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Waste management of the artisanal mining areas in Côte d'Ivoire and associated environmental and health impacts

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Abstract: Waste management of the artisanal mining areas at Hiré and Angovia (localities in west of Côte d'Ivoire) and associated environmental and health impacts were studied. The survey and the field observation carried out in these both localities revealed that artisanal mining generates waste of various kinds, namely liquid waste, solid waste and air emissions, which are managed differently. Some are stored in heap (sterile and processing residues) while others (sludge, wastewater, household waste, worn-out equipment, used oils...) are dumped in wild landfills or in abandoned wells. Some wrapping such as the cans of chemical products and the treatment sludge are reused by the miners. Waste produced on the artisanal mining sites significantly degrades the environment quality and causes health problems for miners. Both at Hiré and Angovia, the environmental impacts mainly concern the pollution and degradation of water resources, soils and air. On a sanitary level, we note the development of illnesses such as respiratory diseases (47 to 72% with a higher rate in Hiré), malaria (14 to 19% with a significant proportion in Angovia), cutaneous diseases (11 to 25% with a higher proportion in Angovia) and headache (3 to 9% with a higher rate in Angovia).

Key words: Waste, artisanal mining, pollution, environmental impacts, health, Côte d'Ivoire.

INTRODUCTION

Since 1990, we observe in West Africa a development of the mining sector sustained by attractive mining policies and by a considerable investment of the foreign private sector[6]. This situation permitted the implantation of many mining exploitations, whose contribution is more and more important in the gross domestic product (GDP) and export earnings[6-12]. However, if mining exploitations are sources of socio-economic development, they cause multiple environmental harms when no precautions are taken. Among these harms, we note the destruction of the vegetation cover, the depletion of water resources and the contamination of environmental matrices (soil, air, surface water and groundwater).

So, in order to deal with such situations, these activities are governed by regulations that ensure the conduct of mining exploitation from a point of view of environment and health protecting. However, if inspections can be carried out on the industrial sites, this is not the same for the artisanal mining which is illegal and operates clandestinely[2-6].In Côte d'Ivoire, the last decades of socio-political crisis and the rise in the cost of gold have involved the intensification and anarchic proliferation of artisanal gold mining, especially near areas of industrial exploitation[4-9]. Besides, artisanal mining sites are subject to wild deforestations, soils and biodiversity destruction, and especially the uncontrolled use of chemicals such as cyanide, mercury, zinc, sulfuric acid and nitric acid, which present real dangers for the environment and the life of populations[10-19].

The regions of the center of Côte d'Ivoire, in particular Marahoué and Loh-Djiboua regions which contain the biggest areas of artisanal mining of the country, are not in margin of this situation. Recent studies conducted in these regions showed a development of many small artisanal mining sites around the industrial mines, and the use of chemicals in the processes of mining exploitation[5-10]. These studies have been directed towards the contamination of surface water and sediments by metallic elements (Cd, Cu, Fe, Hg, Mn, Pb, Zn) [8-13]. If studies have focused on the identification of artisanal mining sites and on the quality of water resources in these regions, no studies have been carried out on the management of waste derived from this activity. Yet, one of the solutions to reduce the environmental and health impacts associated with gold mining remains the control of waste produced and their management methods. The aims of this study were (i) to report on the waste management in the artisanal mining areas in Hiré and Angovia (types of waste produced and waste management methods), and (ii) to identify the environmental and health impacts associated with the wastes produced.

MATERIALS AND METHODS

Study area: Hiré is located in the Loh-Djiboua region in west-central of Côte d'Ivoire. It is located between latitudes 6°15' and 6°10' north and longitudes 5°23' and 5°16' west[19]. The village of Angovia is located in the center of the country and east of the Marahoué region in the sub-prefecture of Bouaflé. This village lies between latitudes 6°53'and 7°05' north and longitudes 5°19'and 5°31' west[1] **(Figure 1).**

Data collection: It consisted to carry out two joint activities, namely a field observation and a survey of the miners in three artisanal mining sites for each locality. The observation provided a general overview of the artisanal mining activity in the localities of Hiré and Angovia. Relatively to the survey, it consisted of interviews with the miners organized in group of 3 to 10 peoples on study sites. It provided information on the nature of waste, management and recovery methods, and diseases manifested by the miners. The number of miners surveyed was established using the simple random sampling method[17]. This allowed selecting sixty (60) miners during the investigation: thirty (30) in Hiré and thirty (30) in Angovia.

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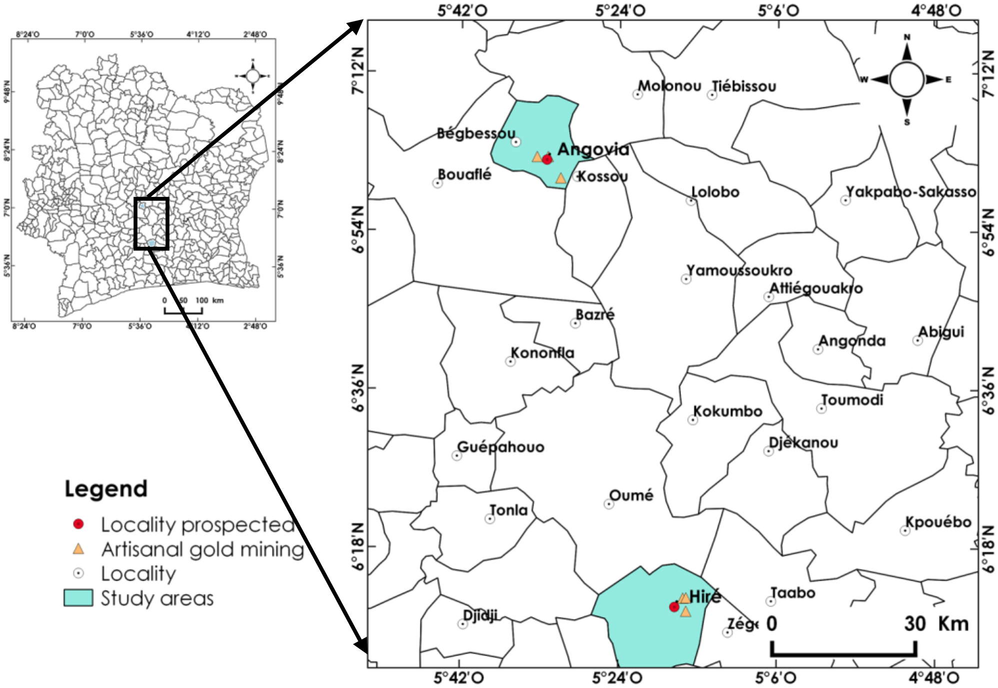

Figure 1 : Location of study areas.

Data analysis: Data from the survey were codified. Then, these data were grouped by zone and by variables (waste types, management mode, nuisances felt and diseases manifested). The frequency of each variable was calculated in relation to the number of miners surveyed according to the following relationship:

$$F = \frac{X}{Y} \times 100$$

F: Frequency (%)

X: Number of the modality (number of miners per zone and per variable)

Y: Total number of miners per zone

RESULTS AND DISCUSION

Typology of waste: In Hiré as in Angovia, artisanal gold mining generates three (3) types of waste: liquid waste, solid waste and atmospheric emissions. These wastes could constitute sources of the environment pollution and miners' disease.Liquid waste consists of wastewater and sludge from the different processes used to process ore and from the waste oils produced by ore grinding equipment.

In accordance with Sorgho[16], some of solid waste listed comes from nearby temporary houses and from the shops located on the sites. The solid wastes were consisted essentially of sterile, residues resulting from mineral processing processes (washing, sluice washing and cyanide treatment), household waste and similar waste including plastic bags, food scraps, food and detergents packaging, used utensils, old buckets, rags, cardboard, beverage cans, etc., and other wastes such as chemicals packaging, non-use equipment (used parts of grinding equipment, used torches and lamps, used batteries, PVC piping, used packaging, plastic bags and sheets).Atmospheric emissions concern the vapor of mercury used for the recovery of gold, the gases resulting from the dissolution of zinc chips to nitric acid and sulfuric acid, dust and exhaust gases of the engines.

Waste management: Waste is managed in different ways depending on its nature. The sterile are stored in the form of mounds in the vicinity of wells (**Figure 2).** The survey showed that for one meter of dug wells, approximately 0.3 m^3 of sterile may been dumped into the environment. Yet, the depths of the dug wells sometimes reached 40 m, corresponding with 12 m^3 of sterile discharged from a dug well.

Similarly, treatment residues are stored near ore processing sites as shown in **Figure 3**, while these wastes contain dangerous chemicals such as cyanide that could seep into the soil or leach into water resources[14].

Figure 2: Outline of sterile in the vicinity of wells.

Figure 3: Storage of treatment residues in the vicinity of a cyanidation site (A) and a washing site (B).

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Concerning household solid waste, they are dumped either in wilds landfills or in abandoned wells or directly at work sites (**Figure 4).** The decomposition of organic matters of household waste is likely to cause olfactory nuisance[3].

Figure 4: Household waste disposal sites in the Hiré and Angovia artisanal gold mining: A = wild landfill, B = work site; C: abandoned well.

The management of wastewater and ore treatment sludge were different depending on the type of washing used: simple washing, sluice washing, mercury recovery or cyanide treatment. In the case of washing, the technique requires a high water volume. Ore is washed in natural water or in basins, and the sludge is mixed with the water during washing. The survey showed that in Angovia area, washing was carried out in basins (**Figure 5A)** whereas in Hiré area, it was produced directly in the surrounding water reservoirs **(Figure 5B**) despite the degradation of water that this could generate.

Figure 5: Ore washing methods encountered in Angovia (A) and Hiré (B).

As for the washing in the basins, they are emptied when the water contained therein becomes totally muddy. The sludge thus removed is discarded either in nature or in the old "dama" sinking wells. Concerning the water reservoirs involved in the Hiré area, the washers periodically remove sediments piled up in the bottom to reject them at the edges of the reservoir. During sluice washing, wastewater and treatment sludge are collected in small basins downstream of the sluice. It should be noted that the water used to wash the ore in this technique contains detergents. Once in the basins, the water is allowed to

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penetrate into the soil and the sludge is subsequently recovered, which is piled in the edges of the basins and then sold to the cyanidation gold diggers. This mode of management of the water and treatment sludge is observed in the two zones visited.

In Angovia, the sluice washing of the ore takes place in places called "counters" set up for this purpose, while in that of Hiré, it takes place mostly at the homes of the miners. However, a few sluice washers have been identified in the edges of water reservoirs where wastewater and treatment sludge are directly dumped **(Figure 6)**.

Figure 6: Washing with a sluice at the edge of a reservoir of water at Hiré (Agbalé).

In the sluice washing practice, the ore fraction containing gold is retained by the sluice mat. This fraction is recovered in cuvettes, to which water and mercury are added to make the amalgamation. In Hiré, it has been found that wastewaters from this mercury wash are directly discharged to the soil of the sites of activity (**Figure 7**) or to the surface waters after rainfall. This wastewater can promote soil and surface water pollution by mercury.

Figure 7: Wastewater and mercury-contaminated sludge dumped directly on the ground at Hiré.

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Wastewater from the zinc dissolution process is generally discharged into small basins of less than 1 m^3 dug into the soil for infiltration **(Figure 8A).** They are also discharged into the wild (**Figure 8B).** However, these wastes are often contaminated with chemical compounds such as cyanide, nitric acid and sulfuric acid that may contaminate the soil. Direct discharges of wastewater in environment would promote the mobilization and dispersal of heavy metals in the environment, particularly in surface waters and in groundwater[13].

Figure 8: Wastewater management resulting from the operation of dissolving zinc chips in Hiré and Angovia; A = basin; B = wastewater flow to a receiving environment.

The oils used are stored in 20 to 30 liters containers. It has been found that, in their manipulation, they are regularly spilled on the ground of the ore crushing sites (Figure 9). Moreover, after their use in mills, they are directly discharged on the soil of the activity's sites. Releases of waste oil pollute the soil and could end up in surface water after rainfall[11].

Figure 9: Discharge of waste oil on the soil of an ore crushing site.

Environmental impacts: The waters of the study area are not immune to contamination by chemicals which are used in processes. The pollution of surface water by metallic elements (Cd, Cu, Fe, Hg, Mn, Pb, Zn) near artisanal mining' sites in Hiré area was been reported by Koffi[8]. The dumping of treatment sludge into surface waters would lead to the degradation of these ecosystems, as is the case in Akississo and Agbalé in the Hire area (**Figure 10**). This problem has been observed by Koffi *et al.*[9] who found the degradation of a tributary of the Bandama River by this category of waste.

Figure 10: Illustration of degradation status of Hire water reservoirs; A = water of coloring ocher to Agbalé, B = silting of the Akississo reservoir.

Also, spreading waste rock and residues on the soil changes its physicochemical properties, impoverishes it and could make it unfavorable to agriculture. **Figure 11** shows an overview of land degradation by waste rock in the investigated gold mining areas.

Figure 11: Land degradation by waste rock at Hire (A) and at Angovia (B).

Artisanal mining activities generate significant atmospheric emissions such as vapor dissolving mercury, dust, and exhaust gases which are dissipated in the air (**Figure 12).** During the burning operation of the mercury amalgam for example, about two grams of mercury evaporate in air per

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gram of recovered gold[7]. Despite this pollution, no protective measures are taken by miners to reduce or control them.

Figure 12: Emissions of dust (A) and exhaust gas (B) at an ore crushing site

Diseases in the study areas: In Hiré as in Angovia, recurring diseases at the miners are respiratory infections, malaria, skin diseases and headaches. The figure 13 shows the proportion of diseases per prospected area. Respiratory infection is the disease that affects most workers in the studied areas with a frequency of 72% in Hiré and 47% in Angovia. Frequent respiratory infections would be due to their continued exposure to atmospheric emissions from dust and smoke from mills and gases from chemicals (mercury, sulfuric acids and hydrocyanic acids)[15]. Skin diseases are caused by the permanent contact with the wastewater, treatment sludge and chemicals used by the miners.

Malaria is due to the presence of wastewater and treatment sludge at or near the sites of artisanal mining that could promote the proliferation of mosquitoes, vector of this disease. In the case of headaches, exposure to mercury vapors could be one of the causes of the development of this disease. Indeed, a study by Tomicic *et al.*[18] in Burkina Faso showed the prevalence of symptoms, including frequent headaches, sleep disturbances, unusual fatigue, limb tremors and visual disturbances, was higher in people engaged in either the preparation of gold-mercury amalgams and to the heating of these amalgams.

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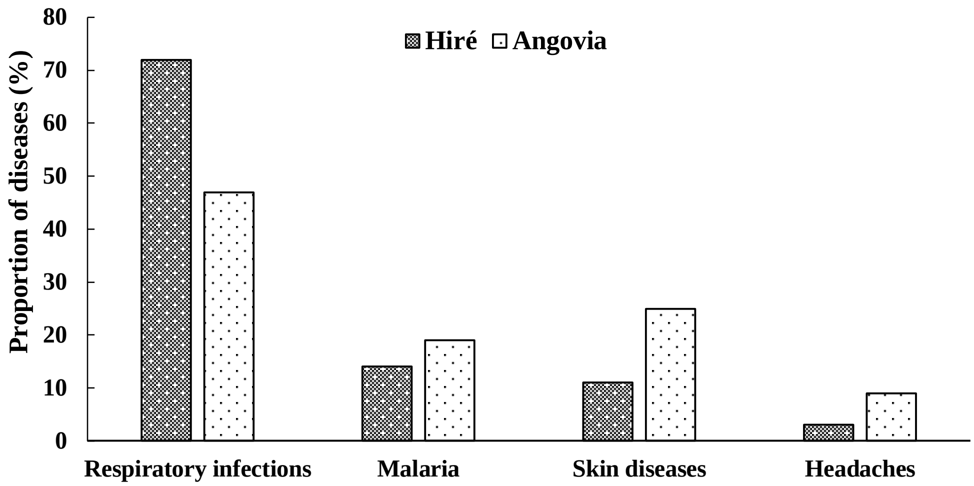

Figure 13: Proportions of diseases exhibited by miners.

CONCLUSION

The results of this study have shown that artisanal mining activities in Hiré and Angovia areas produce three types of waste such as liquid waste, solid waste and atmospheric emissions. Liquid waste includes waste oils, wastewater and treatment sludge. Solid waste consists of waste rock, ore processing waste, household solid waste, chemical packaging, non-use equipment, etc. The gases resulting from the dissolution of zinc chips, dust and exhaust from the machinery constitute the category of atmospheric emissions. Various methods of disposing of wastes such as heap storage (sterile and process residues), discharge to work sites, in wild dumps or abandoned wells (sludge, wastewater, solid waste Household waste, end-of-life equipment, waste oils, etc.) and recycling (sludge treatment and packaging of chemicals) were observed in the studied areas. The environmental impacts of waste management include degradation of water and soil resources and air pollution. The survey of gold miners revealed that respiratory infections, malaria, cutaneous diseases and headaches are manifest diseases related to waste generated by artisanal mining. In order to protect the environment and population health, it's recommended to use protective equipment on artisanal mining sites to reduce the risk of exposure to dust, chemicals and gases, to sensitize minors on dangers of chemicals used and on good hygiene practices, to stop ore washing in surface waters, and to rehabilitate artisanal mining sites after their use.

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