for gold miners increased from 0.81 to 0.95 after the HEP and correct mercury specific health effects (asked as open question) were addressed more frequently. The HEP had a large effect on the topic of reproductive health risks: the response of both local inhabitants and gold miners increased markedly following the HEP (knowledge index changed from 0.40 to 0.61 and from 0.29 to 0.73, respectively). This effect was confirmed in the group that participated both at baseline and after the HEP, and with respective regression analyses, showing that no other variables influenced this knowledge domain. More specifically, the HEP improved knowledge on reproductive effects of mercury for both men and women, on adverse effects for pregnant women, on effects of mercury on the child’s health during pregnancy, and on adverse effects for breastfeeding.

The self-estimated level of knowledge also increased after the HEP, indicating a higher level of confidence among the respondents regarding their knowledge about mercury and its health effects. The perceived magnitude of the mercury issue showed a reduction in the group of inhabitants after the HEP, but this reduction was not seen in the group of gold miners. The numbers of worries and needs expressed by all respondents decreased as well, but not statistically significantly in all groups.

Table 2

<table>
<thead>
<tr>
<th>Characteristics of the participants in the study divided into local inhabitants and gold miners and into participation in the baseline survey and/or the survey after the HEP.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Local inhabitants</strong></td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
</tr>
<tr>
<td><strong>Total number</strong></td>
</tr>
<tr>
<td><strong>Average age in years (SD)</strong></td>
</tr>
<tr>
<td><strong>Number of women (%)</strong></td>
</tr>
<tr>
<td><strong>Place of birth (%)</strong></td>
</tr>
<tr>
<td>Surinamea</td>
</tr>
<tr>
<td>Brazilb</td>
</tr>
<tr>
<td>Otherc</td>
</tr>
<tr>
<td><strong>Level of education (%)</strong></td>
</tr>
<tr>
<td>No education or only primary school</td>
</tr>
<tr>
<td>Region of origin (%)</td>
</tr>
<tr>
<td>Sarakreek</td>
</tr>
<tr>
<td>Brokopondo</td>
</tr>
<tr>
<td>Boven Saramacca</td>
</tr>
<tr>
<td>Beneden Marowijne</td>
</tr>
<tr>
<td>Brownsweg</td>
</tr>
<tr>
<td>Klaaskreek</td>
</tr>
<tr>
<td><strong>Type of health education programme (%)</strong></td>
</tr>
<tr>
<td>Direct</td>
</tr>
<tr>
<td>Indirect</td>
</tr>
</tbody>
</table>

<sup>a</sup> Statistically significant difference between local inhabitants and gold miners (p-value < 0.05, ANOVA).

<sup>b</sup> Including: French Guyana, Guyana, Dominican Republic, Jamaica, China.

<sup>c</sup> Statistically significant difference comparing questionnaire results before and after the introduction of the health education programme (HEP) (p-value < 0.05, ANOVA).

Fig. 2. Graphical presentation of the Pearson correlation coefficients for the characteristics of the participants in one of the two surveys (left) and both surveys (right).

Direction and strength of the correlations are represented by the colours and the size of the dots. Statistically significant positive correlations are shown as blue dots, whereas negative correlations are shown as red dots. No statistically significant correlations are left empty. Characteristics include: age, survey before or after HEP (Before_After_HEP, only for participants in one of the two surveys), place of birth (Born, Suriname or not), educational level (Education), gender, being a local inhabitant or gold miner (Inhabitant_Miner, only for participants in one of the two surveys), and Location (6 regions). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
3.3. Routes of exposure and participation in a future human biomonitoring programme

Regarding potential mercury exposure routes, measures to reduce exposure, and participation in a future human biomonitoring programme, a total of 77 local inhabitants and 30 gold miners were interviewed. Of the local inhabitants 46% were living together with a gold miner, of which almost 70% regularly took work clothes and tools home. Clothes were washed daily with water and soap, mostly by the worker himself (66%). A large group of local inhabitants consumed fish weekly or more frequently (61%). However, no distinction was made between the types of fish in this survey. Of the local inhabitants 65% indicated that they did not see any possibilities to reduce their own exposure to mercury. The questionnaires for the gold miners were slightly different, with a more specific focus on their mercury related work tasks. Excavation systems most used in the gold fields were hydraulic systems with or without excavator, small hydraulic systems (maximal 3 men), crusher systems, or panning. Mercury was applied in hydraulic systems with or without excavator, small hydraulic systems (maximal 3 men), crusher systems, or panning. Mercury was applied in hydraulic systems with or without excavator, small hydraulic systems (maximal 3 men), crusher systems, or panning. Mercury was applied in hydraulic systems with or without excavator, small hydraulic systems (maximal 3 men), crusher systems, or panning.

Of the respondents 70% indicated to have touched mercury with bare hands (maximal 3 men), crusher systems, or panning. Mercury was applied in hydraulic systems with or without excavator, small hydraulic systems (maximal 3 men), crusher systems, or panning. Mercury was applied in hydraulic systems with or without excavator, small hydraulic systems (maximal 3 men), crusher systems, or panning. Mercury was applied in hydraulic systems with or without excavator, small hydraulic systems (maximal 3 men), crusher systems, or panning.

Almost all respondents indicated to be interested in their mercury body burden and were willing to give permission to provide urine, exhaled breath, hair, and blood (with a few exceptions for the last two sample types, e.g. because of religion). The respondents were also willing to give consent for participation of their children in a biomonitoring study.

Table 3
Knowledge indices of the different content areas, expressed on a scale from 0 to 1.

<table>
<thead>
<tr>
<th></th>
<th>Local inhabitants</th>
<th>Gold miners</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>After HEP</td>
<td>Baseline</td>
</tr>
<tr>
<td><strong>General knowledge on mercury</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Answered correctly (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One survey</td>
<td>0.48 (0.25)</td>
<td>0.48 (0.24)</td>
<td>0.58 (0.16)</td>
</tr>
<tr>
<td>Two surveys</td>
<td>0.64 (0.28)</td>
<td>0.78 (0.22)</td>
<td>0.67 (0.28)</td>
</tr>
<tr>
<td><strong>Exposure routes of mercury</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Answered correctly (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One survey</td>
<td>0.58 (0.40)</td>
<td>0.70 (0.37)</td>
<td>0.48 (0.40)</td>
</tr>
<tr>
<td>Two surveys</td>
<td>0.81 (0.39)</td>
<td>0.85 (0.36)</td>
<td>0.81 (0.39)</td>
</tr>
<tr>
<td><strong>Health risks for children</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Health effects for adults</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Answered correctly (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One survey</td>
<td>0.47 (0.50)</td>
<td>0.68 (0.47)</td>
<td>0.58 (0.50)</td>
</tr>
<tr>
<td>Two surveys</td>
<td>0.40 (0.40)</td>
<td>0.61 (0.37)</td>
<td>0.29 (0.31)</td>
</tr>
<tr>
<td>b) Correct health effects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Answered correctly (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One survey</td>
<td>0.18 (0.23)</td>
<td>0.30 (0.25)</td>
<td>0.13 (0.21)</td>
</tr>
<tr>
<td>Two surveys</td>
<td>0.66 (0.35)</td>
<td>0.57 (0.34)</td>
<td>0.65 (0.39)</td>
</tr>
<tr>
<td><strong>Perceived magnitude of the mercury issue</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One survey</td>
<td>0.44 (0.50)</td>
<td>0.38 (0.49)</td>
<td>0.54 (0.50)</td>
</tr>
<tr>
<td>Two surveys</td>
<td>0.93 (0.26)</td>
<td>0.87 (0.34)</td>
<td>0.91 (0.29)</td>
</tr>
<tr>
<td><strong>Reproductive risks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Answered correctly (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One survey</td>
<td>0.18 (0.23)</td>
<td>0.30 (0.25)</td>
<td>0.13 (0.21)</td>
</tr>
<tr>
<td>Two surveys</td>
<td>0.20 (0.23)</td>
<td>0.32 (0.23)</td>
<td>0.20 (0.23)</td>
</tr>
<tr>
<td><strong>Expressed worries</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With worries (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two surveys</td>
<td>0.44 (0.50)</td>
<td>0.38 (0.49)</td>
<td>0.54 (0.50)</td>
</tr>
<tr>
<td>Two surveys</td>
<td>0.93 (0.26)</td>
<td>0.87 (0.34)</td>
<td>0.91 (0.29)</td>
</tr>
<tr>
<td><strong>Expressed needs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With more needs (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two surveys</td>
<td>0.97 (0.17)</td>
<td>0.92 (0.27)</td>
<td>0.97 (0.17)</td>
</tr>
</tbody>
</table>

* Statistically significant difference comparing questionnaire outcome at baseline and after introduction of the health education programme (p-value < 0.05, tested with independent and dependent Student's t-tests for participants in one or two surveys, respectively).

4. Discussion

This study is a first attempt to evaluate and quantify the effects of an information campaign in an active gold mining area and surrounding communities in Suriname. Existing programmes in the ASGM sector mostly focus on monitoring of the levels of mercury in the environment, in fish, or in the human body, instead of knowledge and education levels. Before changes in attitudes and beliefs can be expected to occur, knowledge and awareness should be developed first (Heemskerk et al., 2016; Pavilonis et al., 2017; Sousa and Veiga, 2009). The HEP implemented in this study made use of different methods of information provision, including videos and visual materials, to ensure reaching as many people as possible. All materials used can be found online (Medische Zending, 2017). The trainers (from the health care organization) were either local inhabitants themselves and/or were familiar with the specific local habits. Also, the HEP was always discussed with the head of the village first, to ensure support and acceptance. The HEP in this study focused on the health effects of mercury, which is different from other programmes that also include cleaner technologies and mineralogy (Zolnikov and Ramirez Ortíz, 2018). The programme introduced in this study is a starting point for mercury exposure reduction in the ASGM community and surrounding villages in Suriname, including training on alternative techniques. Up-to-date and practical mining laws and regulations are necessary to empower miners to achieve higher productivity and recovery rates. This may eventually lead to more environmentally sustainable gold mining (Healy and Heemskerk, 2005). The HEP in this study proved to be effective and was implemented within a local healthcare organization, which opens up possibilities for future continuation and expansion, as well as further development in the interior of Suriname.

The ASGM sector is very unpredictable. Many miners are working illegally and the mobility of miners is very high; they are frequently moving from one mining site to another where they believe to find "easier" extractable gold (Sousa and Veiga, 2009). The ASGM sector is distinct by boom and bust cycles in the gold rush, mostly directed by economical aspects. Many of the gold miners are hardworking individuals, searching for a better economical position. People tend to see mining as a better alternative than traditional agriculture and farming. The necessity of generating a livelihood often outweighs the potential negative implications on health. Also, the level of education is usually
low and the miners live far away from their families and hometowns. In Suriname, the mining population is heterogeneous in terms of ethnic origin, family background, living conditions, and many other sociocultural aspects (Duijves and Heemskerk, 2014; Healy and Heemskerk, 2005). Interventions in the mining process have not been widely accepted because the miners did not believe that the new processes removed as much gold as possible. In addition, a lack of knowledge about mineralogical characteristics of the ore affects the gold recovery, which may be reflected in an increase in the use of mercury (Zolnikov and Ramirez Ortiz, 2018). Combined with a lack of systematic organization, these aspects make it even more challenging to raise levels of knowledge and awareness in the ASGM sector.

This intervention study included 1099 unique participants, among which 140 gold miners. In addition, selection of the study population was done carefully, taking into account the presence of current and past gold mining activities, combined with closely related villages and communities. Although the number of participants involved in a training programme alone is not the best indicator of efficacy, since it does not reveal the consequences of the training, which main goal is to change attitudes (Sousa and Veiga, 2009). Inclusion of local inhabitants in this study gives a better view on the total community as strong ties exist between the ASGM activities and the nearby villages. These villages are often dependent on the income from gold mining and related activities. Many inhabitants work in the gold fields during the day and return after work to eat and sleep in the villages with their families, thereby transferring exposure. In addition, local inhabitants are exposed by frequently eating mercury-contaminated fish from the area and drinking river water. The characteristics of the local inhabitants included in this study are representative for the general population of Suriname in terms of gender and place of birth (see the Supplementary Material Table S3) (Algemeen Bureau voor de Statistiek, 2012). The characteristics of the participants showed correlations between being a gold miner, place of birth, and gender, which is explained by the large group of Brazilian immigrants among the predominantly male gold miners. The gold miners interviewed after the HEP were found to be higher educated than those who participated in the baseline survey, potentially slightly overestimating the effects of the HEP observed among the gold miners.

The HEP had the largest influence on the knowledge of exposure routes, health risks related to children, health effects attributed to mercury, and reproductive health risks. On all of these topics, approximately 70 to 80% of the respondents provided correct answers after following the HEP, as compared to between 40 and 65% before taking part in the information sessions. General knowledge on mercury might not have been covered sufficiently in the HEP, as especially many of the local inhabitants were not aware of the appearance and characteristics of metallic mercury. They had often heard of the substance mercury, but had never seen it themselves and were not able to describe it. Local inhabitants addressed diet more often as a route of exposure, while gold miners referred more frequently to a contribution of inhalation as most important route of exposure. This is in line with the most important route of exposure to be expected in each of the groups. Only approximately 12% of the local inhabitants were familiar with the fact that mercury is also present in items in the home environment, such as thermometers. Our results indicate that all respondents became more aware of the larger sensitivity of children living in active gold mining areas. The explanations given the most were ‘Children have a lower resistance’, ‘Children are not fully grown yet’, and ‘Children are not aware of health risks and they put everything in their mouth’. Previous knowledge on the reproductive health risks was relatively low, resulting in a large increase in knowledge on this topic. Impotency was mentioned the most as reproduction toxic health effect. Effects mentioned as caused by mercury exposure during pregnancy were ‘miscarriage’, ‘feeling weak and ill’ (for both mother and child), and ‘giving birth to a disabled child’. Effects on breastfeeding were less often recognised, with most answers relating to mercury being toxic and being able to enter the child’s body through breastmilk.

The self-estimated level of knowledge was increased after the HEP, implicating more confidence and awareness among the respondents. The perceived magnitude of the mercury issue and the expressed needs and worries were decreased, which is a desired result of such an education programme. Still, mercury was perceived as a significant issue for adverse health effects. People declared that it was dangerous and lethal, contaminating the environment, water, and fish. Even though many people knew mercury exposure was an issue, they remained concerned because of low knowledge in understanding its dose-response. ‘It is a big issue because you do not know when the concentration in your body is too high.’ The needs and worries expressed differed before and after the HEP, being more specific after. Some of the answers given were: ‘What are the long-term effects of mercury? How soon will the effects occur or disappear?’, ‘How much mercury is present in my food?’, and ‘What can we do to reduce our own exposure and that of our children?’. These questions indicate that the participants were well informed about the health risks and were searching for more specific information for their situation.

Only a few other studies investigated the levels of knowledge on the health effects of mercury in gold mining areas. A cross-sectional study was performed among 160 gold miners in Tanzania (Charles et al., 2013). In that area, just 60% was aware of the health effects of mercury, compared to 81% and 95% in our study before and after the HEP, respectively. In Tanzania only 21% were able to identify at least one health symptom associated with mercury exposure, whereas, even before the HEP, 58% of the gold miners were able to do so in Suriname. In Tanzania, knowledge regarding mercury toxicity was associated with gender and the economic activity of the individual (Charles et al., 2013). Males were more knowledgeable than females and those involved in mining were more knowledgeable than those who were not miners (Charles et al., 2013). This finding was observed in Suriname as well for general health risks, but not for risks among children or reproductive risks.

A study in Brazil aimed to assess the effects of the GMP, launched by the United Nations in 2002, by using so called performance indicators (Sousa and Veiga, 2009). The GMP aims to reduce mercury emissions through the introduction of simple technologies, education campaigns, and environmental awareness. After participation in the training programme, a substantial reduction in the amount of mercury used was achieved, in particular by mercury recycling, amalgamation in designated places (e.g. away from water bodies, such as rivers), and the use of retorts. These improvements in work practices were a direct result of increased knowledge, and were quite similar to the situation observed in Suriname after the HEP. However, the access to mercury was not controlled so it could be bought without any requirements (equal to the situation in Suriname), creating another difficulty in the control of mercury reduction.

The potential exposure reducing measures which can be taken differ for the local inhabitants and the gold miner populations, since their exposure scenarios are partly different. Local inhabitants should be made aware of the high concentrations of methylmercury in predatory fish and secondary exposure to mercury vapours from items, such as the working clothes of a gold mining family member. For gold miners, direct exposure during mercury application and the amalgam burning process can be reduced by changing work practices, for example amalgamation in a designated place and use of a retort (Sousa and Veiga, 2009). Although promoting retorts has been done repeatedly, the aversion of gold miners remains (Bosse Jansson et al., 2013). Mercury exposure reduction projects are currently aiming for alternative work practices to reduce exposure, such as gravimetric processing (Teschner et al., 2017), of which some pilots are running in Suriname. These projects are small-scale and further expansion should go along with educational programmes and small businesses to provide the expertise and machinery needed, resulting in local economic benefits (Heemskerk et al., 2016).
To have a large scale impact, governmental cooperation is essential to involve all stakeholders in the ASGM community and the large mining companies in the area (Fritz et al., 2016; Spiegel and Veiga, 2017). Human biological monitoring for mercury exposure for assessment. AIMS Environmental Science 4 (2), 251–276. https://doi.org/10.3934/envsci.2017.2.251.


