



Water, Fish, and Sediment Quality in a Gold Mining Area in Hiré (Southern Côte d'Ivoire)

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Abstract: Mining is one of the main causes of environmental pollution due to the use of numerous toxic chemicals. The purpose of this study was to assess the quality of water, fish, and sediments in a gold mining area in Hiré, located in southern Côte d'Ivoire. A total of 18 water, fish, and sediment samples were collected from 6 different pits at gold mining sites and analyzed. Physicochemical parameters were measured using electrochemical methods (pH and dissolved oxygen), dilution (BOD₅), and titrimetry (total alkalinity). Heavy metals were analyzed by spectrometry. Pesticides, cyanides, and hydrocarbons were quantified by GC-MS and HPLC-UV. The pH, dissolved oxygen, BOD₅, and total alkalinity values were within the standards. The concentrations of cadmium (0.03 ± 0.06 mg/L) and lead (0.66 ± 1.02 mg/L) in the water were above the standards. The levels of Cd (6.74 ± 7.78 mg/L), iron (151.7 ± 132 mg/L), and lead (18 ± 31 mg/L) in the fish were also above the standards. The metals found in high concentrations in the sediments are iron (1611 ± 707 mg/L), copper (7.2 ± 4.5 mg/L), and cadmium (6.49 ± 7.7 mg/L). The cyanide concentrations detected were 1.075 ± 0.42 , 1.82 ± 0.22 , and 0.735 ± 0.6 mg/L in water, fish, and sediments, respectively. Cyanide levels in water and fish exceed the standards recommended by the WHO. Fish, water, and sediments were simultaneously contaminated by several pesticides, most of which were urea-derived herbicides. Most of the pesticides found in the various matrices exceeded environmental quality standards. This study revealed multifaceted chemical contamination of aquatic environments in the Hiré gold mining area, simultaneously affecting surface water and fish

1. Introduction

The mining industry is one of the main pillars of the economy in many West African countries. In Côte d'Ivoire, this sector has experienced significant growth in recent decades with the discovery and exploitation of numerous deposits throughout the country (Dongo *et al.*, 2018; Konan *et al.*, 2025). This industry is largely dominated by open-pit gold mining, which accounts for more than 93 % of active permits (GPMCI, 2024). However, the success of this dynamic extractive industry is accompanied by growing environmental pressures, particularly on water resources and aquatic ecosystems. Gold extraction processes rely heavily on the use of mercury and cyanide, which are used for cyanidation and amalgamation of the ore, respectively (Ibrahim *et al.*, 2019; Illatou,

2021). Many other toxic chemicals, such as trace metals, can be released into the environment during various gold mining operations (Koné *et al.*, 2018), (Aristide *et al.*, 2021). The effluents from these activities are discharged into surface waters and sediments, leading to a gradual decline in the quality of aquatic environments. The effluents from these activities are discharged into surface waters and sediments, leading to a gradual decline in the quality of aquatic environments. Numerous studies conducted in mining areas report high levels of contamination of water resources and fish by chemicals (metals, cyanide, pesticides), posing significant health risks to local populations (Bempah *et al.*, 2016; El Hammari *et al.*, 2026; Kouadio *et al.*, 2023; Inabanza *et al.*, 2025; Aboah *et al.*, 2026). Exposure to heavy metals (mercury, cadmium, iron, lead) and pesticides in humans can lead to gastrointestinal, pulmonary, renal, reproductive, neurodegenerative, and cardiovascular diseases, as well as cancers (Kotnala *et al.*, 2025; Jomova *et al.*, 2025; Shekhar *et al.*, 2024; Lushchak *et al.*, 2025). Exposure to these various chemical compounds therefore constitutes a major public health problem. The subprefecture of Hiré, located in a forested area, is rich in significant gold deposits, some of which were initially subject to intensive artisanal mining before being granted to industrial operators by the Government of Côte d'Ivoire (Diakité, 2024). The pits dug during gold mining gradually fill with rainwater and runoff, and aquatic life eventually takes root there. In addition to mining activities, these areas are often characterized by intensive agriculture that relies on the increased use of pesticides and fertilizers (Kablan *et al.*, 2020). The coexistence of these two major sources of pollution from mining and agriculture leads to combined chemical contamination of aquatic environments. Consuming water and fish from these mining sites can pose a significant health risk to local communities. Therefore, to protect the environment and prevent any health risks, mining sites are rehabilitated before being returned to local communities for agricultural use. Furthermore, rehabilitation that complies with environmental quality standards requires an assessment of the level of pollution caused by mining activities. It is in this context that this study was conducted. It aims to assess the environmental impact of the combined effects of gold mining and the use of pesticides on the quality of surface water, fish, and sediments in the Hiré mining area in southern Côte d'Ivoire.

2. Materials and methods

2.1. Description of the study area

The study area is located in the subprefecture of Hiré, 210 km northeast of Abidjan. The geographic coordinates of this location are between 06°15'08.6 and 06°10' north latitude and 05°23'44.8 and 05°16'32.1 west longitude (Figure 1). This gold mine, one of the largest in the country with an estimated 100 tons of reserves, has been in operation since 2008. The climate in this area is equatorial, with an average annual rainfall of approximately 1,200 mm (Yapi *et al.*, 2014). Cash crops (cocoa, coffee, rubber) and food crops are widely cultivated there due to the very favorable climatic conditions (Yao *et al.*, 2020).

2.2. Sampling

A total of 18 samples including 6 water samples, 6 fish samples, and 6 sediment samples were collected from 6 different gold mining pits in the study area (Figure 1). The fish collected were tilapia of the species *Oreochromis niloticus*, with an average weight of 150 g. The water and sediment samples were collected in amber glass bottles and black bags, respectively. All collected

samples were transported in coolers with dry ice to maintain cold temperatures. The samples were transported to the Laboratory of Toxicology and Agro-Industrial Hygiene at Félix Houphouët Boigny University in Abidjan for analysis.

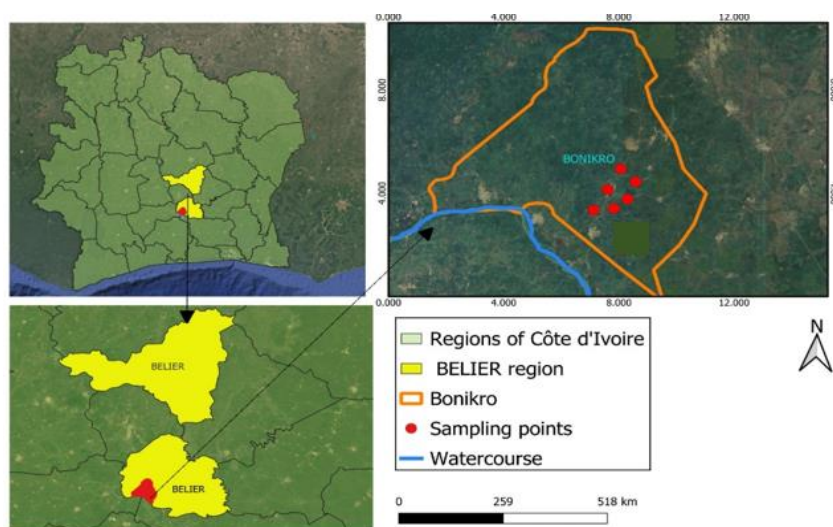


Figure 1 : Study area

2.3. Methods for analyzing physicochemical parameters

Physicochemical parameters such as pH and dissolved oxygen were measured electrochemically in accordance with standards NF T 90-008 and ISO 5814, respectively. Biochemical Oxygen Demand (BOD₅) was measured using the dilution method in accordance with standard NF T 90-103. Total alkalinity was determined by titrimetry in accordance with ISO 9963-1.

2.4. Methods for analyzing trace metals, cyanides, and total hydrocarbons

Trace metals (As, Cd, Cu, Fe, Pb, Zn) were analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Mercury was analyzed by cold-vapor atomic absorption spectrometry (AAS). Total cyanides and total hydrocarbons were determined by UV-Vis spectrophotometry in accordance with ISO 14403-1 and NF T90-203 standards.

2.5. Pesticide Analysis

Pesticides (organophosphates, organochlorines, carbamates, ureas, triazines) were quantified by GC-MS and HPLC-UV according to the method described by [Al-Rimawi, \(2014\)](#).

2.6. Determination of the Bioconcentration Factor

The Bioconcentration Factor (BCF) were calculated for metals, cyanide, and total hydrocarbons using the formula proposed by [Casas, \(2005\)](#) :

$$BCF = C_o/C_e$$

where

C_o = concentration of each chemical in the fish;

C_e = concentration of the substance in the water.

2.7. Data Analysis

Statistical analyses were performed using SAS software. The Proc MEANS procedure was used to calculate the mean values of the chemical compounds.

3. Results and discussion

3.1. Physicochemical parameters of the water

The average pH of the sampled water is 7.22. The average biochemical oxygen demand (BOD₅) and dissolved oxygen levels are 4.8 mg/L and 1.11 mg/L, respectively. The average total alkalinity (TAC) is 20.54 mg/L (Table 1). All measured physicochemical parameter values comply with WHO and Ivorian standards set by the Ivorian Anti-Pollution Center (CIAPOL). These results, which are consistent with those of several other studies, suggest that mining and agricultural practices have little impact on certain physicochemical parameters of the water in this area (Yao *et al.*, 2020; Yapi *et al.*, 2014).

Table 1: Physicochemical parameters of the water

	pH	Dissolved oxygen (mg/L)	BOD5 (mg/L)	Total alkalinity (mg/L)
Average	7.71±0.25	0.11±0.1	4.8 ± 4.4	20.54 ±9.9
Min	7.22	0	1.3	10.61
Max	8.02	0.63	18.2	50.21
Ivorian standards (CIAPOL)	5.5 – 8.5		100	
WHO Standard	6.5 – 8.5	>5		80 - 400

3.2. Trace metals, cyanide, and hydrocarbons in the matrices

Cyanide was detected in all the samples analyzed. Cyanide concentrations in water and fish were 1.075±0.42 and 1.82±0.22 mg/L, respectively (Table 2). These cyanide concentrations in these samples exceeded the WHO guideline values (WHO, 2017). Furthermore, mercury was not detected in any samples from this gold mining area. With the Minamata Convention on restrictions on mercury use, cyanide is becoming the chemical compound increasingly used in the extractive industry for gold cyanidation (Bamba, 2015; Djade, 2020). The discharge of effluents from gold extraction processes is the cause of contamination in surface waters, fish, and sediments. Moreover, the severe environmental pollution associated with the use of cyanide at gold mining sites in this region has been documented by several authors (Kouadio *et al.*, 2023). These high cyanide levels at these sites may be partly linked to intensive illegal gold mining. Indeed, these sites were initially subject to illegal gold mining practices before being developed for industrial mining (Diakité, 2024). Various trace metals were detected in the water, fish, and sediments at the mining sites, with highly variable concentrations (Table 2). In the water, cadmium, iron, and lead were found at concentrations of 0.03±0.06 mg/L, 0.03±0.08 mg/L, and 0.66±1.02 mg/L, respectively. The cadmium and lead concentrations exceed the regulatory limits established by the WHO for water. The levels of Cd (6.74 ± 7.78 mg/L), iron (151.7 ± 132 mg/L), and lead (18 ± 31 mg/L) in fish are significantly higher than the WHO recommended standards of 0.05 and 0.2 mg/L, respectively. The metals found in high concentrations in the sediments are iron (1611 ± 707 mg/L), copper (7.2 ± 4.5 mg/L), and cadmium (6.49 ± 7.7 mg/L). Fish contamination is linked to high levels of metal pollution in water and sediments. Gold mining has led to the dispersion of these metals into the environment and their contamination of surface water, sediments, and

consequently, fish. Furthermore, the high level of sediment contamination is linked to sediments' high capacity to accumulate metals. These metals, released through leaching, constitute an endogenous source of water and fish pollution. These findings are corroborated by several studies that have highlighted the high concentration of trace metals in the gold-bearing areas of Côte d'Ivoire (Yapi et al., 2014; Ibrahim et al., 2019; Dadjé et al., 2020). Concentrations of total hydrocarbons of 3.75 ± 2.3 mg/L, 0.75 ± 0.43 mg/L, and 0.735 ± 0.6 mg/L were found in the water, fish, and sediments, respectively. These hydrocarbons, primarily derived from petroleum (fuels, oils, lubricants), originate from the machinery used for gold extraction.

Table 2 : Levels of Heavy Metals, Cyanide, and Hydrocarbons in Water, Fish and sediments

Matrices	Cadmium (mg/L)	Copper (mg/L)	Zinc (mg/L)	Iron (mg/L)	Lead (mg/L)	Total cyanide (mg/L)	Total hydrocarbons (mg/L)	
Water	Average	0.03±0.06	ND	ND	0.03±0.08	0.66±1.02	1.075±0.42	3.75 ±2.3
	Min-max	0.01 - 0.16	-	-	0.012 -0.26	0.07-2.45	0.54- 2.1	1.23 – 8.86
Fish	Average	6.74 ±7.78	1.67±0.78	10.7±11	151.7±132	18, ±31	1.82±0.22	0.75± 0.43
	Min-max	0.07 -13	1.9-2.45	1.22-23.4	5.58-262	0.4 -54	1.59-2.12	0.28-1.12
Sediments	Average	6.49±7.7	7.2±4.5	ND	1611±707	ND	1.63±1.6	0.735±0.6
	Min-max	1.03-11.95	4.05-10.44	-	1111-2111	-	0.47-2.78	0.3-1.17
WHO guideline (2017)	0.003* 0.05**	2*	3*	0.3*	0.001* 0.2**	0.07*	10*	
Limit of quantification	0.001	0.003	0.017	0.066	0.003	0.01		

*guideline value for surface water : ** guideline value for fish. ND : undetermined

3.3. Pesticides in water, fish, and sediments

A total of 21 pesticides belonging to the chemical families of organophosphates, triazines, urea derivatives, and carbamates were detected in the water, fish, and sediments. The most common pesticides across all samples were triazines, followed by urea derivatives and then organophosphates. Organochlorines and carbamates were present in very low concentrations in the samples. The pesticides detected were predominantly herbicides, followed by insecticides. Fish were contaminated with 12 different pesticides, most of which were urea-derived herbicides. The pesticides with the highest concentrations in fish are desethylatrazine (261 mg/kg), linuron (62.80 mg/kg), fenuron (61.29 mg/kg), monolinuron (33.09 mg/kg), and atrazine (32.57 mg/kg). In the water samples, 11 different pesticides were detected. The highest concentrations were found for aldicarb (211.6 mg/kg), desisopropylatrazine (93.85 mg/kg), monuron (52.02 mg/kg), and cyanazine (51.81 mg/kg) (Table 3). In the sediments, which constitute the most contaminated matrix, 13 pesticides were found, dominated by desisopropylatrazine (165 mg/kg), monuron (21.72 mg/kg), and terbuthylazine (21.15 mg/kg) (Table 3). Most of the pesticides detected in the various matrices exceed environmental quality standards. The total concentrations of organophosphates and triazines found in the various matrices exceed environmental quality standards. These results indicate significant environmental pollution from pesticides in this area. These pesticides originate from cash crops (cocoa, coffee, rubber) and food crops, which are the region's primary agricultural products. Rainfall patterns in this forested region favor large-scale agriculture with increased use of plant protection products (Yao, 2015).

3.4. Bioconcentration Factors

The bioconcentration factor (BCF) measures the tendency of a chemical substance to accumulate in fish at a concentration higher than that in water, through direct absorption. The fish analyzed in this study is tilapia (*Oreochromis niloticus*), a species widely consumed in Côte d'Ivoire. The highest BCFs were observed for trace metals. These values were 5,056 for iron, 224.7 for cadmium, and 27.3 for lead. Among pesticides, the BCFs were high for atrazine (3.7) and fenuron (3.65) (Table 4). The BCF values for cyanides and total hydrocarbons were 1.7 and 0.2, respectively. The order of accumulation of trace metals in the various animal species studied (Pb < Cd < Fe) corresponds to their order of concentration in the sediments and water of the excavated pits. These BCF values are linked to the high concentration in water and sediments, their persistence, and their high capacity to accumulate in aquatic organisms.

Table 3: Pesticides detected in the matrices

NA :	Chemical class of pesticides	Concentration (mg/kg)			EQS (mg/kg)	Not
		Water	Fish	Sediments		
Organochlorines	Metolachlor***	0,57			NA	
	Parathion-methyl*	8.03	-	-		
Organophosphates	Parathion-ethyl*	-	-	4.43	0.0003	
	Chlorfenvinphos*	8.00	-	3.26		
Carbamate	Aldicarb*	211.6	20.43	16.22	NA	
Dicarboximide	Vinclozolin**	-	-	5.47		
	Cyanazine***	51.81	19.15	-		
Triazine	Désisopropylatrazine***	93.85	-	165		
	Atrazine***	8.81	32.57	10,5		
	Prometryn***	9.03	-	-	0,002	
	Terbutryn***	8.38	-	-		
	Désethylatrazine***	-	261	6,93		
	Simazine***	-	9.99	-		
	Terbuthylazine***			21.15		
Urea derivatives	Monuron***	52.02	15.42	21.72		
	Fenuron***	16.81	61.29	115		
	Linuron***		62.80	3.98	NA	
	Monolinuron***		33.09	2.50		
	Methabenzthiazuron***		27.41	10.46		
	Chlortoluron***		20.84			
	Metoxuron***		17.97			

Applicable

EQS : Environmental Quality Standards

* : Insecticide

** : Fungicide

*** : Herbicide

Table 4 : Bioconcentration factors for the various compounds

Compounds	Trace metals			Pesticides					Total cyanide	Total hydrocarbons
	Cadmium	iron	Lead	Aldicarb	Cyanazine	Atrazine	Monuron	Fénuron		
FBC	224,7	5056	27,3	0,097	0,37	3,7	0,3	3,65	1,7	0,2

Studies conducted by various authors have corroborated these results, showing high accumulation of metals in the tissues of specimens collected from waters subject to metal pollution (N'Doua *et*

al., 2023; Dione *et al.*, 2018). The low accumulation of cyanide and pesticides (carbamates, triazines, and urea derivatives) in fish is linked to their low persistence in water and sediments. Trace metals, cyanides, and pesticides found in water and fish are known for their harmful and carcinogenic effects. Simultaneous exposure to these substances, even at regulatory levels, can have a deleterious effect on the exposed organism (Karim *et al.*, 2019; Beronius *et al.*, 2020; Crépet, 2021; Sprong *et al.*, 2023; Sprong *et al.*, 2023; Adokiya *et al.*, 2025).

Conclusion

This study revealed widespread chemical contamination of aquatic environments in the Hiré gold mining area, affecting both surface waters and fish. The results reveal high concentrations of cyanides and heavy metals (Fe, Pb, Cd), directly linked to mining activities, as well as a significant presence of agricultural pesticides, dominated by urea derivatives and triazines. The detection of high levels of these contaminants in water, fish, and sediments confirms that this mining activity has a significant impact on the environment and public health. These findings underscore the need for integrated management measures, including the control of mining waste, the rehabilitation of previously mined sites, and environmental monitoring. These combined efforts will ensure the long-term protection of the environment in this area.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.

Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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