***Original Research Article***

**Heavy Metal Exposure In Peri-Mineral Areas Of The Bandama River Zone: The Case Of The Village Of Zagouta In Bouafle Department**

**Abstract**

**Background and objective**: Humans are exposed to metals through their diet and lifestyle,such as in gold panning. Some metals are essential to the physiological functions of the body,

while others are non-essential and can be toxic to humans. The aim of this study is therefore to assess the level exposure to heavy metals of people living near gold-mining sites. **Materials and methods**: this was a prospective study of populations living near a gold-mining site. The parameters studied were sex, age and duration of exposure, and heavy metals. Heavy metal assays were carried out using the IPC-AAS Solaar S2. Wilcoxon rank sum. A p-value 0.05 was considered significant. **Results:** Our study involved 22 people with an average age of 58 years, with exposure duration of over 10 years in 95% of the study population and less than 5 years in 4.5%. More than the half of the population drank alcohol. Biological assays detected the presence of 10 heavy metals, some of which, such as mercury, lead, arsenic and cadmium, had mean values above the threshold limit. **Conclusion**: These results point to environmental pollution, which can be explained by the high levels of heavy metals found. This study highlights the importance of representative population studies to manage the consequences of gold panning on public health and the environment, ensuring the safety and well-being of the populations living in this vulnerable region.

Keywords: heavy metals; peri-mineral areas; gold-mining; exposure assess, Wilcoxon rank sum

**1.INTRODUCTION**

Gold panning began in Côte d'Ivoire in the second half of the 18th century. (Joseph G. J. 1913)**.** Currently, 30 out of 31 Côte d'Ivoire's regions are affected by gold panning with more than 23,000 miners (CNDH, 2022). Studies carried out on gold panning along the Bandama River revealed that the total surface area exploited by artisanal gold panning for 2018 was 3.39 km2, rising to 5.16 km2 for 2019, and 8.80 km2 for 2021. These figures show that this activity has more than tripled in three years, corresponding to a growth rate of 0.24 km2/month.

Artisanal gold mining may seem like a lucrative business, but it has many negative impacts, both social and biophysical. People working in mining areas contribute significantly to ecosystem pollution through the handling of heavy metals from the digging of the deposits to the extraction of gold (Eisler, 2003). All these heavy metals are dumped and abandoned in nature, exposing human beings, especially those living around mining areas, to heavy metal poisoning. The most common are mercury, lead, cadmium, arsenic and other heavy metals such as nickel and cobalt (Bamba et al., 2013; Nyanza et al., 2021; Nyanza et al.,2019).

Studies carried out by Ivorian researchers as part of their environmental monitoring program have revealed the state of water pollution in Bandama river, with the presence of cyanide, arsenic, chromium, mercury, lead, zinc, etc (Armah et al., 2012). This polluted water affects fish, for which analyses have revealed the presence of mercury, lead, chromium, cadmium and zinc. This polluted water affects fish, for which analyses have revealed the presence of mercury, lead, chromium, cadmium and zinc. These mercury levels exceed the thresholds recommended by the FAO for human consumption (Bouchard et al., 2023; Zhuang et al., 2014)**.** However, although heavy metals have harmful effects on humans, very few studies on thehealth impact of heavy metals on humans have been carried out in Côte d'Ivoire. It wastherefore the effect of gold panning on those exposed to it that led us to carry out thisstudy to assess the level of exposure to heavy metals of people living near gold panning sitesin the village of Zagouta.

**2. MATERIAL AND METHOD**

**Type and period of study**: This is a prospective study conducted over a 4-month period.

**Study design**: The recruitment of the study population was carried out in the village of Zagouta in the Bouaflé sub-prefecture, and biological tests were performed at the National Agricultural Development Support Laboratory (LANADA). Any person who had lived permanently in Zagouta for at least one year and was not wearing a dental implant was included.

This study did not include people who refused to be surveyed or to have a sample taken. The variables studied were socio-demographic data and lifestyle habits, notably in relation to water, alcohol and tobacco consumption, as well as data on health status.

Material and methods

Material

Biological material

In our study, the biological material consisted of the blood of the surveyed subjects.

Technical equipment

Samples and analyses were carried out using small laboratory equipment and specific apparatus. These included tubes with heparin to collect the blood samples, a cooler with carboglasses and a thermometer to maintain and monitor the temperature of the blood samples taken during transport; sampling needles; a thermal sand bath basket; an evaporator; a mineratizer; an IPC-AAS Solaar S2 automaton (Thermo Electron; Corporation, Orion, England); standard solutions (Merck KGaA; Durmstalt, Germany) of the various metals were used as standards.

Methods

The methodology involved three main phases: pre-survey, survey and assays.

Pre-survey

It was the preparation phase for the choice of the village and also for the survey itself. This phase enabled us to make contact with the village and departmental administration and the health authorities. It also enabled us to collect data on volunteer participation and acceptance of biological samples.

Survey

In order to characterize the volunteers, an interview was carried out. For this purpose, a questionnaire guide was drafted and submitted to each respondent.

Blood was collected by superficial venipuncture in the morning, from subjects who had fasted (for at least twelve hours) the previous day. Blood was collected from each subject in a tube containing heparin. Blood sampling was carried out at the Zagouta rural health center, in a specially equipped courtyard.

Samples were immediately transported to the laboratory in a cooler containing carboglass, then stored in a refrigerator at -4°C overnight for analysis (ISO 15189, 2022).

Assays

Dosage was carried out according to the method of (Labat, 2010).

0.5 to 2 ml of blood sample was collected in a Teflon glass. A mixture of perchloric acid and nitric acid was added to facilitate decomposition of the organic compounds. The Teflon glass was placed under a fume hood or closed digestion system to avoid nitric and perchloric acid dispersion.

o In a Teflon beaker, 4 ml of 65% HNO3 (Labosi Oulshy-Lechâteau-France) were added to 5 ml of the blood sample. Mineralization was carried out in a “sand bath” at 150°C for at least 2 hours, until the supernatant evaporated. Then, to facilitate pellet dissolution, 2 ml of 65% HNO3 and 2 ml of distilled water were added to the pellet, which was again heated for 20 min.

o The resulting mixture was cooled to room temperature for 15 min. The mixture was then reduced to 5 ml with distilled water. After filtration on paper (MN 640 dd, Machery-Nagel+Co, Germany), the heavy metals (cadmium, lead, copper, nickel, arsenic, mercury; zinc; cobalt; iron and aluminum) were released in solution in mineral form.

o This solution, containing the heavy metals released in mineral form, was placed in the sampler for determination by IPC-AAS. The IPC-AAS is an automated instrument that has been pre-calibrated to identify and determine the concentrations of ten heavy metals.

 Interpretation of the results

The instrument automatically determined the results. Results were interpreted by comparison with reference values for each metal.

Detection thresholds for the ten metals are: Lead : 0,01 mg/L ; Cadmium : 0,0005 mg/L ; Copper : 0,01 mg/L ; Nickel : 0,0004 mg/L ; Arsenic : 0,0005 mg/L ; Mercury : 0,0001 mg/L ; Zinc : 0,001 mg/L ; Aluminum : 0,0001 mg/L ; Iron : 0,001 mg/L ; Cobalt : 0,0002 mg/L.

**Statistical analysis**: All tests were first entered into an Excel spreadsheet. Épi Info software version 7.2.0.1 was then used for statistical processing. Comparisons between different proportions (quantitative data) using the statistical tests were performed using Wilcoxon rank sum exact test (alpha = 5%).The values were interpreted by comparing the concentrations obtained with the reference values for each metal. We have listed the normal biological reference values according to National Research and Safety Institute (INRS, 2025). These values are shown in **Table 1.**

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**Table 1**: The 10 heavy metals to be measured in blood, with their normal and abnormal values.

|  |  |  |
| --- | --- | --- |
| **Heavy metal** | **Normal value** | **Abnormal value** |
| Lead (Pb) | < 70 μg/L | > 100 μg/L |
| Cadmium (Cd) | < 1 μg/L | > 5 μg/L |
| Mercury (Hg) | < 5 μg/L | > 20 μg/L |
| Arsenic (As) | < 10 μg/L | > 10 μg/L |
| Nickel (Ni) | < 0.9 μg/L | > 10 μg/L |
| Copper (Cu) | [10.9 - 23.5] μmol/L | < 10.9 and > 23 μmol/L |
| Iron (Fe) | [12 - 30] μmol/L | < 12 and > 30 μmol/L |
| Zinc (Zn) | [590 - 1440] μg/L | < 700 μg/L |
| Aluminum (Al) | < 0.35 μmol/L | > 30 μmol/L |
| Cobalt (Co) | < 0.8 μg/L | > 5 μg/L |

**3. RESULTATS**

The mean age of the study population was 58, with extremes ranging from 46 to 67. There were more men (64%) than women (36%). Twenty-one people (21), or 95% of the population, had lived in the locality for more than 10 years, while one person, or 4.5%, had lived there for less than 5 years. Among those surveyed, all said they did not use river water for drinking or cooking. One hundred percent (100%) occasionally ate fish or other aquatic animals from the Bandama River. As for alcohol consumption, 15 people (68%) drank alcohol and 7 (32%) did not. Concerning work on or near gold panning sites, 18 (82%) people did not work there and 4 (18%) did. 19 people (86%) said that gold-panning activities had affected their health (table 2).

There are 10 heavy metals found in the population. Among these, 7 or 70% (lead, cadmium, nickel, cobalt, aluminum, iron and copper) have values above the threshold limit. The values of heavy metals according to the size of the population surveyed showed that 95 to 100% of the population had a high value for cadmium, followed by nickel, copper, cobalt and aluminum. For lead, 64%, and for iron, 50% (Table 3).

Table 2: General characteristics of the population

|  |  |
| --- | --- |
| **Variables** | **N=** **22** |
| Age | 58 (46, 67) |
| Gender |  |
| Woman | 8 (36%) |
| Male | 14 (64%) |
| Water |  |
| No | 22 (100%) |
| Animals |  |
| Occasionally | 22 (100%) |
| Alcohol |  |
| No | 7 (32%) |
| Yes | 15 (68%) |
| Lead | 76 (58, 99) |
| Cadmium | 3.37 (1.47, 5.03) |
| Mercury | 1.93 (0.90, 4.40) |
| Arsenic | 8.80 (7.10, 10.30) |
| Nikel | 3.30 (2.07, 6.60) |
| Copper | 14.2 (9.6, 20.5) |
| Iron | 17 (14, 22) |
| Cobalt | 2.62 (1.87, 3.43) |
| Aluminum | 0.50 (0.28, 0.70) |
| Zinc | 726 (633, 848) |
| Dwelling period |  |
| 1 to 5 years | 1 (4.5%) |
| over 10 years | 21 (95%) |
| Gold panning sites |  |
| No | 18 (82%) |
| Yes | 4 (18%) |
| Water consumption |  |
| No | 22 (100%) |
| Gold panning effects |  |
| No | 3 (14%) |
| Yes | 19 (86%) |

*1*Median (Q1, Q3); n (%)tt

Table 3: Summary table of metals detected

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Heavy metal** | **Average value** | **Minimum value** | **Maximum value** | **Normal**  **Value** | **Median**  **Value** |
| Lead(Pb) | 82,637(μg/L) | 35.500 (μg/L) | 221,966(μg/L) | <70(μg/L) | 75.8 (μg/L) |
| Cadmium(Cd) | 3,807(μg/L) | 0.733 (μg/L) | 9.833 (μg/L) | < 1 (μg/L) | 3,363(μg/L) |
| Mercury (Hg) | 3,008(μg/L) | 4.333(μg/L) | 9.6 (μg/L) | < 5 (μg/L) | 1,933(μg/L) |
| Arsenic (As) | 8,790(μg/L) | 5.066(μg/L) | 13.8 (μg/L) | <10 (μg/L) | 8,800(μg/L) |
| Nickel (Ni) | 4,633(μg/L) | 1.233(μg/L) | 14,266(μg/L) | <0,9(μg/L) | 3,300(μg/L) |
| Copper (Cu) | 14,865(μg/L) | 6.433(μg/L) | 27,033(μg/L) | 10,9-23,5(μg/L | 14,200(μg/L) |
| Iron (Fe) | 18,669μmol/L | 7.266μmol/L | 44,400μmol/L | 12,0 - 30,0μmol/L | 17,400μmol/L |
| Cobalt (Co) | 2,600(μg/L) | 1.233(μg/L) | 4.266(μg/L) | < 0,8(μg/L) | 2,616(μg/L) |
| Aluminum(Al) | 0,521μmol/L | 0.133μmol/L | 1,133μmol/L | < 0,35μmol/L | 0,500μmol/L |
| Zinc (Zn) | 796,048μmol/L | 527,966μmol/L | 1,502μmol/L | 590 - 1440μmol/L | 725,9167μmol/L |

Table 4: Heavy metal values by survey population size.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Heavy metal** | **Headcount – Normal value** | **Percentage -**  **Normal value (%)** | **Headcount -**  **Abnormal value** | **Percentage -**  **Abnormal value**  **(%)** |
| Lead (Pb) | 8 | 36,36 % | 14 | 63,64 % |
| Cadmium(Cd) | 1 | 4,55 % | 21 | 95,45 % |
| Mercury (Hg) | 15 | 78,95 % | 4 | 21,05 % |
| Arsenic (As) | 15 | 68,18 % | 7 | 31,82 % |
| Nickel (Ni) | 0 | 0,0 % | 22 | 100,0 % |
| Copper (Cu) | 0 | 0,0 % | 22 | 100,0 % |
| Iron (Fe) | 10 | 45,45 % | 12 | 54,55 % |
| Cobalt (Co) | 0 | 0,0 % | 22 | 100,0 % |
| Aluminum(Al) | 0 | 0,0 % | 22 | 100,0 % |
| Zinc (Zn) | 18 | 81,82 % | 4 | 18,18 % |

Table 5: Heavy metal concentrations and health effects

|  |  |  |  |
| --- | --- | --- | --- |
| **Characteristic** | **no N = 3*1*** | **yes N = 19*1*** | **p-value2** |
| Lead (µg/L) | 85 (76, 99) | 73 (55, 101) | 0.5 |
| Cadmium (µg/L) | 7.20 (1.47, 8.70) | 3.37 (1.47, 3.47) | 0.3 |
| Mercury (µg/L) | 2.27 (1.93, 8.30) | 1.43 (0.88, 3.60) | 0.3 |
| Arsenic (µg/L) | 8.80 (7.57, 9.53) | 8.80 (6.57, 10.60) | >0.9 |
| Nikel (µg/L) | 2.33 (1.57, 3.27) | 3.73 (2.07, 8.30) | 0.3 |
| Copper(µg/L) | 17.9 (6.4, 21.3) | 13.9 (9.6, 20.5) | >0.9 |
| Iron μmol/L | 18 (18, 24) | 17 (11, 22) | 0.4 |
| Cobalt (µg/L) | 3.43 (1.43, 3.53) | 2.60 (1.87, 3.43) | 0.8 |
| Aluminum μmol/L | 0.57 (0.53, 0.73) | 0.43 (0.27, 0.67) | 0.4 |
| Zinc μmol/L | 600 (528, 680) | 779 (660, 885) | 0.040 |

*1*Median (Q1, Q3)

*2*Wilcoxon rank sum exact test; Wilcoxon rank sum test No:

No effect

Yes: With effect

Table 6: Heavy metal concentrations and gold-mining sites

|  |  |  |  |
| --- | --- | --- | --- |
| **Metals** | **No N = 18*1*** | **Yes N= 4*1*** | **p-value*2*** |
| Lead (µg/L) | 76 (58, 99) | 80 (52, 96) | 0.8 |
| Cadmium (µg/L) | 3.37 (1.47, 5.03) | 2.43 (1.07, 5.78) | 0.6 |
| Mercury(µg/L) | 1.93 (0.90, 4.40) | 2.05 (0.87, 5.50) | >0.9 |
| Arsenic (µg/L) | 8.80 (7.10, 10.30) | 8.28 (7.10, 10.82) | >0.9 |
| Nickel (µg/L) | 3.50 (2.07, 6.60) | 2.98 (1.93, 6.02) | 0.8 |
| Copper (µg/L) | 16.2 (9.6, 20.6) | 10.4 (9.4, 12.9) | 0.2 |
| Iron μmol/L | 17 (14, 22) | 17 (14, 31) | 0.8 |
| Cobalt(µg/L) | 2.62 (1.53, 3.43) | 2.72 (1.97, 3.65) | 0.6 |
| Aluminum μmol/L | 0.47 (0.30, 0.67) | 0.57 (0.27, 0.77) | 0.8 |
| Zinc μmol/L | 726 (633, 848) | 756 (656, 1,155) | 0.7 |
|  |  |  |  |

*1*Median (Q1, Q3)

*2*Wilcoxon rank sum exact test; Wilcoxon rank sum test

Yes: People working on or near the sites.

No: People not working on or near the sites

N: Number of employees

Table 7: Heavy metal concentration and dwell time

|  |  |  |  |
| --- | --- | --- | --- |
| **Metals** | **1 to 5 years**  **N= 1*1*** | **over 10 years**  **N = 21*1*** | **p-value2** |
| Lead (µg/L) | 50 (50, 50) | 76 (63, 99) | 0.3 |
| Cadmium (µg/L) | 6.53 (6.53, 6.53) | 3.37 (1.47, 3.47) | 0.3 |
| Arsenic (µg/L) | 5.07 (5.07, 5.07) | 8.80 (7.57, 10.30) | 0.091 |
| Nikel (µg/L) | 1.77 (1.77, 1.77) | 3.33 (2.10, 6.60) | 0.3 |
| Copper(µg/L) | 9.6 (9.6, 9.6) | 14.5 (9.6, 20.5) | 0.6 |
| Iron μmol/L | 7 (7, 7) | 18 (14, 22) | 0.091 |
| Cobalt (µg/L) | 4.27 (4.27, 4.27) | 2.60 (1.87, 3.43) | 0.11 |
| Aluminum μmol/L | 0.33 (0.33, 0.33) | 0.53 (0.27, 0.73) | 0.6 |
| Zinc μmol/L | 1,340 (1,340, 1,340) | 711 (633, 811) | 0.2 |

*1*Median (Q1, Q3)

*2*Wilcoxon rank sum exact test; Wilcoxon rank sum test

N: Number of employees

**4. DISCUSSION**

A total of 22 people were selected for this study. The mean age of the population was 58, with extremes ranging from 46 to 67, suggesting that younger people took less part in the survey. The male population was predominant, which could be explained by the interest men took in the study. Most participants (95%) had lived in Zagouta for more than 10 years indicating that the village is made up of long-term residents.

The determination of heavy metals in the blood of local residents detected the presence of 10 metals: lead, cadmium, mercury, arsenic, nickel, copper, cobalt, aluminum, zinc and iron. Most of the populations surveyed had very high concentrations of heavy metals, with nickel, copper, aluminum and cobalt at 100%, followed by cadmium (95%), lead (63%) and iron (54.55%). The high percentages of abnormal values for several metals indicate significant pollution, necessitating action to reduce the population's exposure. The high levels of heavy metals could be explained by a bioaccumulation phenomenon, given the long years of residence.

The high mercury content is of particular concern. It is common practice to use mercury to extract gold in artisanal gold panning areas, resulting in significant contamination of surrounding ecosystems. The presence of mercury in the aquatic food can have dramatic repercussions on populations that depend on fishing for their livelihood. Gold panning produces contaminated residues that can be found in the environment and have an impact on the health of local residents, espacially children exposed to lead. The neurotoxic effects of lead are well known, and high levels can have serious repercussions on cognitive development.

Mining waste frequently contains arsenic and cadmium, which can lead to serious illnesses such as cancer and respiratory disorders. The concentrations detected in the blood of Zagouta residents highlight the importance of regular monitoring and specific interventions.

The literature establishes a correlation between heavy metal exposure and chronic diseases, such as cardiovascular and kidney disease. An increase in these conditions has been observed in communities likely to be exposed to mining activities, suggesting a direct correlation with levels of body contaminants. Exposure to mercury and other heavy metals can cause problems during pregnancy and impact women's reproductive health. Zagouta's findings underline the importance of taking into account the reproductive health of women living gold-mining areas.

The medians of heavy metals for people claiming to have effect on their health or not revealed a significant difference only in zinc.

There was no significant difference in heavy metal concentrations people living on and off the gold panning, proximity to mining was not associated with exposure risk. This thesis is confirmed by studies 6 which found that the risk of mercury exposure was highest in communities classified as indigenous, regardless of proximity to mining activity. Heavy metal concentrations in people who had spent more than 10 years in the study area showed no significant difference from those of less than 5 years. This could be explained by the large difference in numbers, as only one person had spent less than 5 years in the study area.

**Study limitations**

Difficulties arose on three levels.

This work was carried out with great difficulty due to the lack of equipment or outdated equipment at our university.

Gold panning is a clandestine activity, so it's difficult to get into the area. The population has not been opened up.

Analysis a single heavy metal costs an average of 30 euros. With no outside help, we were faced with financial difficulties.

Because of all these difficulties our sampling has been reduced to this small number, equal to 22.

**CONCLUSION**

Analysis of heavy metal levels in the blood of the inhabitants of Zagouta, Bouaflé sub-prefecture of the Marahoué region, where the Bandama river flows, reveals a major public health problem associated with gold-panning activities. The results of this research reveal worrying levels of metals such as mercury, lead, arsenic and cadmium in the blood of the local population. The majority of the population surveyed had very high concentrations of heavy metals, particularly nickel, copper, aluminum, cobalt, cadmium, lead and iron. All this suggests a worrying exposure of local populations to these pollutants. The main cause of this exposure is the unregulated practice of artisanal gold panning. This study needs to be carried out on a large scale to gain a better understanding of the level of exposure to heavy metals of populations living in the vicinity of gold panning, and seek measures to reduce the general population's exposure to these substances, in particular by acting on sources of exposure.

With this in mind, it is essential to implement measures such as: awareness-raising campaigns on the dangers of heavy metals, stricter regulations on gold panning and their strict enforcement, an assiduous health monitoring program, close collaboration between health authorities, local communities, NGOs and administrative authorities to develop effective strategies to reduce exposure to heavy metals and improve living conditions for residents.

As a recommendation, public university laboratories need to be provided with the necessary equipment and qualified personnel to carry out research studies for the well-being of the population.

Ethical approval and consent : All the participants of this study were informed of its benefits. In addition, informed consent was obtained from each individual before the study began

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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