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Research Article

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Mercury Exposure among Artisanal and Small-Scale Gold Miners in Four Gold Mining Districts in the East Region of Cameroon

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Abstract

Artisanal and small-scale gold mining (ASGM) is the single largest intentional-release of mercury (Hg) in the world. In Cameroon, there is paucity of data concerning the contribution of ASGM to human mercury contamination. This study aimed at providing new data for a region in Cameroon where ASGM is practiced, through an assessment of the concentration of total mercury (T-Hg) in hair as a function of occupational exposure, and investigating symptoms related to Hg toxicity. A quantitative cross-sectional survey design was employed involving 60 gold miners from four gold mining districts: Batouri, Kette, Ngoura and Bétaré-Oya. Questionnaire was used to collect sociodemographic data, nature of work processes and symptoms of Hg toxicity. Scalp hair samples were drawn from all 60 respondents and analysis for total mercury (T-Hg) in hair was done via a milestone DMA-80 Mercury Analyzer. The results show that males (86.7%) were generally represented than females (13.3%). The minimum, maximum and mean concentrations of Hg in hair of miners across the four districts was 0 µg/g, 8.97 µg/g and 2.09±1.84 µg/g respectively. Over three-quarters (71.7%) of the miners had T-Hg in hair above the occupational toxic threshold of 1 µg/g set by the United States Environmental Protection Agency (USEPA), also identified as 66.7% in the "alert level" and 5% as "high" according the German Human Biomonitoring (HBM) Commission. The factors affecting the concentration of mercury in hair according to a multiple linear regression model (R2 = 0.400 and p = 0.03) were living in Bétaré-Oya, younger age, male sex, burning of amalgam, and increased number of working days per week. According to the same model (R2 = 0.076 and p = 0.940), the symptoms associated with mercury exposure were unusual tiredness, excessive sleeping, dizziness and visual difficulties. ASGM in the east region of Cameroon, therefore, is significantly contributing to Hg contamination in humans as a result of occupational exposures to Hg, and there is urgent need for interventions to mitigate human exposure, especially as adverse health effects cannot be excluded following long-term exposures.

Keywords: Mercury, Exposure, Artisanal and Small-Scale Gold Mining, Miners, Hair, Occupational Toxic Threshold, Cameroon.

1. Introduction
1.1 Background
Artisanal and small-scale mining (ASGM) refers to gold mining operations by individuals, groups, families or cooperatives with minimal or no mechanization, often in the informal (illegal) sector of the market [1]. It takes place in diverse regions around the world, mostly in the global South – sub-Saharan Africa, Asia, Oceania, Central and South America. It is considered as a considerable source of revenue and livelihood for over 40.5 million people from more than 80 countries worldwide [3,4]. According to the U.S. Geological Survey, ASGM alone accounted for about 11.5 – 13.6% of total world's gold production in 2019 [5]. In Cameroon, ASGM has been taking place principally in the eastern and northern regions since 1933, and forms part of a rapidly growing informal sector largely stemming from poverty. Typically, ASGM involves extracting gold from sediments or rocks with use of rudimentary tools through an array of events from ore extraction to gold capture through mercury (Hg) amalgamation, thanks to mercury's ability to bind to gold forming a mercury-gold alloy called "amalgam" [6]. This amalgam is further heated (smelted) to vaporize the Hg and recovering the gold (WHO, 2016) [6]. Among other methods, the Hg amalgamation is still being widely used [5].

Mercury (Hg) is a chemical element with a silver-grey color. It is environmentally distributed in three forms (elemental, organic and inorganic), each with specific chemical characteristics [7]. Elemental Hg, also known as quicksilver, is liquid at room temperature and it is poorly absorbed in the gastrointestinal tract. However, when volatized into vapor, it is well-absorbed through the lungs and quickly enters the circulatory system to the central nervous system (CNS), blood cells, and kidneys where it is converted to HgCl2 and retained for years [8]. Organic Hg (i.e., methyl, ethyl, or phenylmercury) is usually formed through bioaccumulation of mercuric compounds by aquatic microorganisms and eventually released into the environment. Among the various forms, methylmercury (MeHg) seems to be the most toxic in aquatic environment [9]. Inorganic Hg, usually referred to as mercury salts, are useful for several products including medicines, explosive detonators, and mercuric fulminates (WHO, 2003) [9].

Humans can be exposed to two forms of Hg in an ASGM context: elemental Hg and organic Hg, and this can be direct or indirect [6]. Direct exposure is chiefly through inhalation of vaporized form of elemental Hg present in ambient air during amalgam smelting (the main source of exposure), or direct skin contact through handling [6,11]. Indirect exposure, on the other hand, occurs as a result of the presence of elemental Hg vapor contaminating surrounding surfaces, getting into water bodies, fishes, foodstuffs etc. The major sources of all non-occupational exposures are through dietary intake of contaminated fishes and seafood [7].

The main adverse health effects of Hg exposure include neurotoxicity, teratogenicity, nephrotoxicity, and immunotoxicity. Based on global human biomonitoring data, between 3.3 and 6.5 million miners suffer from moderate to chronic metallic Hg vapor intoxication [12]. In Cameroon, Obase et al., (2018) found that 9.1% of artisanal gold miners exhibited symptoms probably related to chronic Hg intoxication. Acute exposure through inhalation could lead to erosive bronchitis and bronchiolitis with symptoms of sore throat, chest pain and shortness of breath. Acute exposure through skin contact could lead to dermatitis. Chronic exposure could cause neuropsychiatric symptoms such as fatigue, insomnia, anorexia, shyness, withdrawal, depression, nervousness, irritability and memory problems, or kidney disease [6].

Human exposure to Hg can be measured through biological samples like blood, urine and hair. Compared to blood and urine, however, total mercury (T-Hg) content in hair is widely used as a bioindicator of Hg contamination because of its non-invasive sampling technique, and since it can readily be obtained and stored [13]. The internationally recommended limit (occupational toxic threshold) of hair mercury concentration according to WHO and the US Environmental Protection Agency (UNEPA) is 1 µg/g dry weight (dw) in hair [14].

2. Problem Statement
Despite its social and economic importance to many rural communities, ASGM contributes significantly to global mercury contamination with clinical implications on human health, what is described as the "mercury problem" [7]. On global basis, ASGM is the single largest intentional-release of mercury (Hg) in the world, accounting for about 38% of all mercury emissions and releases [15]. Global estimation of the release of airborne elemental mercury attributed to inappropriate mining practices is about 400 tons [16]. It is estimated that for every gram of gold produced by amalgamation, 1 or 2 grams of metallic Hg is lost [17]. Even though trends in current studies point to the increasing disruption of organ and metabolic functions among artisanal and small-scale gold miners as a result of Hg exposure, there is very limited data in Cameroon to show if ASGM is contributing to mercury contamination and toxicity or not. In many African countries, the health and environmental effects of Hg pollution from ASGM has been reported by many authors like Niane et al., (2015), Afrifa et al., (2019), Kwaansa-Ansah et al., (2019), and Wanyana et al., (2020) but very little information is available in Cameroon [7,13,18,19].

The overarching objective of the Minamata Convention on Mercury is "to protect human health and the environment from anthropogenic emissions and releases of Hg and Hg compounds," through the development and implementation of public health strategies as part of a national action plan, and through education, training and raising public awareness on the effects of human and environmental exposures to Hg. This Convention was ratified by the government of Cameroon under Law No.2018/017 of 11 December 2018, but the level of its implementation, monitoring and evaluation in the ASGM sector of Cameroon is not clear.

This study aimed at providing new data, as a baseline for public health actions, for a region in Cameroon where ASGM activities involves the use of mercury. The main objective was to assess the level of exposure of artisanal gold miners to mercury, by measuring the total concentration of mercury in hair, and investigating clinical symptoms relating to mercury toxicity. The study was conducted as part of the Mines, Environment, Health and Society Phase 2 (ProMESS 2) project by a Cameroonian NGO, Forêt et Développement Rural (FODER), drawing evidence from four gold mining districts in the East Region of Cameroon.

2. Materials and Methods

2.1 Study design

A quantitative cross-sectional survey design was employed conducted between May and July 2022.

2.2 Study Area and Setting

The study was conducted in four (4) artisanal gold mining districts in the east region of Cameroon namely Batrouri, Ngoura, Kete and Bétaré-Oya. Mining is one of the major economic activities in these districts besides other subsistence activities like agriculture, and the activity is primarily informal in nature. Each of the district is characterized by numerous mining sites and access within the sites is by tracks and forest roads. Gold exploitation is principally carried out by the natives (artisans) with the use of rudimentary tools such as diggers, pickaxes, spades, shovels, pans and water pumps. The activity does not respect age or gender, and in some households, both the parents and children are involved. The mining process was basically the same in all the four districts involving ore extraction, processing, concentration, amalgamation and burning of amalgam. Generally, there are two main methods of amalgamation in ASGM: whole-ore amalgamation and concentrate amalgamation [6]. It is worth noting that concentrate amalgamation was the method observed in all the four districts. In this method, the Hg is added only to the smaller quantity of material (concentrate) that results from the concentration step. As a result, considerably less Hg is generally used. Whereas in whole-ore amalgamation, Hg is added with little prior comminution and concentration. Burning of the amalgam was mostly done on shovels or metal pans over open air using blow torches or open locally made fire, and usually in household vicinities. The final product (gold) is then sold to gold collectors either at the sites of amalgamation or taken to gold shops. Some gold collectors further burn the final product to further separate Hg from gold.

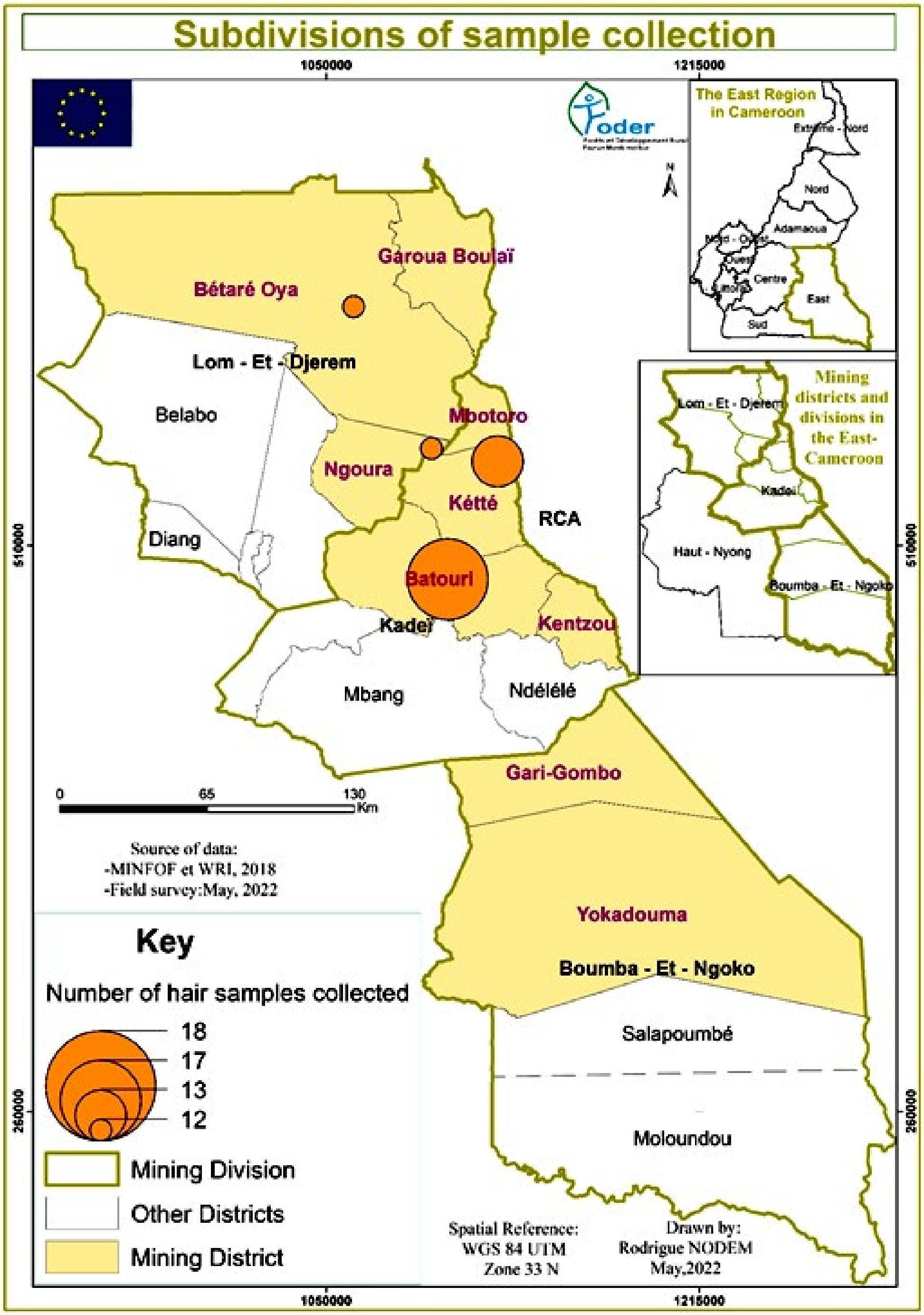

Figure 1: Location map of study areas showing the four artisanal gold mining districts: Batouri, Kette, Ngoura and Bétaré-Oya

2.3 Study Population and Sampling

The target population of study included all artisanal gold miners (adults, adolescents and children) with at least one year of working experience in ASGM who consented to participate. Miners with no ongoing direct occupational-related mercury exposure or who use other methods for gold extraction (e.g., borax or cyanide) were excluded.

A nonprobability purposive method of sampling was used to select the four (4) gold mining districts. These districts were selected based on their pervasiveness of mining activities and also because of their accessibility. Recruitment of study participants and selection of the mining sites was done through non-probability convenience sampling based on participants' involvement in ASGM, and proximity of the mining sites respectively. A total of 60 participants were recruited as follows: Batouri (18), Kette (17), Ngoura (12) and Bétaré-Oya (13).

3. Data Collection Procedure

In each of the mining districts, community sensitization was done by field facilitators in the pre-data collection phase. Data collection then began with mass recruitment of study participants with the help of the field facilitators, gatekeepers and local authorities, followed by field visits of various ASGM sites. At each level, the aim of the study was explained to the participants, health talks on "mercury as a chemical hazard in ASGM" were offered, and consent to participate were then obtained from the participants. Structured questionnaires were used to collect sociodemographic characteristics and information on the mining processes (including number of days of work per week, number of working hours per day, nature of tasks, frequency and modes of exposure to mercury). The questionnaire was also used to screen for ten (10) symptoms relating to mercury toxicity. This was followed by collection of scalp hair samples, cut from the occipital region, of varying lengths (0.5 – 1 cm) and quantities (50 – 100 strands). The samples were labeled in pieces of tin foil and stored in transparent plastic bags containing desiccants prior to transportation to the Analytical Chemistry Laboratory of the University of Michigan in the USA for analysis. The hair samples were collected from all the 60 participants. Covid-19 prevention and barrier measures were strictly respected throughout the entire data collection process.

4. Laboratory Analysis

Total mercury (T-Hg) in hair was analyzed via a Milestone DMA-80 Direct Mercury Analyzer calibrated with linear, low range (0 – 20 ng) calibration curve using known standard reference materials. The instrument thermally decomposes the sample, amalgamates the mercury, and uses spectrophotometry to quantify the concentration of Total Mercury in each sample. Samples were weighed into cuvettes prior to analysis and ranged from 0.5 – 10 mg depending on density of hair. Cuvettes were loaded into the sample tray and taken into the instrument individually for analysis. Blanks were run along with the samples.

5. Ethics Approval

An ethical approval was obtained from the Institutional Review Board of the Faculty of Medicine and Biomedical Sciences (FMBS) of the University of Yaoundé 1.

6. Data Analysis

The data collected were analyzed with the help of the IBM Statistical Package for the Social Science (SPSS) version 20. Descriptive statistics was employed, and means were compared using analysis of variance. The Pearson Chi-square test was used to test the relationship between variables, and p-value $P<0.05$ at 95% confidence interval (CI) was considered statistically significant. Multiple linear regression was conducted to determine the effects of various sociodemographic characteristics as predictors for the concentration of total mercury in hair (T-Hg), and relationship between T-Hg and various symptoms of Hg toxicity. The data was presented on tables.

7. Results

7.1 Sociodemographic Profile

Table 1 shows the sociodemographic characteristics of the respondents. Hair samples were drawn from a total of 60 respondents: 18 (30.0%) from Batouri, 17 (28.3%) from Kette, 12 (20.0%) from Ngoura, and 13 (21.7%) from Bétaré-Oya. Males were more represented (86.7%) than females (13.3%). The modal age group was 20 – 29 years representing 22 (36.7%) of the respondents, with a mean of 30.5±10.9 years. Most of them were married (64.4%), and the highest level of education attained by a majority (48.3%) was secondary education. Of the 60 hair samples collected, 47 (78.3%) were from amalgam burners, while 13 (21.7%) were from gold collectors. The average duration spent in mining activities by the participants was 11.6±11.0 years. They work on average 6 days a week, and their average frequency of use or direct contact with mercury was at least once every week.

Variable	**Batouri n (%)**	**Kette n (%)**	**Ngoura n (%)**	**Bétaré-Oya n (%)**	**Total N (%)**
Number of samples	18 (23.4)	17 (17.9)	12 (23.6)	13 (35.1)	60 (100)
Sex					
Male	13 (72.2)	16 (94.1)	11 (91.7)	12 (92.3)	52 (86.7)
Female	5 (27.8)	1 (5.9)	1 (8.3)	1 (7.7)	8 (13.3)
Age group					
10 – 19 years	1 (5.6)	2 (11.8)	1 (8.3)	5 (38.5)	9 (15)
20 – 29 years	8 (44.4)	4 (23.5)	7 (58.3)	3 (23.1)	22 (36.7)
30 – 39 years	7 (38.9)	3 (17.6)	2 (16.7)	5 (38.5)	17 (28.3)
40 – 49 years	1 (5.6)	5 (29.4)	1 (8.3)	0	7 (11.7)
50 – 59 years	1 (5.6)	3 (17.6)	1 (8.3)	0	5 (8.3)
Mean age (years)	30.8±8.7	36.18±12.5	28.8±10.3	24.0±9.1	30.5±10.9
Marital status					

Married	10 (55.6)	13 (81.3)	9 (75.0)	6 (46.2)	38 (64.4)
Not married	8 (44.4)	3 (18.8)	3 (25.0)	7 (53.8)	21 (35.6)
Highest level of education					
No schooling	4 (22.2)	2 (11.8)	0	1 (7.7)	7 (11.7)
Primary	7 (38.9)	7 (41.2)	5 (41.7)	5 (38.5)	24 (40.0)
Secondary	7 (38.9)	8 (47.1)	7 (58.3)	7 (53.8)	29 (48.3)
Role					
Amalgam burners	13 (72.2)	12 (70.6)	11 (91.7)	11 (84.6)	47 (78.3)
Collectors	5 (27.8)	5 (29.4)	1 (8.3)	2 (15.4)	13 (21.7)
Duration of mining (years)	10.2±9.6	16.8±14.0	13.4±10.3	4.3±1.7	11.6±11.0
Number working days a week	6.3±0.8	5.4±1.3	5.8±1.3	5.8±1.6	5.9±1.3
Number of working hours a day	9.6±2.4	7.9±2.3	7.5±3.8	8.9±2.8	8.6±2.8
Frequency of use of Hg					
Daily	7 (46.7)	5 (29.4)	4 (33.3)	5 (41.7)	21 (37.5)
Weekly	7 (46.7)	10 (58.8)	8 (66.7)	7 (58.3)	32 (57.1)
Monthly	1 (6.7)	2 (11.8)	0	0	3 (5.4)

Table 1: Sociodemographic characteristics of artisanal gold miners

7.2 Total Hair Mercury (T-Hg) Levels

Table 2 shows the total mercury concentrations in hair (T-Hg) of miners across the four districts. The values ranged from 0 µg/g – 8.97 µg/g. The minimum, maximum, median, and mean levels of T-Hg were 0 µg/g, 8.97 µg/g, 1.68 µg/g and 2.09 µg/g respectively. The concentrations were highest in Bétaré-Oya with a mean of 3.38 µg/g, and lowest in Kette with a mean of 1.63 µg/g. One-way ANOVA showed a statistically significant difference in T-Hg across the four districts. Figure 2 shows a box plot on the distribution of T-Hg across the four districts.

Total mercury levels (µg/g)	Batouri	Kette	Ngoura	Bétaré-oya	Total	p-value*
N (%)	18 (23.4)	17 (17.9)	12 (23.6)	13 (35.1)	60 (100)	0.009
Mean	1.63	1.32	2.46	3.38	2.09	
Median	1.61	1.10	2.75	2.24	1.68	
Standard deviation	1.21	0.82	1.37	2.98	1.84	
Minimum	0.00	0.00	0.00	0.79	0.00	
Maximum	3.62	3.56	4.63	8.97	8.97	
Range	3.62	3.56	4.63	8.18	8.97	
*One way ANOVA, Chi-square: P<0.05 is statistically significant.						

Table 2: Total mercury concentrations in hair (T-Hg) across the four mining districts

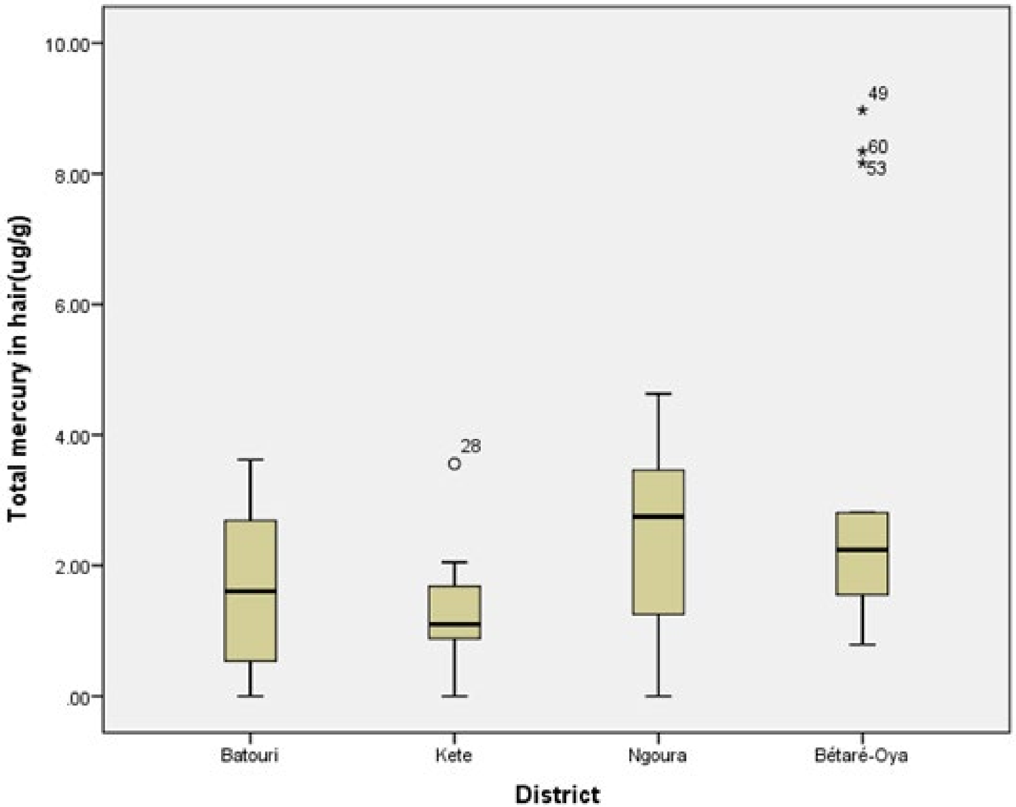

Figure 2: Box plot of mercury concentration in hair

Table 3 shows the T-Hg according to the Human Biomonitoring (HBM). The mercury levels were normal (i.e., <1 µg/g) in 28.3% of the subjects while 71.7% had values above the occupational toxic threshold (i.e., ≥1 µg/g). Forty (66.7%) subjects had values in the alert level (between 1 and 5µg/g) while 3 (5.0%) had high values (> 5 µg/g). Of the three (3) subjects who had high T-Hg values, 2 (3.3%) were adolescents (<20 years of age), while 1 (1.7%) was an adult (≥20 years). All the three subjects with high T-Hg values were males who were amalgam burners, and were from Bétaré-Oya. The results also showed no statistical difference in the T-Hg levels between males and females, and amalgam burners and gold collectors.

Variable	**Toxicological threshold limit**			**Total n (%)**	**P-value***
	HBM I (<1 µg/g)	**HBM I-II (1 – <5 µg/g)**	**>HBM II (≥5 µg/g)**		
Sex					**0.74**
Males	15 (25.0)	34 (56.7)	3 (5.0)	52 (86.7)	
Females	2 (3.3)	6 (10.0)	0	8 (13.3)	
Total	17 (28.3)	40 (66.7)	3 (5.0)	60 (100)	
Age					**0.025**
< 20 years	1 (1.7)	6 (10.0)	2 (3.3)	9 (15)	
≥ 20 years	16 (26.7)	34 (56.7)	1 (1.7)	51 (85.0)	
Mining district					**0.032**
Batouri	7 (11.7)	11 (18.3)	0	18 (30.0)	
Kete	6 (10.0)	11 (18.3)	0	17 (28.3)	
Ngoura	2 (3.3)	10 (16.7)	0	12 (20.0)	
Bétaré-Oya	2 (3.3)	8 (13.3)	3 (5.0)	13 (21.7)	
Role					**0.058**

Amalgam burners	10 (16.7)	34 (56.7)	3 (100)	47 (78.3)	
Gold collectors	7 (11.7)	6 (10.0)	0	13 (21.7)	
Total	17 (28.3)	40 (66.7)	3 (5.0)	60 (100)	
Chi-square: P<0.05 is statistically significant.					

Table 3: Total mercury concentrations in hair (T-Hg) according to the Human Biomonitoring (HBM) categories

7.3 Multiple Linear Regression and Analysis

7.3.1 Factors Affecting Total Concentration of Mercury in Hair

Table 4 represents the symptoms of Hg toxicity while table 5 represents the results of the multiple linear regression and the tested independent predictors affecting the concentration of Hg in hair samples of the respondents. The most prevalent symptom was unusual tiredness (58.3%). The factors predicted to affect the T-Hg included sex (X_1), age (X_2), level of education (X_3), role in the mining process (X_4), duration of mining in years (X_5), frequency of direct exposure to Hg (X_6), number of working hours per day (X_7), number of working days per week (X8), and district of mining (X_9). The results indicated that five factors affected the T-Hg levels: sex, age, role in the mining process, number of working days a week, and district of mining. The predictive ability of the regression model is qualified by $R^2 = 0.400$ and $p = 0.03$. Our study also found that the most important risk factor for T-Hg in hair was number of working days per week ($\beta = 0.425$, $p = 0.002$) followed by district of mining (i.e., living in Bétaré-Oya; $\beta = 0.358$, $p = 0.006$).

Variable	Batouri N (%)	Kette N (%)	Ngoura N (%)	Bétaré-Oya N (%)	Total N (%)
Symptoms					
Headache	10 (30.3)	7 (21.2)	9 (27.3)	7 (21.2)	33 (55%)
Unusual tiredness	7 (20.0)	8 (22.9)	10 (28.6)	10 (28.6)	35 (58.3)
Cough	6 (35.3)	6 (35.3)	3 (17.6)	2 (11.8)	17 (28.3)
Excessive sleeping	1 (20.0)	1 (20.0)	2 (40.0)	1 (20.0)	5 (8.3)
Dizziness	3 (27.3)	1 (9.1)	3 (27.3)	4 (36.4)	11 (18.3)
Tremors	6 (85.7)	0	1 (14.3)	0	7 (11.7)
Pins and needles	7 (31.8)	2 (9.1)	7 (31.8)	6 (27.3)	22 (36.7)
Hearing difficulties	1 (50.0)	0	1 (50.0)	0	2 (3.3)
Visual difficulties	5 (55.6)	2 (22.2)	1 (11.1)	1 (11.1)	9 (15)
Loss of taste sensation	4 (66.7)	0	0	2 (33.3)	6 (10)

Table 4: Symptoms relating to mercury exposure

Predictors	Standardized coefficients		Unstandardized coefficient	P-value
	B	SE	Beta	
Sex (X_1)	0.508	0.665	0.094	0.448
Age (X_2)	-0.004	0.034	-0.022	0.912
Education level (X_3)	1.632	0.765	0.285	0.038
Role in the mining process (X_4)	1.134	0.683	0.246	0.104
Duration of mining (years) (X_5)	-0.006	0.030	-0.032	0.855
Frequency of direct exposure to Hg (X_6)	-1.369	1.164	-0.163	0.245
Hours work per day (X_7)	-0.129	0.082	-0.194	0.124
Number of working days week (X_8)	0.623	0.185	0.425	0.002
District of mining (X_9)	1.650	0.570	0.358	0.006
Regression model $R^2 = 0.400$, $p = 0.03$				

Table 5: Factors affecting total concentration of mercury in hair according to multiple linear regression

7.3.2 Association between Symptoms of Mercury Toxicity and Hair Mercury Levels

Ten (10) symptoms of relating to mercury exposure were explored as shown in table 5. The multiple logistic regression model between the symptoms and the levels of total mercury in hair of the respondents showed four symptoms which were associated with concentration of mercury hair: unusual tiredness, excessive sleeping, dizziness, and visual difficulties. However, these associations were not statistically significant. Symptoms such as persistent cough, resting tremors, paresthesia, hearing difficulties, and loss of taste sensation were not found to be associated with mercury exposure in this study.

Model		Unstandardized Coefficients		P-value
		B	Std. Error	
	Constant	2.376	0.468	0.000
	Unusual tiredness	0.415	0.609	0.499
	Persistent cough	-0.843	0.684	0.224
	Excessive sleeping	0.461	1.001	0.647
	Dizziness	0.351	0.779	0.655
	Resting tremors	-0.012	0.941	0.990
	Paresthesia	-0.859	0.636	0.183
	Hearing difficulties	-0.602	1.506	0.691
	Visual difficulties	0.269	0.837	0.749
	Loss of taste sensation	-0.664	1.014	0.516
	Persistent headaches	-0.053	0.657	0.936

Table 6 :Association between clinical symptoms and mercury hair levels.

8. Discussion

In Cameroon, the use of Hg in the ASGM sector has persisted despite the known negative health effects, and very little is known about the regulations put in place to reduce Hg exposure among artisanal and small-scale gold miners. The present study sought to assess the level of Hg exposure among gold miners in the east region of Cameroon though an assessment of the total hair mercury concentrations (T-Hg) and Hg-related clinical symptoms.

9. Sociodemographic Characteristics

In this study, males were more represented (86.7%) than females (13.3%). The mean age of our participants was 30.5±10.9 years, and over two-third (64.4%) of them were married. This was the physically more active age group, which took advantage of the high demand for physical activity in the ASGM generally. Majority of our subjects (88.3%) had attended some schooling, and the highest level of education attained was secondary education. Sana et al., (2017) in Burkina Faso revealed that over two third of the artisan miners in their study were without any formal education, while two previous studies in Cameroon showed that the highest level of education attained by a majority was primary level [20-22]. The very fact that ASGM is a poverty-driven activity could explain its negative impacts on education. These results are consistent with findings in most literature from countries like Ghana, Burkina Faso, Democratic Republic of Congo, South Africa and Nigeria, positing that the workforce in the mining industry is principally male-dominated. Most literature also revealed that the age group mostly represented was less 30 years, and the sector generally involved less-educated workforce [20,23-26].

10. Hair Mercury Concentration and Threshold Limits

Hair is considered one of the ideal biomarkers for Hg because it provides integrated data over time. The migration of Hg to hair is irreversible; once Hg combines with hair, it never separates and remains consistently [14]. In addition, hair has often been recognized as a biomarker for assessing exposure to MeHg, as this toxic organic form is incorporated into the hair follicle in proportion to its blood content [12]. The internationally recommended limit of hair Hg concentration (the occupational toxic threshold) is 1 μg/g recommended by WHO and the USEPA [14]. However, hair Hg concentration does not generally exceed 10 μg/g [6,14].

An occupational toxic threshold is the level of exposure to a hazardous substance that is considered safe to workers in occupational setting. It is the maximum amount of a substance that a worker can be exposed to without experiencing adverse health effects [27]. According to the German Human Biomonitoring (HBM) commission (1992) of the Federal Environmental Agency Berlin, threshold limits can be adjusted in three categories: T-Hg <1μg/g are considered normal, T-Hg between 1 and 5 μg/g are within the alert level, and T-Hg > 5 μg/g are considered high level. The three categories are termed <HBM I, HBM I-II, and >HBM II respectively [28]. At the “high” level (>HBM II) adverse effects cannot be excluded, especially if exposure occurs over a long period of time. Therefore, interventions are necessary as from the “alert level” (HBM I-II) such as identifying the source and reducing it urgently [29].

In this study, the overall mean (2.09 μg/g) and the individual means of the Hg concentrations measured in hair samples from miners across the four districts were above the occupational toxic threshold (internationally recommended limit) of 1 μg/g. The difference in the means across the four mining districts was statistically significant (table 1). Also, over three-quarters (71.7%) of the miners had T-Hg in hair above this threshold of 1 μg/g, identified as 40 (66.7%) in the "alert level" and 3 (5%) as "high" (table 2).

Since ASGM is the major economic activity in these four districts, it is most likely that these elevated values of hair mercury concentrations are as a result of occupational exposure to mercury. Even though there was no control group in this study, many studies have shown that the Hg concentrations in hair of subjects living outside gold mining areas rarely exceed the occupational toxic threshold, while the reverse is true for individuals living in gold mining areas. For example Niane et al., (2015), in a case control study in Senegal, showed that the mean T-Hg in hair of inhabitants of two ASGM communities Tinkoto and Bantako were 2.12 μg/g and 2.03 μg/g respectively, while that of two non-mining communities Kedougou and Samekouta were 0.46 μg/g and 0.41 μg/g respectively [13]. In our study we evaluated human exposure to elemental Hg by sampling amalgam burners and gold collectors who were directly exposed to elemental Hg while in their study, they evaluated human exposure to organic Hg as a result of fish consumption. Kwaansa-Ansah et al., (2019) in Ghana argued that even though exposure to Hg by humans in ASGM settings occur primarily through dietary sources, especially fish, and occupational Hg vapor, inhalation of Hg vapor is the primary exposure pathway for miners, gold shop workers and people near areas where Hg is handled [18]. They also argued that it is usually difficult to obtain quantitative and reliable data on Hg releases from ASGM sites as miners do not freely offer information about the amount of Hg they use.

11. Factors Affecting Concentration of Mercury in Hair

According to a multiple linear regression, we found five factors, which affected the concentration of Hg in hair in our study: district of mining, sex, age, role in the mining process, and the number of working days per week (table 4).

Generally, miners in Bétaré-Oya were more at risk to having elevated T-Hg in hair than miners living in the other districts. A comparison of the mean T-Hg in hair of miners across the four districts showed that Bétaré-Oya had the highest mean (3.38) when compared the other three districts (table 2) and also, all the three miners in the >HBM-II (high) category were from Bétaré-Oya (table 3). This could be as a result of differences in the levels of occupational exposures to elemental Hg which might be explained by other factors such as the use of personal protective equipment, which was not explored in the present study. Another explanation for such difference could be exposure to Hg from other non-occupational sources such as dietary sources (levels of fish consumptions) and water consumption. Niane et al., (2015) in Senegal showed that in locations where T-Hg in hair exceed the toxic threshold, inhabitants consume large quantities of fish [13]. Clarkson and Magos (2006) argued that the mercury concentrations in hair generally reflect environmental exposures to organic Hg, although they state that about 20% of Hg in hair may be derived from inorganic sources [30]. Calao-Ramos et al., (2021) in Colombia showed that high values of T-Hg in hair in ASGM were related to high manipulation and burning of amalgam, and high consumption of fish [12].

Another factor which affected Hg concentration in hair in this study was sex. Males generally had higher concentrations of Hg in hair than females, even though the difference between the two groups wasn't statistically significant. This is because majority of amalgam burners and gold collectors in our study were males. We discovered that Hg was only being used clandestinely across these four districts since its use in ASGM has been restricted by the Cameroonian government due to its potential negative health effects. As a result, women were less courageous and less involved in this clandestine practice for fear of violating the legal requirements. In contrast, other studies have revealed relatively higher concentrations of T-Hg in hair of women especially in settings with very traditional distribution of daily tasks as a function of gender, where women are generally given lesser physically demanding manual tasks like amalgamating and smelting, than men [13].

Age was another factor that affected the concentrations of T-Hg in hair in this study. The concentration of Hg in hair was inversely proportional to age. This is simply because the age group mostly represented and thus frequently exposed to mercury were adolescents and adults < 30 years of age who are the most physically active. Of the three miners classified as >HBM II (high), 2 (3.3%) were adolescents <20 years of age (table 3). Also, the older miners and elderly generally have shorter work duration and exposure period. Similar findings were observed by Kwaansa-Ansah et al., (2019) in Ghana, who reported that Hg levels were highest for miners around 29 years of age [18].

Concerning the roles, T-Hg concentrations in hair were generally higher in amalgam burners compared to gold collectors. Although the use of Hg in ASGM is illegal in many countries, amalgamation is the preferred method employed in ASGM since Hg is cheap and readily available [18]. In our study, amalgam burners were more frequently exposed to mercury than gold collectors. After the grinding step, the fine product is transferred into bowls where the amalgam is separated by panning, and finally burned in open air usually in backyards of neighborhood. Amalgam burners are exposed to Hg during both amalgamation and smelting prior to selling it to gold collectors. On the other hand, gold collectors are exposed occasionally in their shops where some of them burn the final product to further separate gold from Hg, or when they visit amalgam burners to purchase gold. However, few of them 6 (10%) had T-Hg values above the toxic threshold compared to amalgam burners 37 (61.7%) (table 3).

Finally, the multiple regression model also showed that the number of working days per week was directly proportional to the concentration of T-Hg in hair. This is because the higher the number of working days per week, the greater the frequency of exposure to mercury and thus the higher the T-Hg in hair (table 4).

Concerning other predictors of T-Hg in hair, the duration in mining (B = -0.006), number of working hours per day (B = -0.129), frequency of exposure (B = -1.369) and education level (B = 1.62) were not found to affect the concentration of T-Hg in hair in this study. This negative correlation indicated that they were below detection limits. Similar finding were reported in Gahan [18]. However, these finding differ from other studies like that of Wanyana et al., (2020) who showed that longer work duration in artisanal gold mining was associated with longer duration of exposure and consequently greater accumulation of Hg in the body [19]. Concerning education level, Wanyana et al., (2020) in Uganda reported that knowledge alone may not always translate to safer occupational health practices, while on the other hand, Harianja et al., (2020) in Indonesia showed that respondents with higher education tended to have lower T-Hg levels [19,31].

12. Symptoms of Mercury Exposure

Mercury toxicity in humans can be asymptomatic or symptomatic depending on the severity of intoxication and organ system involved. Hg vapor being fat soluble readily moves to the pulmonary alveolar membranes, where between 74% and 80% of the inhaled dose may be retained. Once absorbed, it is transported to the circulatory system, where it attacks red blood cells, the kidneys, and the CNS. The half-life of Hg in the body is about 70 days [14,28]. Independent of the district of mining, we observed a positive correlation between concentration of T-Hg in hair and unusual tiredness, excessive sleeping, dizziness and visual difficulties (table 6). CNS involvement may cause symptoms such as excessive sleeping, dizziness, and visual difficulties observed in our study. Also, Hg may bind to red blood cells and reduces their oxygen-carrying capacities, leading to hypoxia which may manifest clinically as unusual tiredness as seen in this study. Similar symptoms were also reported by Wanyana et al., (2020) in Uganda [19,20].

13. Limitation

The sample size considered for analysis of T-Hg in hair in this study was small due to financial constraints thus these results may not be generalized to other regions. Also, it was difficult to obtain enough quantitative reliable data on Hg releases from ASGM sites, as miners did not freely offer information about the use of Hg for fear of being exposed to legal restrictions. Secondly, neurological examination to clinically investigate for signs of Hg toxicity wasn't conducted due to budget and time constraints. Also, in older subjects, it could not be known if the neurological symptoms were related to age or mercury intoxication. Finally, speciation of mercury in hair samples to differentiate between inorganic and methyl-mercury was not financially possible to perform so as to distinguish between exposure pathways of inorganic and methyl-mercury.

14. Conclusion

This study describes work that was undertaken in four ASGM districts in East Cameroon to assess the level of exposure of artisanal gold miners to mercury and investigate symptoms related to mercury toxicity. The study found that gold miners manipulating mercury had elevated hair Hg content with 71.7% of them having values above the occupational toxic threshold. The factors affecting the level of Hg in hair included male gender, living in Bétaré-Oya, age, burning of amalgam, and increased number of working days per week. The symptoms related to mercury exposure included unusual tiredness, excessive sleeping, dizziness and visual difficulties. Artisanal and small-scale gold mining in the east region of Cameroon is therefore contributing to human contamination with mercury, and there is urgent need for interventions to mitigate human exposures to mercury especially as adverse health effects can't be excluded over long-term exposures.

15. Recommendation

To the Ministry of Labor and Social Security, we therefore recommend awareness training on the supply and regular use of personal protective equipment for all amalgam burners and gold collectors, and also the training and use of mercury retorts by amalgam burners and gold collectors, to mitigate the level of air pollution by mercury vapors.

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Statements and Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Obase M. Ralph, Nodem F. Rodrigue and Ngoran Gilles N. Justin L. Chekoua was the grant holder for the research project. The first draft of the manuscript was written by Obase M. Ralph and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Consent to participate

Written consents to participate in the study were obtained from all the study participants on a separate form attached to the questionnaire. Copies are available from the corresponding author on reasonable request.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Consent to Publish

This manuscript does not contain individual details, images or videos of the participants.

References

1. Hentschel, T., Hruschka, F., & Priester, M. (2003). Global report on Artisanal and Small-scale Mining: challanges and opportunities. London: International Institute for Environment and Development (IIED).
2. IGF. (2017). Global trends in Artisanal and Small-scale Mining (ASM): A review of key numbers and issues. Winnipeg: International Institute of Sustainable Development (IISD).
3. UNEP. (2013). Minamata convention on mercury. Geneva: United Nations Environment Program.
4. The World Bank. (2013). Artisanal Mining in Criticlal Ecosystems: A Look At Gabon, Liberia, and Madagascar. Washington DC: Program on Forests (PROFOR).
5. Taux, K., Kraus, T., & Kaifie, A. (2022). Mercury exposure and its health effects in workers in the Artisanal and Small-Scale Gold Mining (ASGM) sector—A systematic review. International journal of environmental research and public health, 19(4), 2081.
6. World Health Organization. (2016). Artisanal and small-scale gold mining and health. World Health Organization: Geneva, Switzerland.
7. Afrifa, J., Opoku, Y. K., Gyamerah, E. O., Ashiagbor, G., & Sorkpor, R. D. (2019). The clinical importance of the mercury problem in artisanal small-scale gold mining. Frontiers in public health, 7, 131.
8. Clarkson, T. W. (1997). The toxicology of mercury. Critical reviews in clinical laboratory sciences, 34(4), 369-403.
9. Chen, Y.-W., Zhou, M.-D., & Tong, J. B. (2005). Application of photochemical reactions of Se in natural waters by hybride generation atomic fluorescence spectrometry. Anal Chim Acta(545), 142-148.
10. WHO. (2003). Elemental Mercury and inorganic Mercury Compounds: Human Health Aspects. WHO.
11. Bose-O'Reilly, S., Schierl, R., Nowak, D., Siebert, U., William, J. F., Owi, F. T., & Ir, Y. I. (2016). A preliminary study on health effects in villagers exposed to mercury in a small-scale artisanal gold mining area in Indonesia. Environmental research, 149, 274-281.
12. Calao-Ramos, C., Bravo, A. G., Paternina-Uribe, R., Marrugo-Negrete, J., & Díez, S. (2021). Occupational human exposure to mercury in artisanal small-scale gold mining communities of Colombia. Environment international, 146, 106216.
13. Niane, B., Guédron, S., Moritz, R., Cosio, C., Ngom, P. M., Deverajan, N., ... & Poté, J. (2015). Human exposure to mercury in artisanal small-scale gold mining areas of Kedougou region, Senegal, as a function of occupational activity and fish consumption. Environmental Science and Pollution Research, 22, 7101-7111.
14. Ye, B. J., Kim, B. G., Jeon, M. J., Kim, S. Y., Kim, H. C., Jang, T. W., ... & Hong, Y. S. (2016). Evaluation of mercury exposure level, clinical diagnosis and treatment for mercury intoxication. Annals of Occupational and Environmental Medicine, 28(1), 1-8.
15. UNEP. (2018). Global Mercury Assessment.
16. Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. International Scholarly Research Notices, 2011.
17. Timmins, K. (2003). Artisanal gold mining without mercury pollution. (UNIDO, Ed.) Organization UNID.
18. Kwaansa-Ansah, E. E., Armah, E. K., & Opoku, F. (2019). Assessment of total mercury in hair, urine and fingernails of small–scale gold miners in the Amansie West District, Ghana. Journal of Health and Pollution, 9(21), 190306.
19. Wanyana, M. W., Agaba, F. E., Sekimpi, D. K., Mukasa, V. N., Kamese, G. N., Douglas, N., & Ssempebwa, J. C. (2020). Mercury exposure among artisanal and small-scale gold miners in four regions in Uganda. Journal of Health and Pollution, 10(26), 200613.
20. Sana, A., De Brouwer, C., & Hien, H. (2017). Knowledge and perceptions of health and environmental risks related to artisanal gold mining by the artisanal miners in Burkina Faso: a cross-sectional survey. The Pan African Medical Journal, 27.
21. Djibril, K. N. G., Cliford, T. B., Pierre, W., Alice, M., & Kuma, C. J. (2017). Artisanal gold mining in Batouri area, East Cameroon: Impacts on the mining population and their environment. Journal of Geology and Mining Research, 9(1), 1-8.
22. Ralph, O., Gilles, N., Fon, N., Luma, H., & Greg, N. (2018). Impact of artisanal gold mining on human health and the environment in the Batouri Gold District, East Cameroon. Academic Journal of Interdisciplinary Studies, 7(1), 25.
23. Babatunde, O. A., Ayodele, L. M., Elegbede, O. E., Babatunde, O. O., Ojo, O. J., Alawode, D. A., ... & AIBINUOMO, A. O. (2013). Practice of occupational safety among artisanal miners in a rural community in Southwest Nigeria. International Journal of Science, Environment and Technology, 2(4), 622-633.
24. Bansah, K., Ishmael, Q., & Greg, G. N.-D. (2017). Occupational Healthe and Safety Practices in Artisanal and Small-Scale Gold Mining Sector in Ghana. ResearchGate, 17-24.
25. Elenge, M. M., & De Brouwer, C. (2011). Identification of hazards in the workplaces of artisanal mining in Katanga. International journal of occupational medicine and environmental health, 24, 57-66.
26. Zungu, L. I. (2012). Occupational health and safety challenges reported by women in selected South African gold and platinum mines. Occupational Health Southern Africa, 18(5), 6-13.

27. Aldridge, W. N. (1995). Defining thresholds in occupational and environmental toxicology. Toxicology letters, 77(1-3), 109-118.
28. Basri, Sakakibara, M., & Sera, K. (2017). Current mercury exposure from artisanal and small-scale gold mining in Bombana, southeast Sulawesi, Indonesia—future significant health risks. Toxics, 5(1), 7.
29. Pereira Filho, S. R., Dos Santos, R. L. C., Villas Bôas, R. C., Castilhos, Z. C., Yallouz, A. V., Peregovich, B., ... & Lettmeier, B. (2004). Environmental and Health Assessment in two Small-Scale Gold Mining Areas-Indonesia. Final Report. Sulawesi and Kalimantan.
30. Clarkson, T. W., & Magos, L. (2006). The toxicology of mercury and its chemical compounds. Critical reviews in toxicology, 36(8), 609-662.
31. Harianja, A. H., Saragih, G. S., Fauzi, R., Hidayat, M. Y., Syofyan, Y., Tapriziah, E. R., & Kartiningsih, S. E. (2020). Mercury exposure in artisanal and small-scale gold mining communities in Sukabumi, Indonesia. Journal of Health Pollution, 10(28), 201209.
32. EITI. (2019). Cameroon. Extactive Industries Transparancy Initiative.