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Mercury Levels Assessment in the Population of Aby and Frambo Villages in the Vinicity of Aby Lagoon in Côte d'Ivoire (West Africa)

Stéphane Jean Claon[1,2*], Serge Kouakou Kouassi[3], Nina Laurette Ahouéfa[4], Laurent Kipré Seri[5], Arsène M'bassidjé Seka[2,6], Joseph Allico Djaman[3,5], Luc Kouakou Kouadio[1]

[1]Analytical Sciences and Public Health Department, University of Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire
[2]Water Quality Control and Analysis Laboratory (LACQUE), Office National de l'Eau Potable (ONEP), Abidjan, Côte d'Ivoire
[3]Biology and Health Laboratory, University of Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire
[4]Laboratory of Nutrition and Food Safety, Department of Science and Food Technology, Nangui Abrogoua University, Abidjan, Côte d'Ivoire
[5]Department of Medical and Fundamental Biochemistry, Institut Pasteur of Côte d'Ivoire, Abidjan, Côte d'Ivoire
[6]Laboratory of Environmental Sciences (LSE), University of Nangui Abrogoua, Abidjan, Côte d'Ivoire
Email: *claonstephane@gmail.com, n.ahouefa6@gmail.com

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Abstract

The Minamata Convention in the aim to protect human life and the environment, seeks to reduce mercury (Hg) by monitoring it concentrations in the environment. Artisanal and Small-scale Gold Mining (ASGM) has been identified as the most important anthropogenic source of human exposure to Hg. In this context, the main goal of this study was to assess the level of mercury in hair of two (2) populations living along two lagoons respectively Aby and Tendo, in Ivory Coast. To reach this goal, hair samples of 138 residents were collected and analyzed by using Cold Vapor Atomic Fluorescence Spectrophotometry (CV-AFS) technique for mercury concentration. Results showed that for the entire population the Hg mean was 2.34 µg/g. Also, they were ranged between 0.15 to 8.53 µg/g and presented substantial differences amongst the villages. In Aby village, we observed the highest Hg concentrations (Mean = 2.62 µg/g). Our findings showed that almost the entire sample group (82%) exceed the USEPA recommended limit, furthermore 56% of them exceed the normal level of WHO and 2% of the respondent has the unhealthy levels of mercury (≥6 µg Hg/g) of hair by WHO standards. Gender differences in hair mercury varies greatly among reports. Lower levels in women's hair compared to men were reported in the both village. Considering age, the lowest concentrations were observed with children. However, when we take in account the age groups, data suggested that the most exposed sub-population of [18-29] years old is from Aby village in opposite at

Frambo village, the same case those who were ≥ 40 years old. It's convenient to note that, the proportion of Mercury levels would not to be neglected among studied population especially with the resident from Aby village. So, some measures need to be taken at the political level to control mercury contamination.

Keywords

Mercury, Hair, ASGM, Population Exposure, Côte d'Ivoire

1. Introduction

The global impact's understanding of mercury (Hg) usage in artisanal and small-scale gold mining (ASGM) has most improved [1] [2]. It should be noted for this purpose that ASGM activity in developing countries is the largest source (37%) of mercury contamination worldwide [2] [3]. It also provides a primary and additional source of income, particularly in rural regions where economic alternatives to agriculture are limited [4].

One of the mainly important region where ASGM is a widespread activity is West Africa because of its important gold reserve [5]. Indeed, in Sub-Saharan Africa, during the last three decades, the gold mining sector has been on the rise because of the increase in global gold prices [6] [7] [8].

Although the use of Hg in gold processing is considered illegal in most countries, it remains the preferred method using by ASGM miners around the world despite especially in Africa and that's due to it availability, easiness to use, and low cost [9]. For artisanal and small-scale gold miners, mercury amalgamation provides a simple and inexpensive solution to recover gold and the process entails combining mercury with gold-bearing ore or concentrate. A gold-mercury amalgam is formed, then Burning the amalgam vaporizes Hg into gaseous form leaving behind gold [10].

The vaporized Hg eventually settles in soil and the sediment of lakes, rivers, bays, and oceans and it is transformed by anaerobic organisms into methylmercury (MeHg) [11]. Biomagnification of mercury levels in aquatic systems contributes to relatively high levels of methylmercury in predatory fish and marine organisms. Populations that consume large amounts of these organisms can be affected by mercury exposure and neurological, respiratory effects, including lung inflammation and renal effects have been observed [12].

Many studies have shown that concerning the problem of using mercury in ASGM, Ivory Coast isn't considered in isolation [1] [11] [13].

However, in Côte d'Ivoire, the increase of ASGM has been developed since the outbreak of the sociopolitical crisis of September 19, 2002. ASGM attracts rural populations through the incomes it provides [14] [15]. Unfortunately, all over the world, the miner considered exposure to MeHg pollution as minimal to absent [16] [17].

An important study has been done concerning two lagoons (Aby and Tendo) and showed a mercury accumulation in sediments of these lagoons but through fishing activities, they constitute and provide a real source of living for the local populations [18].

Hence, in the current study, the mainly aim is focused to assess the level of mercury concentrations in human hair from populations recruited in Aby and Frambo villages residents nearby Aby and Tendo lagoons.

2. Material and Methods

2.1. Study Area and Selected Population

Aby lagoon (5˚05'N-5˚22'N and 3˚16'W-2˚55'W) is located in West Africa, on the coast of the Gulf of Guinea between Côte d'Ivoire and Ghana. Aby lagoon covers 24.5 km and 56 km, respectively, from east to west with an estimated area of 420 km2, while the Tendo lagoon is formed by the band from west to east and has a width of about 20 km. Aby and Tendo lagoons are located in an equatorial climate [19].

We indicated successively from north to south for Aby north and south lagoons, and from west to east for Tendo. The 2 north and south Aby lagoons will simply be called Aby throughout this study. Several towns, villages and seasonal fishing camps exist around the Aby and Tendo lagoons (**Figure 1**). The population estimated to 30,000 are living around Aby and Tendo lagoons that constitute and provide a real source of food and living for these populations through fishing activities. Aby and Tendo lagoons are under the influence, respectively, of the Bia river whose watershed is estimated at about 10,000 km^2 with an average flow estimated at 300 m^3/s during rainy floods and the Tanoe river whose watershed is at about 16,074 km2 with an average flow estimated at 142 m^3/s [20].

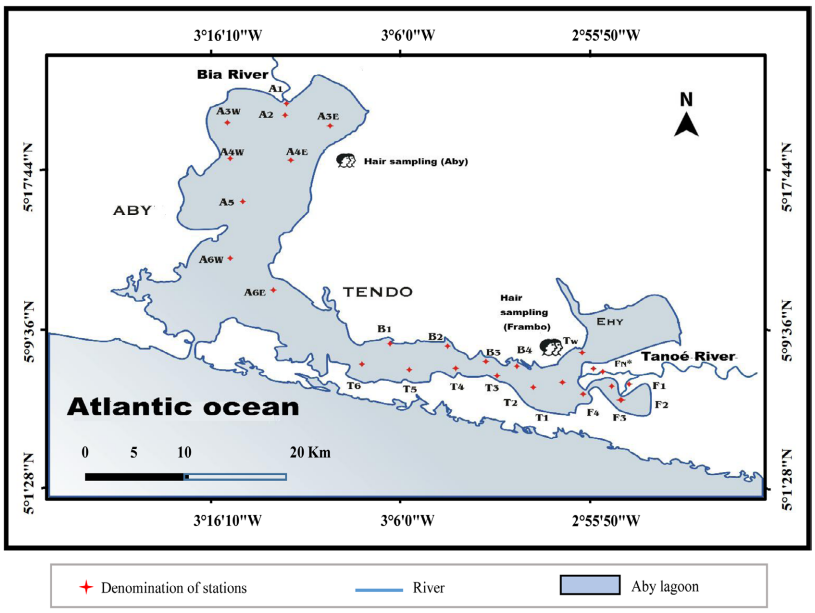

Figure 1. Map showing study location.

These rivers are home to numerous gold deposits that have gradually developed over the years. Thus, artisanal and industrial gold mining around the Bia and Tanoe rivers fears that these rivers will serve as a pollution vector for heavy metals, especially mercury from gold-mining areas to its outlets in Aby and Tendo lagoons. Aby and Tendo lagoon are exposed to pollutants resulting directly or indirectly from gold-mining activities, namely, mercury. In addition to spatial, bathymetric, and hydrological variations, Aby and Tendo lagoons were influenced by the Bia and Tanoe rivers, respectively. Those lagoons are the estuaries of the Bia and Tanoe rivers, respectively [18].

2.2. Sample Collection and Ethical Aspects

The study conducted in Frambo and Aby village has involved 44 children, 60 female subjects and 78 males one. Mercury exposure can be assessed by examining different biomarker like urine, blood, fingernail and hair. The populations in our study have a diet rich in fish and see food and hair was chosen as the preferred biomarker for Hg levels in our subjects because it reflects exposure over several months [12] [21]. The hair sample was collected after recruitment into the study. To determine mercury exposure, hair samples (about 1g) were obtained from each person. A lock of scalp hair about 2 cm long was cut with stainless steel scissors in the occipital region of scalp of each person. After cutting down the hair, samples were coded and packed in polyethylene bags and stored at room temperature until analysis [22].

To be included on the research, participants should be a resident of the study area for at least six months and given informed consent after receiving clear information on the objectives and the phases of the project, including the anonym treatment of the collected human scalp hair samples and information. Informed consent for children (<18 years old) was given by their parents or guardians. Each subject was asked to provide their age, gender, profession by completing a brief questionnaire.

We chose not to wash the hair samples because washing procedures have been reported to leach mercury compounds incorporated into the hair at the follicle, resulting in underestimation of hair mercury content [23] [24] [25] [26] [27].

This research was approved by the Minister of Health Ethical Committee of Côte d'Ivoire and it was carried out according to the Declaration of Helsinki. Informed consent was obtained from all respondents as a prior condition of inclusion as subjects of the study.

2.3. Sample Preparation and Analysis

The total mercury (THg) analyses were determined by cold vapor atomic fluorescence spectrophotometry (CV-AFS) (Merlin PSA 10.023), following [28] [29] [30]. For THg, 5 mg dry weight (DW) of hair were transferred to glass tubes and digested in 1 ml of 16 N HNO_3/6 N HCl (10:1) mixture in an oven during for 6-8 hours at 90˚C [29]. After digestion, the analytical solution (5 ml) was allowed to cool then diluted to 50 ml deionized water obtained from a Milli-Q system (Mil-

lipore, Molsheim, France). Mercury was reduced to elemental Hg (Hg^0) vapor using a $SnCl_2$ solution. For the analysis, 200 µl of the digestion solution was injected in the CV-AFS [30]. The same process was adopted for each hair's sample and each one was analyzed in duplicate and average mean concentrations of Hg was used for data treatment in the statistical analysis.

2.4. Statistical Analysis

Statistical descriptive analysis was performed on the demographic data, including age groups (children and adults), sex and place of residence of residence. First of all, variables were expressed as arithmetic mean (AM) ± standard deviation (SD) and range (minimum and maximum) value, percentages and median to describe study population. Thus, significant differences mercury (Hg) value between population, gender group were evaluated at t-test. The t-tests for independent samples were used to test the differences in the mean levels. Besides, a one-way ANOVA test was used to assess the statistical significance of differences in the Hg level among group. Hair Hg mean was compared to the World Health Organization (WHO) reference level of 2 µg/g) [31] and USEPA normal limit [32]. All statistical analyses were conducted with the IBM SPSS Statistics, version 26. The significance level for all tests was $p \leq 0.05$ (two-tailed).

3. Results and Discussion

3.1. Description of the Studied Population

Descriptive statistics for research populations are presented in **Table 1**. The communities of two villages were investigated regarding mercury levels in hairs The 138 participants were from Aby and Frambo village located along respectively Aby and Tendo lagoons. Of the total, 70% were enrolled in Aby village and the other 30% in Frambo village. Within the total studied population, the majority (55%) corresponded to female. The volunteers (ranged from 1 to 78 years old with most (69.6%) below 30 years old) were classified into five groups according the respective age: children (> 12 years old), adolescents (12 - 17 years old), early adulthood (18 - 29 years old), second adult age (30 - 39 years old), Older adult age (≥40 years old). All the individuals studied were dedicated to fishermen and their families.

3.2. Mercury concentration in hair

Figure 2 displays THg concentration in hair for the participants of Frambo and Aby village.

The maximum concentration (233.1 µg Hg/g) was so high than 10 µg Hg /g and was excluded from subsequent calculations.

The particularly data that have been presented, (233.1 µg Hg/g), was over the WHO No Observed Adverse Effect Level (50 µg Hg/g) [33] and have found with a woman. According to some authors, this observation may due to hair pigmentation (decrement in white hair than dark, red, and light brown/brown hair) [34] [35] [36], or used of whitening skin products or used of cosmetics [37] [38].

Table 1. Descriptive characteristics of study groups by village.

		Aby		Frambo	
Variables	Total	n	%	n	%
Gender					
Male	60	44	(73)	16	(27)
Female	78	52	(67)	26	(33)
Age (Years)					
<12	44	31	(70)	13	(30)
12 - 17	17	16	(94)	1	(6)
18 - 29	35	20	(57)	15	(43)
30 - 39	23	15	(65)	8	(35)
≥40	19	14	(74)	5	(26)
Occupation					
Fishermen and their families	138	96	(70)	42	(30)

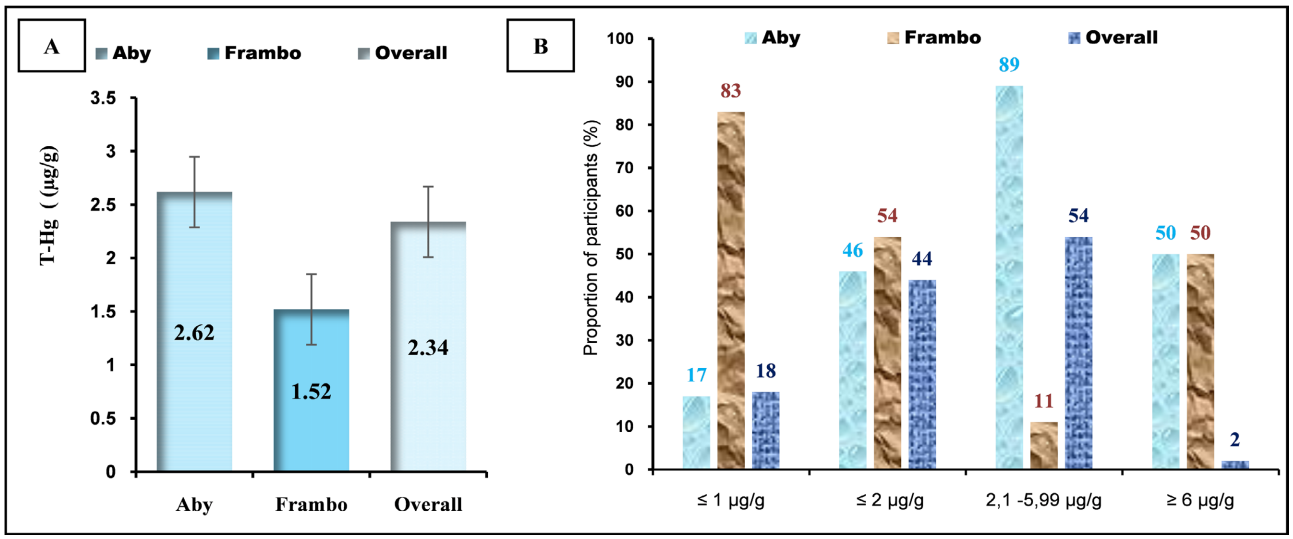

Figure 2. Distribution of mercury level ($\mu g \cdot g^{-1}$) exposure among studied population (A: Mercury means; B: the prevalence by Hg concentration).

Besides, the mercury levels from each respondent were ranged from 0.15 to 8.53 µg/g and the median value of the entire population was 2.34 µg Hg/g. In the village from Aby lagoon, individual hair-Hg concentrations ranged from 0.4 to 8.53 µg Hg/g, with a median of 2.62 for the all the group and in Frambo village the overall mean was 1.52 µg Hg/g.

Regarding to the mercury means (2.62 and 1.52) of respectively Aby and Frambo village, it presented that the two means were above the Reference of Dose (RfD) indicated by USEPA (1 µg/g). However, the mean of Hg of Frambo

is significantly lower than Aby Participants Hg level. We also noticed that about 82% of the volunteer exceed the USEPA recommended limit [32], whereas 56% of the sampled group exceed the normal level of WHO [31]. The percentage of unhealthy levels of mercury (above 6 μg Hg/gram of hair by WHO standards [39] [40] [41], concerned 2% of the population with 50% for each village.

Comparable results were published by some researchers [42] [43] [44]. Consumption of locally harvest fish is the probable source of exposure to Hg in the participants in these two villages [45] [46] [47]. Indeed, Aby and frambo village are two villages located along respectively Aby and Tendo lagoons. Then, previous study was recorded that the both lagoons were mercury contaminated sites [18]. So, the total population exposure could be resulted to the consumption of contaminated fishes particularly those permanently lives in these lagoons that are influenced by mining population. This situation may be the case of in the present study [48] [49].

At the same time, we noticed a significant highest Hg level in Aby village, this difference of mercury level may due to frequency [50], high rate of fish consumption in their dietary habits and its species composition like many favored predatory fish [51].

3.3. Mercury Concentration in Hair by Living Residence According to Gender

The distribution of mercury concentration in hair according to sex by sites showed that in the both villages Aby and Frambo, males had higher levels of mercury than the women, their compatriot (**Figure 3**).

Regards to the population of Aby village, men mercury in their hair was the highest (2.95 μg/g versus 2.45 μg/g). Same gender trends were found in Frambo's village population, men had an average of 1.65μg / g and women, an average of 0.91μg /g. There was no significant difference between males and females of Aby respondents contrary to Frambo participants However, considering the whole sample, the difference associated with gender persists.

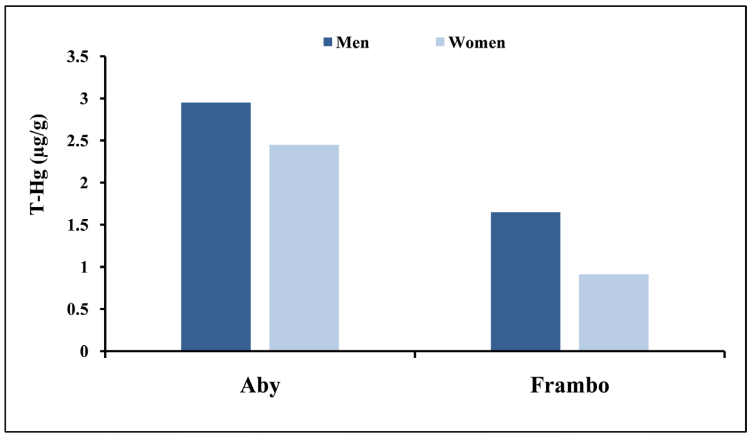

Figure 3. Distribution of T-Hg hair mercury concentrations ($\mu g \cdot g^{-1}$) according to gender genderanamong studied population.

Our finding concerning the lowest mercury level in women was in accordance to others results such us those of [51] and [52], contradictory trend was observed by [50] and [53].

This significant difference between male and female could be attributed to nutritional preferences. Also it can be explained by the differential metabolism [54] or the protective metabolism of female and may be by the cultural drivers of exposure to this toxin [55] or some specific habits [56].

3.4. Mercury Concentration in Hair by Living Residence According to Age Groups

Considering mercury concentration assessment in hair among age groups, **Figure 4** illustrates that Hg levels had variability among respondents in Frambo as in Aby.

However, the most exposed sub-population is from Aby village and priory the age group of [18-29] years old and according to USEPA action level [32]. In contrary at Frambo the highest mercury level was found with the participants who were ≥ 40 years old.

Applying the age range groups of < 18 years old (children) and ≥ 18 years old (Adult) [40] [57], the following result has been shown, the content of mercury hair increased with age in both villages.

The average of mercury was 2.4 $\mu g \cdot g^{-1}$ vs. 2.9 $\mu g \cdot g^{-1}$ respectively for children and adult from Aby village and at Frambo village, it was 1.5$\mu g \cdot g^{-1}$ vs. 1.8$\mu g \cdot g^{-1}$ respectively. For the both villages a significant level of Hg has been found among overall respondents.

Similar data have been presented in some studies. It was recorded that the concentration of mercury in the hair positively correlates with the age of the subjects [58] [59] [60]. The opposite trend was observed when studying the mercury content in the hair from interior villages in Suriname in South America [42].

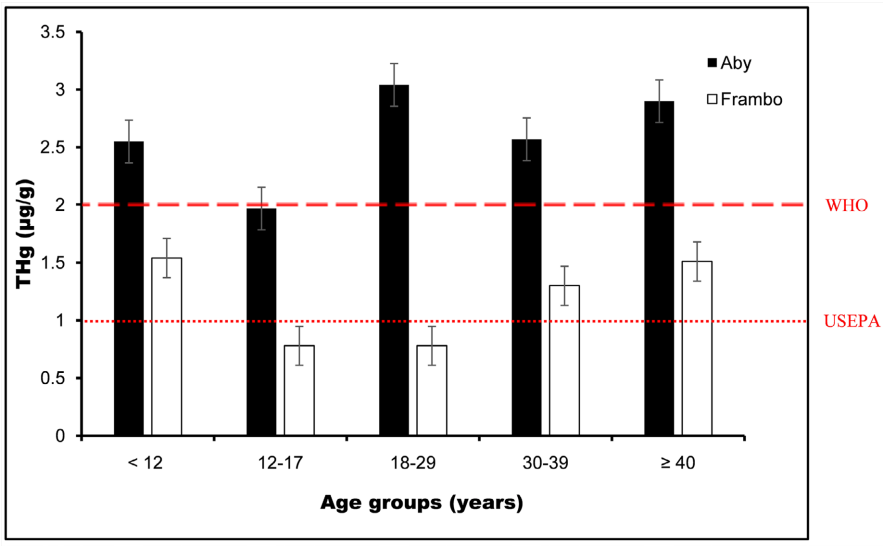

Figure 4. Hair mercury concentrations ($\mu g \cdot g^{-1}$) by village in different age groups of subjects.

Children are seemed to be less exposed to pollution, that could be due to the fact that children consume less food than adult or not used of cosmetics. On other hand, this could be associated to malfunction of the defense mechanisms among elder people [61], or as a result of mercury accumulation in the body through the whole lifetime [62].

4. Conclusions

The work investigated concerning THg hair mercury content among the population living along Aby and Tendo lagoons indicated that for the entire group the concentrations of Hg were ranged from 0.15 to 8.53 μg/g and the median value of the entire population was 2.34 μg Hg/g. This study showed that unhealthy levels of mercury are prevalent in these areas. Relatively high levels of mercury in hair samples from participants of Aby village, as presented in this research and the lowest in Frambo.

Our work according to overall data reveals that almost the respondents (82 %) exceed the USEPA recommended limit, whereas 56 % of the entire group exceed the normal level of [31]. Also, the percentage of unhealthy levels of mercury by WHO standards 27 concerned 2 % of the entire samples.

Moreover, lower levels of mercury concentration in the hair of the entire subjects were recorded from women compared to their compatriot men. The results were the same for the both villages: Aby and Frambo.

Furthermore, the effect of age on hair mercury level suggested a mercury accumulation in body with age. However, in this study, hair Hg concentrations were below the WHO No Observed Adverse Effect Level excluding the only case of about 2331 μg/g observed with a female. Therefore, a risk alert of the mercury exposure should be considered and public actions need to be carry out. The Ivorian government must develop policies and strategies in order to ensure food quantity and quality, access to clean water, human rights, land and health services.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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