Acadlore Transactions on Geosciences
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Biodiversity Degradation Driven by Artisanal and Small-Scale Gold Mining in Daoukro, Côte d'Ivoire

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Received: 07-30-2024 **Revised:** 09-10-2024 **Accepted:** 09-15-2024

Citation: L. Tia, "Biodiversity degradation driven by artisanal and small-scale gold mining in Daoukro, Côte d'Ivoire," *Acadlore Trans. Geosci.*, vol. 3, no. 3, pp. 173–180, 2024. https://doi.org/10.56578/atg030305.

Abstract: Côte d'Ivoire is recognized as one of the principal gold-producing countries in West Africa, where artisanal and small-scale gold mining (ASGM) constitutes the second most prevalent livelihood activity after agriculture, particularly within rural communities. As a result, high concentrations of ASGM activity have been recorded in 78% of the country's regions. In this context, the ecological impacts of ASGM on biodiversity in the Daoukro region were examined. A diachronic geospatial analysis was conducted using satellite imagery from 2010 to 2020, in conjunction with field-based spatial data collection and semi-structured interviews. The findings reveal that extensive environmental degradation has been driven by the unregulated techniques and substances employed in gold extraction processes, including the widespread use of mercury and cyanide. These practices have resulted in severe soil contamination, structural weakening due to erosion, and inhibited vegetative regeneration. Over the decade-long period, the proportion of bare soil increased at an annual growth rate of +7.90%, while forested areas declined markedly from 31,258 hectares to 24,750 hectares—representing a cumulative reduction of 20.34%. This deforestation has contributed to the disruption and loss of native biodiversity that relies on forest ecosystems for survival. Additionally, land fragmentation and habitat degradation have reduced ecological resilience, further intensifying species vulnerability in the region. These findings underscore the urgent need for sustainable land management policies and biodiversity conservation strategies tailored to mitigate the ecological footprint of ASGM in Côte d'Ivoire.

Keywords: Artisanal and small-scale gold mining; Biodiversity degradation; Habitat loss; Daoukro; Côte d'Ivoire

1 Introduction

Côte d'Ivoire is among the main gold producers in West Africa. The mining sector in this sub-region has recorded significant economic growth of 5% since 1990 [1, 2]. Artisanal gold production involves 80 to 100 million individuals, occupying the second place among economic activities employing rural populations after agriculture [3]. In 81 developing countries, artisanal gold mining employs 90% of the workforce and produces 400-600 tonnes/year, approximately 20% of global gold production [4].

In Côte d'Ivoire, the gold rush is justified by the richness of its subsoil in mineral resources. Several gold deposits are exploited by national and international mining companies [5]. This expanding sector represents 27% of Gross Domestic Product (GDP) [6]. Like other gold-producing countries, clandestine artisanal gold mining sites proliferate alongside industrial sites throughout the country [1, 7]. This activity attracts more and more labor because it offers jobs, meets family needs, and allows for local development initiatives [8].

Consequently, the state has taken a series of measures to curb this activity at the national level, such as the implementation of the National Program for the Rationalization of Artisanal Gold Mining (PNRO) in October 2013, the closure of hundreds of illegal gold mines [6], the revision of the mining code in 2014, and the creation of a brigade to repress violations of this code [5]. All these efforts cannot contain the determination of illegal gold miners. The proliferation of new clandestine artisanal gold mining sites is observed in several localities like Daoukro.

In Côte d'Ivoire, this activity, which employs more than 500,000 people in rural areas [7], does not spare the environment at various levels, leading to air and nature pollution, soil depletion, and degradation of biodiversity [9–11]. These environmental problems affect 78% of the country's regions.

In light of these observations, this study aims to provide answers to the process of biodiversity degradation through the proliferation of clandestine artisanal gold mining, based on a case study of the Daoukro sub-prefecture in Côte d'Ivoire. The study methods are based on diachronic analyses of satellite images, interviews, and field geospatial data collection.

2 Materials and Methods

2.1 Study Area

This research was conducted in Daoukro (Figure 1), established as a sub-prefecture by decree No. 69-241 of June 9, 1969. Daoukro covers an area of 2,697 km² with a population of 73,134 inhabitants [12]. Its rural area is dotted with artisanal gold mining sites. Field data collection focused on three representative villages: Kongoti, Kouassi-Diètèkro, and Anoumabo. These villages were chosen because of (i) the existence of the main gold mining centers grouping the largest number of gold miners; (ii) the coexistence of old and new clandestine gold mining sites; and (iii) the coexistence of semi-industrial and artisanal gold mining sites.

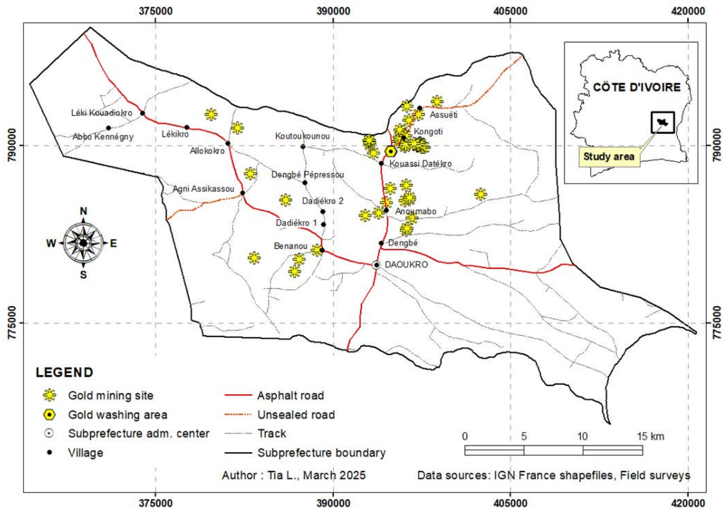

Figure 1. Geographical location of the study area and gold mining sites

2.2 Sampling Design and Data Collection

The probabilistic sampling method was used in this study. The sample size (n) was defined as follows [13]:

$$n = z^2 \frac{p(1-p)}{e^2} \tag{1}$$

where, z represents the 95% confidence level, e represents the margin of error at 5%, and p represents the proportion of households concerned by the survey. A total of 182 participants were surveyed according to the size of the villages and artisanal gold mining sites (Table 1).

In addition to direct observations at gold mining sites and geospatial data collection using a Garmin Global Positioning System (GPS), surveys through questionnaires and interviews were conducted with 46 gold miners and 136 household heads, as well as traditional and administrative authorities.

Table 1. Distribution of survey respondents by village [12]

Villages	Inhabitants	Surveyed Gold Miners	Surveyed Households	Total
Kongoti	1297	12	35	**47** (26%)
Kouassi-Diètèkro	1435	13	38	**51** (28%)
Anoumabo	2323	21	63	**84** (46%)
Total	**5055**	**46** (25.3%)	**136** (74.7%)	**182** (100%)

2.3 Data Processing

After manually processing, organizing and analyzing the questionnaires, tables, figures, and graphs were created using Excel. The data was consolidated with interview results.

Geospatial data collected via GPS was organized into Geographic Information System (GIS) databases, then processed in ArcGIS for cartographic illustrations. Landsat ETM+ satellite images, 197/57 of 2010 and Landsat OLI 8 of 2020 underwent various supervised classification steps to obtain statistics and diachronic land use data.

3 Results

3.1 Practices of Clandestine Artisanal Gold Mining

3.1.1 Establishment of gold mining sites

Access to a portion of land for gold mining operations follows a mutual agreement contract between the landowner and the artisanal gold miner. Consequently, anyone with the means to acquire basic extraction tools can engage in the activity. Before a mining operation, a test needs to be conducted, which consists of detecting indicators of gold presence (gold nuggets and specific stones) using a metal detector. The exploitable space includes fields, virgin forests, etc. The 46 clandestine gold mining sites surveyed in the study area follow this establishment process in Figure 1.

3.1.2 Stages of gold extraction

In general, gold extraction is carried out in five stages: (i) site clearing, (ii) digging or sinking, (iii) sand extraction and spreading, (iv) testing with metal detectors and nugget recovery or sand washing, and (v) gold recovery. The materials and tools used for this purpose include machetes, hoes, pickaxes, jackhammers, generators, shovels, metal detectors, washers, and motor pumps.

Environmental degradation primarily occurs during three stages. Indeed, during the clearing phase, the land is completely stripped and cleared of vegetation. Then, during the digging (or sinking) phase, miners dig holes throughout the plot. The depths of these holes vary between 0.50 and 2 m, or even 10 to 15 m at vein-type mining sites. In addition to pickaxes, jackhammers are sometimes used in operations. During the final stage of ore washing and gold recovery, washers installed along riverbanks are used to wash the sand extracted from the depths to extract small fragments of gold dispersed in the form of granules or powder. The ramps of these washers separate potentially gold-bearing sand from sterile sand. This phase considerably pollutes rivers with motor oil (Figure 2).

Figure 2. Main stages of gold extraction at Kouassi-Diétèkro and Kongoti: (A) Hole dug during the sinking phase, (B) Sand extraction and spreading, (C) Testing with metal detector for gold recovery, (D) Machine washing the sand

3.2 Artisanal Gold Mining and Biodiversity Degradation

3.2.1 Degradation of vegetation cover

The establishment of gold mining sites begins with the clearing phase, which involves cutting vegetation to make the soil surfaces exploitable. Additionally, trees and shrubs are cut down by gold miners (69.6%) who believe that tree roots contain inestimable quantities of gold. This belief accelerates deforestation at gold mining sites.

The gold miners clear paths in the forest to facilitate their movement, the transport of mining equipment and the collection of mining sand by tricycle and trucks. They also build makeshift shelters that impact the natural environment. Surveys reveal that they underestimate the impacts of these practices on the environment (2.2 to 10.9%) (Table 2).

Table 2. Perceptions of respondents regarding the impact of artisanal gold mining on biodiversity

Gold Mining Activity	Households	Gold Miners
Clearing	87(64%)	32(69.6%)
Path opening	19(14%)	5(10.9%)
Housing construction	17(12.5%)	1(2.2%)
Others	13(9.5%)	8(17.3%)
Total	**136**(**100**%)	**46**(**100**%)

3.2.2 Soil degradation and pollution

The sinking technique involves digging small galleries over vast stretches of land in search of gold. These holes are abandoned after exploitation (Figure 3). This modifies the landscape and topography. Gold miners do not undertake any action to close these holes, although they are aware (84.4%) of the negative impacts of their activities on the environment. Observations of old abandoned sites show that these weakened soils are subject to erosion. The soil horizons are disorganized. This can cause an ecological imbalance that logically impacts the organisms connected to it. Consequently, these soils do not promote vegetation regeneration and remain poorly suited or unsuitable for agriculture. The soil situation is aggravated by pollution caused by chemicals, grease, and waste oil from generators and washers.

Figure 3. Degradation of the natural environment by artisanal gold mining: (A) Uprooting of trees by gold miners in Anoumabo, (B) Digging holes under tree roots in Anoumabo, (C) Abandoned hole at a gold mining site in Kongoti, (D) Runoff water from gold extraction sites in Kongoti, (E) Pollution of a river by gold extraction waste in Kongôti

3.2.3 Water pollution

Since ore washing consumes water, gold miners preferably choose to set up their sites near water points. If not available, they draw water from the river through long pipes. Wastewater from the washers is discharged into the environment without any management precautions. Consequently, it infiltrates to contaminate the groundwater or runs off to pollute nearby water points (Figure 3).

3.2.4 Air pollution

The noise from motorized pumps, generators, crushers, and washers is omnipresent at artisanal gold mining sites. These machines produce gases and emissions of various types that pollute the surrounding air. The noise and vibrations from the engines drive away the surrounding wildlife. Surveys reveal that 48% of gold miners and 52% of households are aware of this situation.

3.2.5 Changes in land use patterns from 2010 to 2020

The results of supervised classifications attest to the degradation of the natural environment due to agriculture and gold mining, which increased in scale during the period from 2010 to 2020. The degradation of dense forest areas, the increase in open forest areas, and the extension of cultivated areas are attributable to agriculture. However, the persistence of bare soils and makeshift housing is one of the signatures of gold mining because at gold mining sites, agriculture is abandoned in favor of the quest for gold. Indeed, the techniques of clearing and shaft sinking leave holes everywhere and disrupt the balance and fertility of soils, making them unsuitable for agriculture and livestock farming (Figure 4).

The diachronic analyses of land use over the period from 2010 to 2020 attest to notable changes in the pattern of land use, which is characterized by a regression of dense forest areas, from 31,258 ha in 2010 to 24,750 ha in 2020 with an overall variation rate (OVR) of -20.34%, and an increase in open forest areas from 9,671 ha in 2010 to 11,960 ha in 2020 (OVR = +23.67%). The areas of crops and bare soils experienced notable increases, with OVRs of +6.55% and +7.9%, respectively.

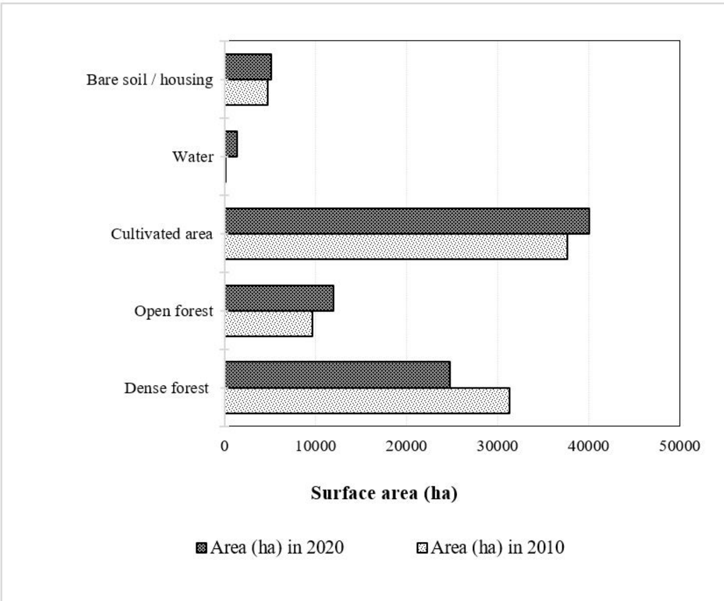

Figure 4. Methodology and result of this study

4 Discussion

4.1 Impacts of Rudimentary Gold Mining Techniques on Biodiversity

The level of awareness among gold miners (69.6%) about the impacts of their activities does not prevent them from degrading biodiversity. They are all obsessed with the sole concern of economic gain. Across the 46 artisanal gold mining sites in Daoukro (Côte d'Ivoire), the degradation of biodiversity begins with the first stage of establishing mining sites and continues to the final stage of extracting gold. All the means, techniques, and methods used in gold mining have considerable impacts on biodiversity.

4.1.1 Soil impoverishment

The holes with depths varying from 0.50 to 2 m, even up to 15 m, dug during the shaft-sinking phase transform the gold mining sites into fields of ruins. The rudimentary tools, namely shovels, hoes, pickaxes, and especially jackhammers, create vibrations that impact soil texture. The bringing up of sand and sterile rubble to the soil surface adds to the ecological imbalance caused by this situation, which affects soil microorganisms. Furthermore, greases, waste oil, and chemical products, such as mercury and cyanide used in gold extraction, make the natural environment barely or not at all favorable for vegetation regeneration, making it unsuitable for agricultural development. These environmental problems are encountered at several gold mining sites in the localities of Bonikro [14], Hiré [15], Ity [16], Bounkani [3], Kanoroba [17] in Côte d'Ivoire, Aouzegueur in Niger [18], Khossanto, Bomboré in Burkina Faso [19], and Dimonika in Congo [20].

4.1.2 Degradation of vegetation and loss of biodiversity

The degradation of vegetation cover is one of the main consequences observed at gold mining sites in the study area, like Kédougou, Senegal [21], and Souanké, Congo [22]. This biodiversity degradation stems from cutting vegetation to open tracks to create exploitable surfaces and build shelters for gold miners, as is the case at several gold mining sites in the Mouhoun River sub-basin in Burkina Faso [23]. Studies conducted at the sites of Hiré [15] and Ity [16] in Côte d'Ivoire confirm these results by providing estimates of the quantities of wood cut and the plant species threatened by this activity in Kanoroba [17]. The accumulation of sand on the surface prevents any possibility of vegetation regeneration and leads to a loss of biodiversity dependent on these habitats.

4.1.3 Pollution of water resources

The phase of washing the ore and recovering gold by washers requires significant quantities of water. The wastewater from this operation is discharged into the environment, and generally into waterways. This causes serious pollution that affects surface waters. Studies conducted at gold mining sites in the Mouhoun River sub-basin in Burkina Faso reveal that 200 liters of water are used to wash 50 kg of ore [23]. The chemical products used in this phase, namely mercury and cyanide, pollute the waterways. These consequences are also highlighted in the study by N'guessan et al. [24] who showed mercury contamination of sediments in the Bagoué River in Côte d'Ivoire, like the gold mining sites in Djikando, Burkina Faso [25]. Other studies confirm water pollution at gold mining sites in Kong, Hiré, and Degbézéré [26]. The waters of Lake Tanganyika in Burundi are contaminated by mercury used to amalgamate gold at mining sites [27]. In addition, the same situation exists in the waters of the Baoulé River in Kémékafo, Mali [28].

4.2 Changes in Land Use Patterns

4.2.1 Conversion of forest areas to bare soils

Diachronic analyses of satellite images at the scale of the Daoukro sub-prefecture attest to the severe degradation of forest areas in favor of bare soils and housing from 2010 to 2020. Dense forest areas decreased from 31,258 ha in 2010 to 24,750 ha in 2020, representing an OVR of -20.8%. During the same period, cultivated areas and bare soils experienced OVRs of +6.55% and +7.9%, respectively. The conversion of "dense forest" classes to "open forest" classes, then to "bare soils/housing" classes has been confirmed across several gold mining sites. In Côte d'Ivoire, at the Bonikro sites, the "forest class" experienced an OVR of -16.60% from 2007 to 2016 [14].

4.2.2 Gold mining and the impossible regeneration of forests

The degradation of forest areas can be attributed to extensive agriculture, which is known for its devastating effects on the natural environment. However, the rapid expansion of gold mining to the detriment of agriculture indicates that this first activity is seriously degrading soils and forest ecosystems, leading to a significant decline in agricultural activity in the sub-prefecture. The clearing caused by opening tracks, excavation, shaft sinking, construction of habitats, and accumulation of sand on the surface destroys forest areas and gives them no chance of regeneration. Gold mining destroys the humus horizons of the soils, creating an ecological imbalance that is at the root of a drastic reduction in arable land, hindering the development of agriculture and livestock and causing significant losses in biodiversity. Similar studies conducted in Senegal [21, 29], Guinea [30], and Cameroon [31] confirm these results.

5 Conclusions

The gold rush is justified by the country's mineral-rich subsoil. The proliferation of clandestine artisanal gold mining sites is explained by the fact that this activity provides employment, meets family needs, and allows for local development initiatives. The lack of control over mutual agreements between landowners and gold miners accelerates the creation of new sites in Daoukro. Numerous consequences stem from this artisanal gold mining activity, particularly the loss of biodiversity.

The damage begins with the establishment of gold mining sites based on the principle that "any space is exploitable." As a result, gold miners destroy the natural environment without any restraint. The 46 artisanal gold mining sites surveyed show significant degradation of biodiversity due to the means, techniques, and methods used to extract gold. The rudimentary tools used negatively alter soil texture. Furthermore, the bringing up of sand and sterile rubble to the soil surface and the use of greases, waste oil, and chemical products, such as mercury and cyanide, affect soil microorganisms and inhibit vegetation regeneration. This affects the biodiversity that depends on the destroyed habitats. Activities related to ore washing and gold recovery considerably pollute and degrade the biodiversity of rivers through mercury and cyanide.

It is important to mention that the state has taken measures to curb the momentum of illegal gold miners at the national level, including the implementation of PNRO, the revision of the mining code, the creation of an enforcement brigade and the progressive establishment of semi-industrial mining companies. In addition, village authorities are trying to contribute to the fight. However, these combined actions contribute to the dismantling of several illegal gold mining sites without weakening the determination of illegal gold miners. Given the scale of the phenomenon and the harmful consequences for biodiversity and agricultural development, other remedies remain to be explored to avoid the worst.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Acknowledgements

Acknowledgments to Mr. Kouassi B. Bruce and his colleagues for their involvement in data collection within the Interdisciplinary Research Team in Environment and Biodiversity Conservation (GéoRESBIO), to the gold miners, and to the village and administrative authorities for enabling the completion of the various field surveys.

Conflicts of Interest

The authors declare no conflict of interest.

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