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Artisanal Mining Practice and Physical Impacts on the Environment in the Ity-Floleu Gold Region, Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This paper describes artisanal gold mining practices and environmental impacts around the Ity-Floleu gold mine, in western Côte d'Ivoire. Interviews and field observations as well as measurements of turbidity and water flow velocity in the section of the river (Cavally) watering the study area, made it possible to identify 13 artisanal mining sites, housing 247 artisans, operating in groups made up mainly of 5 to 10 people. The activity is dominated by local populations from the villages of Ity and Floleu and the surrounding communities. Gold mined comes from alluvial and vein ores, with a predominance of alluvial ore, extracted in the sediments of the bed and the banks of the river and in the soils, inside forests. In the bed of the river, sediments are dredged using machines placed on boats, from where they are washed in mats and then dumped into the watercourse. On the other hand, on the banks of the river and in the forests, the material used

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consists of picks, dabas, mats, and shovels. In all cases, gold is recovered as a concentrate of gold powder. As regards vein ores, they are also extracted along with the soils of cultivable land, but in the form of blocks of stone which are crushed and washed. The gold is then recovered using mercury, followed by cyanidation. The techniques used lead to the silting up and the fall of the banks of the river, reduction of agricultural land, and the degradation of the environment by the tailings. The Cavally River appears to be strongly impacted in the midstream part of the Ity-Floleu axis, marked by a decrease in the bed and the river flow velocity (0.19 m/s) and higher turbidity (255.3 NTU). More effective policies are urgently needed to restore degraded ecosystems, both aquatic and terrestrial.

Keywords: Artisanal gold mining; Practice method; Environmental impacts; Ity-Floleu Gold Region.

1. INTRODUCTION

Since the 1990s, the mining sector has experienced significant development in West Africa, driven by attractive national mining policies and strong investments from the foreign private sector [1]. However, mining activities are a potential source of environmental degradation, in particular through the destruction of arable land and the contamination of soil and surface, and groundwater [2][3]. Thus, to ensure the preservation of the environment and the rehabilitation of exploited sites, mining operations have been governed by a mining code establishing the standards, conditions, and morals of the regulations in force. However, if the establishment of extractive industries is subject to compulsory permits, this is not the case for artisanal practices which are clandestine, and operating mostly in the industrial mines area [4][5]. It, therefore, appears necessary to be concerned about the effects of such activities, which are so devastating on plant cover and water bodies, and which use chemicals (*e.g.* cyanide, mercury, zinc, sulfuric acid, and nitric acid) uncontrollably. Indeed, the processes used by artisans in the search for ore are likely to contaminate soils, surface water, and groundwater and therefore destroy the biodiversity of ecosystems, both terrestrial and aquatic, and reduce agricultural land [6][7].

In Côte d'Ivoire, the establishment of several gold mines across the country also arouses the enthusiasm of many artisanal miners. These include, among others, the Ity gold mine in the west, Bonikro and Agbaou mine in the southwest, Yaouré-Perseus mine in the center, and the Tongon and Sissingué mines in the north of the country [8]. To date, artisanal gold mining is booming across the country, affecting around 24 out of 31 regions of the country, with more than 500,000 artisans [9]. However, in view of the illegal and clandestine nature of the artisanal mining activity, it completely escapes the control of the authorities in charge of environmental management. Thus, several studies have been carried out in particular in the West [10], in the Central West [3], in the North-East [2], and in the North-west [11] of the country, in order to examine artisanal gold mining practices, with a view to controlling their various environmental nuisances. All of these works have shown that artisanal gold mining has a detrimental effect on the soil, water resources, air, flora, fauna, the social environment, and the health of populations.

However, the works carried out in the west of the country only addressed the physicochemical quality of the groundwater [10] [12] and of the waters of the Cavally River [13]. Thus, none of these studies describe the physical impacts of artisanal gold mining activities in the locality, those impacts which constitute the starting point of any nuisance of the said activities. These include, in particular, the plant cover of the soil, the physical aspect of the body of water (Cavally River), etc. On the other hand, the description of the methods of exploitation of the ore practiced by the artisans would make it possible to assess and comprehensively apprehend the nuisances of the artisanal extraction of gold in the locality.

This study aims to describe the activities of artisanal gold mining around the Ity-Floleu gold mine (*i.e.* actors involved, techniques used, type of ore mined), in western Côte d'Ivoire, and to determine their physical impacts near the mine area (*i.e.* degradation of the plant cover, physical aspect of the river [banks, flow velocity, turbidity].

2. MATERIALS AND METHODS

Data collection for this study was carried out on artisanal gold mining sites around the Ity-Floleu gold mine, west of Côte d'Ivoire and, required interviews with the artisanal miners and the use

of equipment such as a Global Position Satellite (GPS) to geolocate the various sites and a digital camera to take pictures of the gold panning environment. In addition, a HI 9829 type multi-parameter was used for the analysis of the turbidity of the Cavally River, and a model 6200 “AA” current meter for the measurement of the flow velocity in the river.

2.1 Description of the Study Area

This study was carried out on artisanal gold mining sites established on the Cavally River and its surroundings near the Ity-Floleu gold mine in the Zouan-Hounien department, west of the Côte d’Ivoire (Fig. 1). Indeed, the study area is located between latitudes 06° 50’ and 06 ° 55’ North and longitudes 08° 05’ and 08° 10’ West. This locality belongs to mountain climates but is moderately rugged with reliefs having altitudes varying between 255 m and 450 m. The region is part of a vast forest area that covers both Côte d'Ivoire and Liberia. Although the department is mainly crossed by the Cavally River, the main activity is the agriculture of which the department was one of the largest producers of coffee, cocoa, and palm oil. However, the development of artisanal gold mining has led to the gradual abandonment of these agricultural activities, which have now become secondary [14]. The Ity gold mineralization is located in the Toulépleu-Ity Birimian unit located in the west of the Sassandra fault in the Kenema-Man domain. This set is oriented according to a NE-SW direction [15]. The geological formations, dominated by metamorphic rocks and gneiss, are essentially shales, rhyolites and migmatites [16] [17].

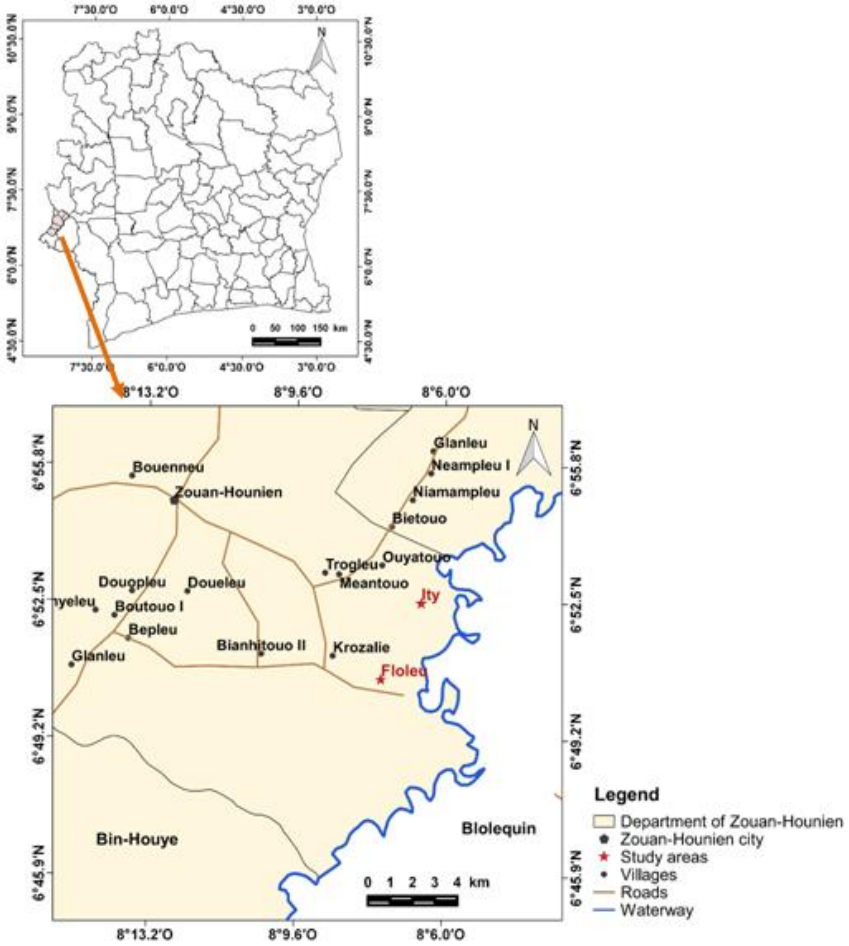

Fig. 1. Location of the study area

2.2 Data Collection

The data was collected from May to June 2021, on thirteen (13) artisanal gold mining sites identified on and around the Cavally River near the Ity-Floleu gold mine. As seen in Fig. 2, the identified sites can be divided into three (3) groups (Upstream, Midstream, and Downstream) depending on the direction of the Cavally River flow, from Ity to Floleu. The upstream part includes three (3) sites (S1, S2, and S3), the midstream one includes four (4) sites (S4, S5, S6, and S7) and the downstream part of the study area has six (6) sites, including S8, S9, S10, S11, S12, and S13. A total of 32 groups of artisanal miners were identified across all the sites and questioned during the interviews.

On the different sites, data collection was carried out through interviews with different groups of artisanal gold miners and determination, of the flow velocity and the turbidity of the water, on the surrounding part of the river. The interviews made it possible to determine, among other things, the number of groups of artisanal gold miners on the different sites, the types of ore (vein or alluvial) sought and the extraction methods and the gold recovery procedures practiced. Field observations consisted of evaluating the state of the environment in order to illustrate the types of activities practiced and their impacts on the environment in particular, on agricultural land and on the Cavally River body.

2.3 Data Analysis

The data collected from the interviews were codified and then grouped by variables (extraction methods, gold recovery procedures practices, etc.). The frequency of each variable was calculated in relation to the number of sites or that of artisanal miners questioned according to relation (1):

$$F = \frac{X}{Y} x\ 100 \qquad (1)$$

Where:

F: Frequency (%);
X: Number of the modality considered;
Y: Total workforce of the modality considered.
The data from each part of the study area (Upstream, midstream, and Downstream), relating to the flow velocity and the turbidity of the river water, were analyzed using the R studio 3.3.2 software. Due to their normal distribution, these data were compared using the N-factor ANOVA test, the significance level of which is set at $p < 0.05$.

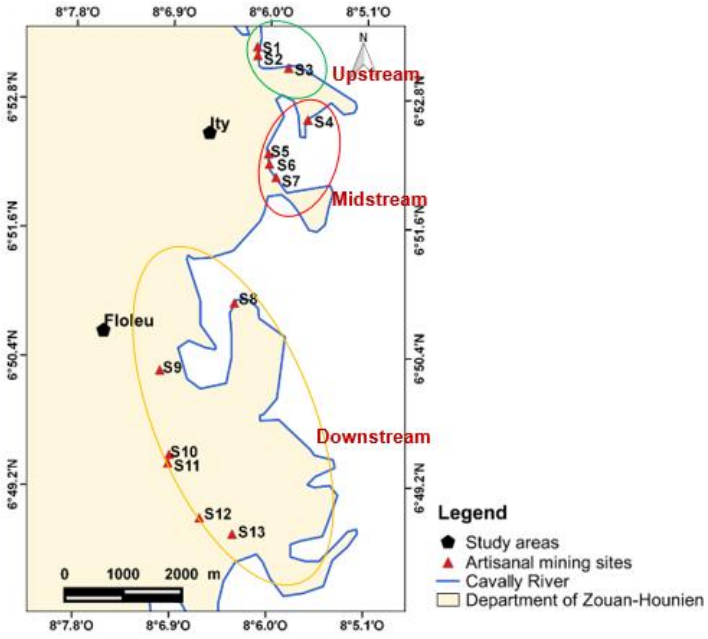

Fig. 2. Location of artisanal mining sites in the study area

3. RESULTS

3.1 Actors of Artisanal Mining

As shown in Table 1 on the 13 gold mining sites identified in the study area, a total of 247 artisans were identified, including 69 in the upstream part, 81 in the midstream part, and 97 in the downstream part of Ity-Floleu section. However, the artisans were distributed to the different activity sites into distinct groups of artisanal miners, each operating with their own. There were a total of 32, with 9 upstream groups, 10 midstream groups, and 13 downstream groups, respectively.

Analysis of the size of the different groups showed that the majority (62.5%) housed between 5 and 10 artisans and very few consisted of 1 to 5 artisans (Fig. 3A). In addition, the gold miners in the Ity-Floleu area were mostly (67.6%) nationals (Ivoirians). Non-nationals were composed of Burkinabe (14.6%), Malian (10.1%), and Guinean (7.7%) [Fig. 3B].

3.2 Description of Activities

Two types of gold mining were observed at Ity and Floleu, depending on the nature of the ore extracted. These include the artisanal exploitation of alluvium and veins (Fig. 4). However, the activity remains dominated by the search for alluvial ore (84.6%). The search for vein ore was carried out on 15.4% of the sites identified in the study area [*i.e.* two (2) sites].

Table 1. Size in the organizations of artisanal miners in the study area (Ity-Floleu)

Sections of the Study area	Gold mining sites	Groups of minors	Size
Upstream	3	9	69
Midstream	4	10	81
Downstream	6	13	97
Total	13	32	247

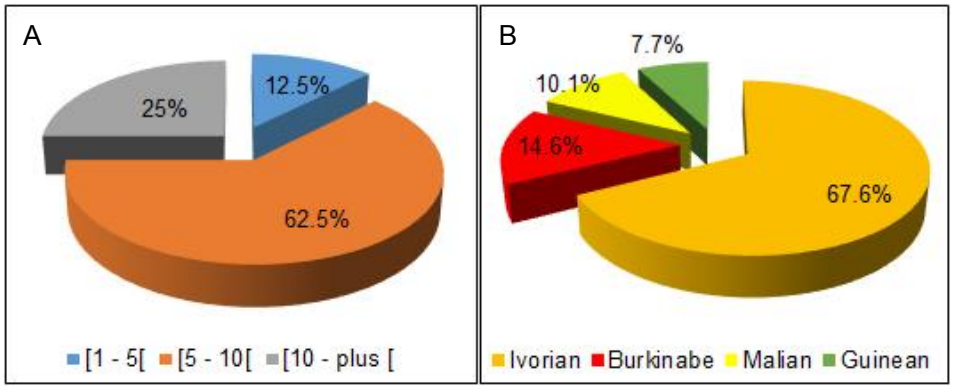

Fig. 3. Number of miners in the groups established on artisanal gold mining sites (A) and their origins (B)

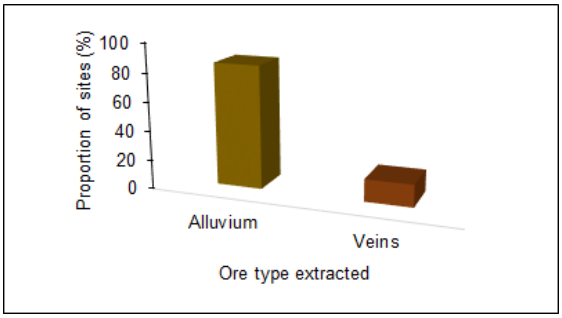

Fig. 4. Nature of the ore extracted in the gold mining sites of the study area (Ity-Floleu)

3.2.1 Alluvial ore exploitation

Alluvial ore extraction is done in three (3) ways, in the study area, depending on whether the activity takes place on the bed of the Cavally River and its surroundings, and on tracks and trails. On the Cavally River, the gold miners, with financial means, use machines placed on the bed of the river, to extract the ore from the sediments of the river. The sediments brought to the surface are washed at the same time as the machines dig the bottom of the stream (Fig. 5). The sediments are spread on pieces of carpet placed inside a washing device to which water is added to separate the clay or sand fraction from the gold. Residues from the wash (clay or sand) were immediately released into the river while the gold was fixed by the underlying carpet.

Another group of miners, operating on the Cavally River, with little means, digs the bottom of the stream using shovels and dabas. Washing is done at the same time with carpet placed inside a washing device to which water is added to separate the clay or sand fraction from the gold (Fig. 6). Residues from the wash (clay or sand) were also immediately released into the river while the gold was fixed by the carpet.

On the other hand, on tracks and paths far from the watercourse, in the forest, the ore is extracted by scraping with pickaxes, dabas, and shovels in pits made in a scattered manner (Fig. 7). The ore obtained is washed on site (Fig. 7AB) or transported by the artisanal miner to a developed water point (Fig. 7C). Water points are watertight depressions where water pumped from a source (well, rivers, etc.) is stored. The alluvium is breaded there using calabashes, bowls, and boxes.

Fig. 5.Practice of gold panning on the Cavally river using machines

Fig. 6. Practice of gold mining on the Cavally River using rudimentary means (shovels, buckets, basin, etc.)

Fig. 7. Practice of gold mining in the forest; washing the ore in situ (A, B), ore washing at a water point (C)

The concentrate consisting of iron filings and gold powder obtained in the three types of gold mining practices is continuously recovered in a small calabash (Fig. 8). It is breaded several times to definitely have the gold dust at the bottom of the calabash. The impurities (iron filings) remaining in the final concentrate are removed with the magnet by the buyers.

3.2.2 Exploitation of vein ore

This practice consists of extracting the ore in the form of blocks of stone in galleries dug along with the soils of cultivable land (Fig. 9). After extraction, the sizes of the stone blocks are reduced on-site and transported by motorcycles to Floleu for crushing (Fig. 10A). Once crushed, the powdered ore is spread over pieces of carpet placed inside a washing device to which water is added to separate the clay fraction from the gold (Fig. 10B).

After fixing the gold in the pieces of carpet, they are agitated very well so as to completely strip them of all the impregnated gold. This results in a cloudy solution now containing gold particles and mud. The solution is left to settle in order to obtain a greyish deposit after a few minutes. At this stage, the greyish deposit is recovered and placed in relation to a relative quantity of mercury. Mercury is used as a reagent to separate pure gold from other residues of the grayish deposit (*e.g.* rock particles, plant debris, carpet debris, etc.). This separation is done by flocculation of isolated gold particles which, helped by the mercury, will form one or more coagulates (gold-mercury mixture). At this level, the gold dissolved in the mercury can only be recovered after having burned the formed coagulates.

After the mercury treatment process, the sand or mud resulting from the ore washing process is purchased by another group of gold miners present at these sites to subject it to second cyanide treatment. The cyanide treatment device consists of an alternation of small full and hollow basins, the depth of which is approximately 1.25 m for the deepest, with a rectangular opening, and approximately 0.40 m for the shallower, also with rectangular openings (Fig. 11).

3.3 Environmental Impact of Activities

3.3.1 Impact linked to alluvial gold exploitation

The visits to the mining sites in the study areas made it possible to observe different forms of pressure exerted on the Cavally River and the soils. The techniques used by the artisanal miners amplify the deterioration of the Cavally River (Fig. 12). These include the dredging of the river bottom by machines and the direct washing of the ore, and the diversion of the stream bed to exploit the sediments. These practices cause the banks of the stream to fall and the river to become silted up and the physical appearance of the water to deteriorate, as seen in Fig. 12.

In addition, the excavation of land and water retention carried out inside forests contribute to the degradation of the plant cover and the reduction of arable land in the locality (Fig. 13).

Fig. 8. Concentrate consisting of iron filings and gold powder obtained by washing the ore.

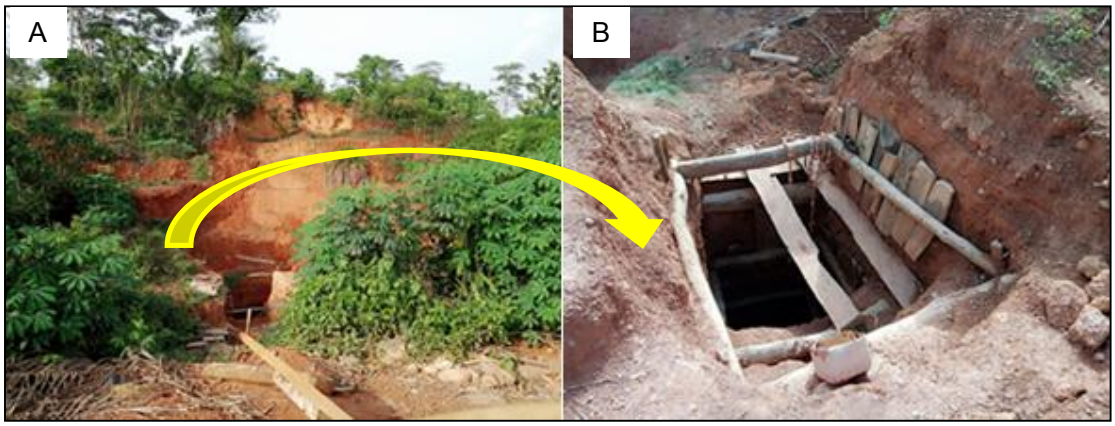

Fig. 9. Well for vein ore extraction (A B)

Fig. 10. Vein ore grinding (A) and washing (B) site by gold miners at Floleu

Fig.11. Device for treating gold with cyanide (A) and the interior of a hollow basin (B) at Floleu (in operation)

Fig. 12. Siltation of the stream and collapse of the banks

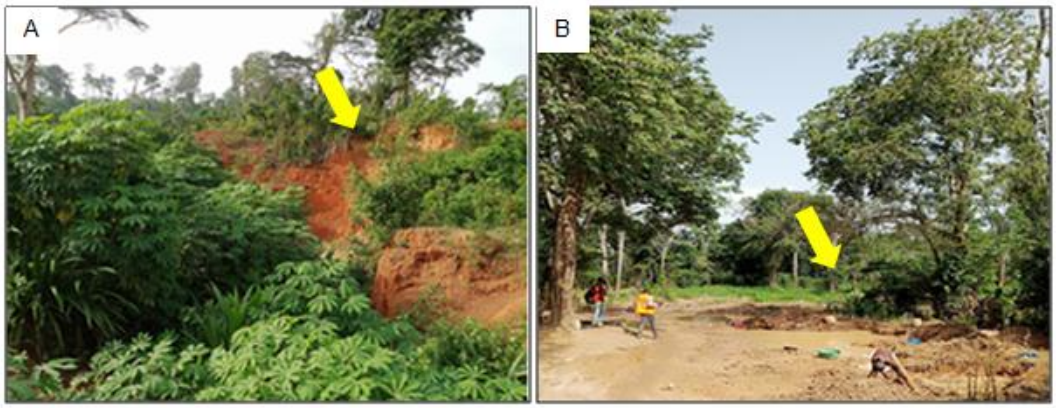

Fig. 13. Illustration of the destruction of agricultural land by gold miners in Floleu (A and B)

3.3.2 Impact linked to vein gold exploitation

After the sinking was carried out in the ground for the search for vein ores, the dug shafts are abandoned without any precaution of filling the holes with the mounds of waste ore excavated (Fig. 14A). The soil is thus irreversibly degraded because it is not reconstituted after the abandonment of the sites. In addition, shrubs are devastated to support the walls of dug wells (Fig. 14B), causing deterioration of surrounding vegetation. The depths of vein wells (greater than or equal to 40 m) could present risks of pollution of the underlying water tables.

In addition, the crushing of the veins generates dust in the environment which could ultimately have an effect on the health of populations (See Fig. 10A). The same is true for wastewater discharges resulting from the washing of crushed ore which could contain mercury residues (See Fig. 10B). At the end of the vein ore processing chain, particularly after crushing and mercury treatment, cyanidation treatment involves a large number of equipment and materials which are most often abandoned on the site, as is the treated sand refuse (Fig. 15).

3.3.3 Turbidity and velocity of water in the Cavally River

Fig. 16 shows the evolution of the turbidity and the velocity of the river water from the upstream sites, to the downstream sites, on the Ity-Floleu axis. Considering turbidity (Fig.16A), the values measured were higher in the midstream of the axis of the river studied and the lowest values were recorded upstream. The values oscillated between 30.8 and 51 UNT upstream, between 215.1 and 334 UNT in the midstream, and between 134 and 212 UNT downstream with respective averages of 40.5±10 UTN, 255.3±54 UTN, and 175.3±39 UTN. These values differ significantly from one section of the river to another (ANOVA t-test, $p < 0.05$).

Like turbidity, the velocity of river water was significantly different from one section of the water body to another (ANOVA t-test, $p < 0.05$). However, the river velocity was lower in the midstream and higher in upstream section of the water body (Fig. 16B). The river velocity went from 0.43 to 0.74 m/s with an average of 0.60 ± 0.16 m/s upstream, from 0.08 to 0.27 m/s with an average of 0.19±0.08 m/s in the midstream, and from 0.24 to 0.026 m/s with an average value of 0.25±0.01 m/s in the downstream section.

4. DISCUSSION

The study identified 13 artisanal mining sites housing 247 artisans around the Ity-Floleu gold mine, on the Cavally River and its surroundings. The artisans were organized into 32 groups, of which 9 were established upstream of the section of the river, 10 in the midstream and 13 downstream, whose workforce composed of 5 to 10 people was the most dominant (62.5%). However, the gold miners identified in the study area were mainly Ivoirians (67.6%), originating from the villages of Ity and Floleu and the surrounding localities. Registered foreigners (33.4%) were made up of Burkinabe, Malians, and Guineans. This configuration, illustrating the strong involvement of local populations in the artisanal gold mining activity, could be explained by the insufficiency of agricultural income and the collapse of the prices of agricultural products [8]

[18]. However, the current configuration of artisans on the Ity-Floleu gold sites is hardly similar to that of other regions of the country, particularly in the north and center-west, where gold activity is strongly dominated by the foreign population [18]. This situation would probably be due to the significant resources required to open and operate artisanal gold mining sites in the aforementioned localities. On this subject, Gho [5] gathered from a notable of Angovia, (locality of artisanal gold mining practice, located in the commune of Bouaflé, in the center-west of Côte d'Ivoire) the following comments: "Does not open an artisanal mining site who wants to but who can. The gold business requires a lot of resources and you need a lot of money to do it". These comments are justified by the fact that the artisanal gold mining activity in the localities is dominated by the search for vein ore which would prove to be much more difficult and cost-intensive, unlike alluvial ore [5] [18]. Indeed, the artisanal gold mining activity in the locality of Ity-Floleu is more oriented towards the search for alluvial ore in the sediments of the Cavally River, on 84.6% of the sites visited. For example, for artisanal miners with little financial means, all that is needed is some rudimentary material (shovel, dabas, carpets, etc.) to obtain gold from the sediments of the banks of the river.

Fig. 14. Accumulation of soil and rock debris on the surface of the soil (A) and excavation of the soil (B) at Floleu

Fig. 15. Illustration of the fate of the waste from cyanidation sites identified in the study area; treatment residues (A), waste rock (B), chemical packaging (C and D)

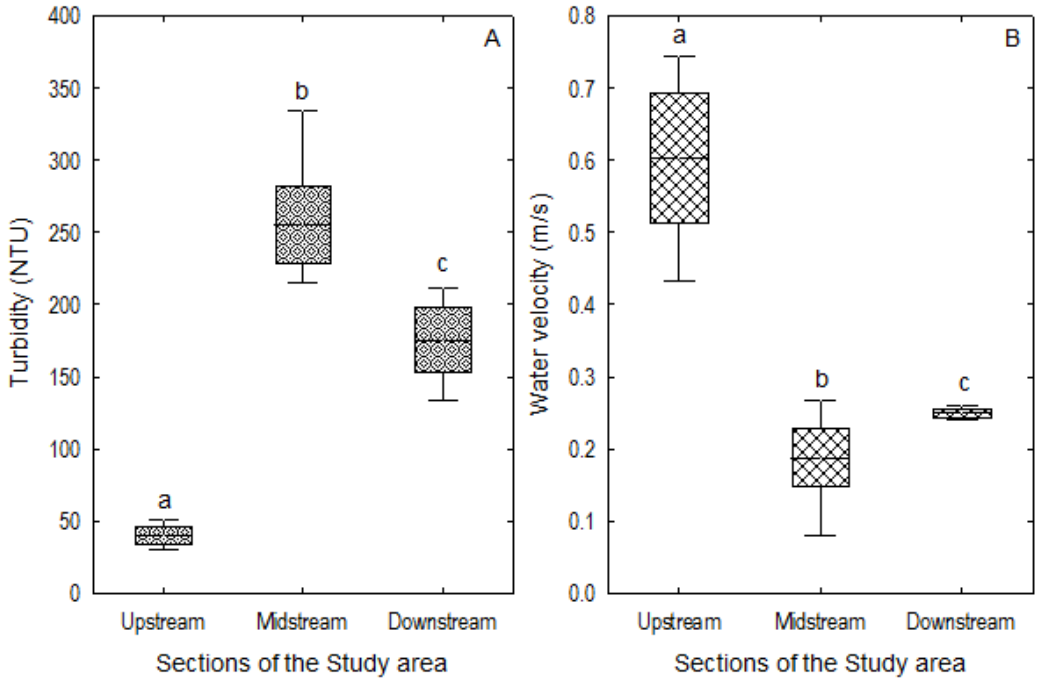

Fig. 16. Variation of turbidity (A) and water velocity (B) in the upstream, midstream and downstream sections of the Ity-Floleu axis of the Cavally River; Box-plots no bearing one alphabetical letter-identical are significantly different (ANOVA test; p < 0.05)

Overall, artisanal gold mining practices in the Ity-Floleu zone are similar to those in the Center-West [3] [19] [20] and in the North [2] [11] of the country. This concerns in particular research on alluvial and vein ores, and on all lode gold recovery techniques (crushing, washing, use of mercury and, cyanidation at the end of the chain). However, the artisanal gold mining activity in Ity and Floleu has a particularity on the river. Indeed, the gold miners who have means, use machines arranged on a kind of boat, on the bed of the river, to extract the ore contained in the sediment, which immediately dredged, is washed on the spot. Also, the washing residues are, at the same time, discharged into the river. This causes the silting up of the river observed in several places in the study area [21].

Indeed, several levels of pressure are being exerted by the artisanal miners on the river, the vegetation and, on the soil of the site of the study area. Water remains an essential element in the functioning of mining, both industrial and artisanal [22]. However, the use of water in gold mining remains a source of pollution of aquifer reserves and surrounding surface water in particular, with the release of intense particles in these environments [10]. At Ity and Floleu, the intensification of activities on the Cavally River by the artisanal miners increases its turbidity, which affects the quality of the water. The pressures exerted (washing the sand, dredging the river beds, discharges of residues and wastewater, etc.) by them cause the banks of the water to collapse and make the water cloudy and muddy. The work of Hue et al. [23] reported the same environmental mutations as those observed in this study.

Regarding the impacts of artisanal gold mining on vegetation and soils, massive destruction of plant cover and soil has been observed. Hue et al. [23] claim that artisanal gold activity in its wake leaves perforated and mutilated soils, as no rehabilitation plan for mined sites is planned at the end of activities. Thus, the lack of rehabilitation of these gold mining sites leads to soil degradation and the disfigurement of the plots, by more or less gaping pits which are left abandoned [24]. In addition, the clearing and cutting of shrubs strongly modify the living conditions of certain wildlife species and increase the risk of biodiversity loss which could upset the ecological balance. The sinking observed on the Ity-Floleu sites would entail a risk of soil erosion by runoff. The storage of mounds of sterile ore

could cause the siltation of nearby rivers, following rainfall events. In addition, the depths of vein wells (greater than or equal to 40 m) also present risks of groundwater pollution. Several studies carried out on the consequences linked to artisanal gold mining activities in the sub-region, in particular those by Diallo et al. [25], and Soma et al. [26] made these same observations.

Monitoring of turbidity and water velocity parameters in the Cavally River revealed that these artisanal gold mining activities have an impact on the river bed and water. Turbidity values, low upstream of the river (36.6 NTU), increased in the middle (271 NTU), to decrease further downstream (177.8 NTU). This indicates that the river water appears cloudier in the middle of the section studied and could be explained by the fact that gold mining activity was more intense in this part of the river. Indeed, the activities of the artisanal miners on the river undoubtedly generate a high suspended matter content due to the overturning of the sediments and their systematic discharge into the watercourse after washing on the boats. This would contribute to reducing the oxygen level in the water, gradually leading to the asphyxiation of the environment, and the alteration or even the disappearance of aquatic flora and fauna [27]. These results corroborate those of Gbamélé et al. [12] and Hue et al. [24] as well as the decrease in the flow velocity of the river water observed in the middle of the section. In fact, the flow speed of the river, which appeared relatively high upstream (0.60±0.16 m/s) dropped drastically in the midstream (0.19±0.08 m/s) to ultimately increase downstream (0.25±0.01 m/s). Thus, this drop in the flow velocity of the river water is likely related to the intensity of the activity observed in the midstream. Field visits suggested mounds of sediment at various locations in the midstream of the river, believed to have come from debris from the incessant washing of ore into the stream. This situation could also threaten the habitat of aquatic organisms in the study area and be the basis for the disappearance of certain species [28].

5. CONCLUSION

Thirteen (13) artisanal gold mining sites housing a total of 247 people have been identified around the Ity-Floleu mine on the Cavally River and its surroundings. At the different sites, the artisanal miners were organized in small groups composed mainly of 5 to 10 people. Activities are practiced in the area by foreigners (Burkinabe, Malians, and Guineans) and local populations from the villages of Ity and Floleu and surrounding localities, in greater number (67.6%).

Two types of gold mining were observed at Ity and Floleu, depending on the nature of the ore extracted, in particular, the exploitation of alluvial ore and that oriented towards vein ore. However, the activity remains dominated by the search for alluvial ore. Alluvial ore extraction is carried out in three places, in particular, on the bed of the Cavally River, the banks of the river, and on tracks and trails inside the forests. These processes require the use of machines arranged on a sort of boat on the river bed, and materials such as pickaxes, dabas, rugs, and shovels in the river banks and on farmland. As for vein ores, they are also mined along with the soils of cultivable lands, but in the form of stone blocks in dug galleries which are crushed, washed, and for the extraction of gold using mercury, then by cyanidation.

The techniques used by the artisanal miners deteriorate the Cavally River through its siltation and the fall of the banks. Also, the excavation of the land and the water reservoirs carried out inside the forests degrade the plant cover, reducing the cultivable land in the locality. The wells made in the soil for the search for vein ores are abandoned without any precaution to fill the holes with the mounds of waste ore excavated. The grinding of the vein ore, after crushing generates dust in the environment, just like the cyanidation treatment mobilizes a lot of equipment and materials which are abandoned on the site, as well as the treated sand refuse. The midstream of the Ity-Floleu axis of the Cavally river appears to be more impacted by gold panning activities in the locality with higher turbidity values obtained (255.3±54 NTU) and very low flow velocities of the water (0.19±0.08 m /s) measured.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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