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Assessment Of The Environmental Impacts Of Open-Pit Manganese Mining In Lauzoua–Guitry (South-West Côte d'Ivoire)

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Abstract
Background*: Open-pit mining contributes significantly to environmental pollution. The aim of this study was to assess the impact of manganese mining on surface water, air quality, and noise pollution.*
Materials and Methods *: A total of 21 samples (water, dust, noise) were taken from the mining site for analysis of various physical, chemical, and toxicological parameters. Trace metal elements (mercury, manganese, iron, copper, nickel, cadmium) were measured in the water using inductively coupled plasma mass spectrometry (ICP-MS). The physicochemical parameters and hydrocarbons were evaluated using electrometry and UV-Visible spectrophotometry, respectively. Thoracic and alveolar dust were analyzed in accordance with standards EN 1 2341 and NF X 43-259, respectively. Noise pollution was measured using a sound level meter.*
Results*: Analysis of the physical and chemical parameters and other contaminants in the water revealed that it was heavily laden with suspended solids, with values ranging from 85 to 19,619.40 mg/L. Turbidity (833-30826 NTU) and conductivity (849-10180 µs/cm) were both higher than the WHO standards of 50 NTU and 400 µs/cm, respectively. The values of trace metals (Hg, Cd, Cu, Fe, Mg) found in the water were all within the established limits. The value of thoracic dust in all areas of the site (11.6-250 mg/m^3) and the alveolar fractions sampled in the crusher area (6.5 mg/m3) were all above the set standards of 10 and 5 mg/m^3, respectively. Some noise levels measured in the northern areas of the site and at the factory exceeded the limits set at 85 dBA.*
Conclusion: *This manganese mining operation has a significant impact on the environment. It contributes to water and air pollution and is responsible for noise pollution emitted by machinery. It is therefore necessary to protect workers' health through biomonitoring supplemented by atmospheric monitoring. These combined measures will help control the health and environmental effects of this mining operation.*
Keywords*: mining; dust; noise pollution; trace metals, maganese*

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I. Introduction

The mining sector in Côte d'Ivoire is one of the most dynamic and diversified in Africa thanks to the discovery of several mineral deposits nationwide. The Ivorian government has made mining one of the pillars of the country's economic takeoff. Among these minerals, gold and manganese have been mined on an industrial scale since 2010[1]. Thanks to a mining code conducive to investment, the State of Côte d'Ivoire has granted several exploration and exploitation permits to mining companies operating throughout the country. In addition to significant local and national economic benefits (job creation, increased GDP and tax revenues), several studies have reported on the human and environmental impacts of these mining operations. As a result, water resources are regularly polluted by heavy metals (mercury, iron, lead) and other chemical compounds used or released by mining activities[2,3]. The physicochemical parameters of the water (Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Turbidity, Conductivity) can also be altered by pollutants from these mining activities. Open-pit mining is also one of the activities that generates a lot of dust in the workplace[4]**.** Depending on their aerodynamic diameters, fine dust particles can reach different areas of the respiratory tract in exposed workers. PM10 particles lodge in the chest, while PM2.5 particles reach the pulmonary alveoli[5]. The particles generated by this dust cause numerous respiratory diseases, including pneumoconiosis, silicosis, and cancer [4,5]. In mines, workers are also exposed to noise from machinery. Exposure to high noise levels can cause hearing loss or lead to nervous fatigue, which increases the risk of accidents[4]. The Lauzoua manganese deposit in the Guitry department was discovered several decades ago and was first mined industrially from 1960 to 1970[6]. Since 2012, this deposit has been the subject of industrial open-pit mining[7]. This mining operation has a direct impact on the environment, wildlife, and communities in the area. These environmental impacts can result in the contamination of drinking water, air pollution, and noise pollution affecting workers and surrounding communities. This study is part of a series of direct assessments of the impact of mining operations on the immediate environment of the site. The purpose of this study is therefore to assess the impact of mining on surface water, air quality, and noise pollution.

II. Materials And Methods

Type of study

This was a descriptive study with an analytical focus on samples of water, dust, and noise emissions taken at the manganese processing site in Lauzoua in the department of Guitry. Our study was conducted over three (3) months from September 1 to November 27, 2023.

Study area

The Lauzoua manganese mine is located in southwestern Côte d'Ivoire in the sub-prefecture of Lauzoua, Guitry department. It is covered by mining permit PE 36, covering an area of 100 km² (Figure 1), and the new exploration permit PR 248, covering an area of 88.6 km². The geographical coordinates of the site extend between latitude 05°17'00'' and 05°20'30'' North and longitude 05°23'00'' and 05°25'00'' West [8].

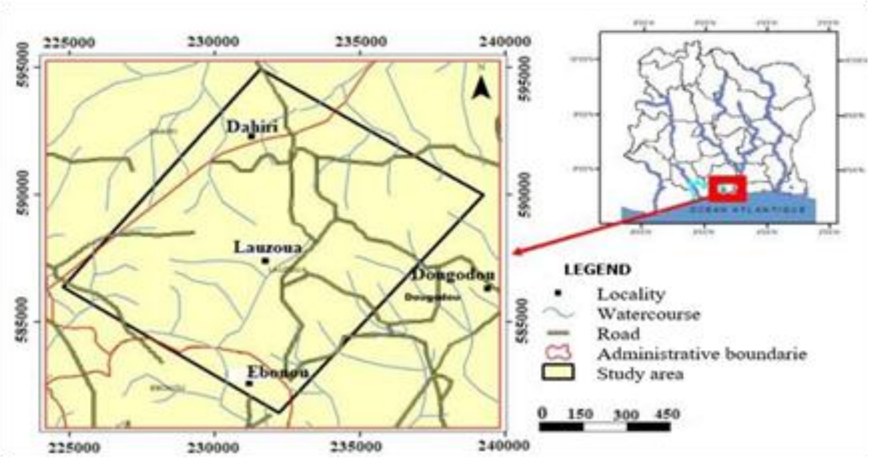

Figure 1 : Location map of the Lauzoua operating permit

Sample collection

A total of 21 samples were collected from the mining site in three (3) different matrices for analysis. These included 6 water samples, 6 dust samples, and 9 noise samples (Table 1).

Table 1: Different types of samples collected

Matrices	Location of the sampling site	Geographic coordinates	Quantity
Water (wastewater)	Laundry section	n = 05°19'20.5'' w = 005°23'24.3''	2
	Dam entrance upstream of the site	n = 05°19'03.3'' w = 005°23'16.0''	2
	Slurry dam pumping station	n = 5°19'09.3'' w = 005°23'09.0''	2
Dust	Crusher	n = 05°19'20.5'' w = 005°23'24.3''	2
	Northern extraction zone (K2 screen)	n = 05°18'39.3'' w = 005°24'29.8''	2
	Extraction route		2

Noises	North Zone H	K1 screen	1
		K2 screen	1
		Extraction	1
	Factory (ore reception and mechanical preparation area)	Control room	1
		Laundry supplie	1
		Tromelle	1
		Screen	1
		Classification	1
		Engine room	1
Total samples			**21**

Water samples

Water samples were collected using the techniques described by Rodier J et al. (2009)[9]. Samples were collected in new high-density polyethylene (HDPE) borosilicate glass bottles with Teflon caps (Figure 2). The bottles used to collect samples for mineral analysis were treated with nitric acid to prevent any contamination of the samples. The sampling points identified follow the water flow path of the site's mining activity: ore washing, water drainage channel, and retention pond. The water sampling points are summarized in Table 1 and the analytical parameters in Table 2.

Figure 2: Water sampling

Table 2: Parameters analyzed

Designation		**Matrices**		
		Water	**Dust**	**Noise**
Physical and chemical characteristics	pH	X		
	Temperature	X		
	conductivity	X		
	Total dissolved solids (TDS)	X		
	Turbidity	X		
	Suspended solids (SS)	X		
	Sulfates (SO_4^{2-})	X		
	Biological Oxygen Demand (BOD))	X		
	Chemical Oxygen Demand (COD)	X		
External contaminants	Oils and fats	X		
	Total Hydrocarbons	X		
Trace elements of metals	Arsenic (As)	X		
	Cadmium (Cd)	X		
	Chrome VI (Cr^{6+})	X		
	Total chrome (Cr)	X		
	Copper (Cu)	X		
	Total iron (Fe)	X		
	Manganese (Mn)	X		
	Mercury (Hg)	X		
	Nickel (Ni)	X		
	Lead (Pb)	X		
Dust	Chest dust (PM 10)		X	
	Alveolar dust (PM 2.5)		X	
Noise	Noise			X

Dust samples

Sampling

Sampling was carried out in accordance with standard NF 43-257[10] using a Casella Tuff Plus pump (Figure 3) set at a flow rate of 1 ml/l for a sampling period of 8 hours per site. This pump is equipped with a 10 and 2.5 µm cyclone head that separates particles according to their aerodynamic diameter. The dust sampling points are summarized in Table 1 and the analytical parameters in Table 2.

Figure 3: Sampling equipment (pump and cassette)

Principle

The mass of the sampled aerosol is determined by the difference between the mass of the unsampled substrate and the mass of the sampled substrate. Each identified point was sampled for 8 hours. For each sampling method, the operation was repeated three times.

Analysis

Thoracic and alveolar dust were analyzed in accordance with standards EN 12341 and NF X 43-259 [11,12], respectively. The filters are weighed before and after sampling in the laboratory to determine the mass of dust collected. Our scales are accurate to 1/1000 of a gram. Possible mass deviations due to variations in climatic conditions (wind speed and direction) are corrected using control cassettes following the route of the sampling cassettes.

Expression of results

The weight of dust was calculated using the following formula

- Calculate the average mass variation of the samples:

$$\overline{\Delta T} = \frac{1}{n}\sum_0^n \Delta T_y = \frac{1}{n}\sum_0^n \left(T_{fy} - T_{iy}\right).$$

Let Mix be the initial mass of the xe substrate used,
M_{fx} be the final mass of the xe substrate used,
T_{iy} be the initial mass of the ye control substrate,
T_{fy} be the final mass of the ye control substrate,
Δ the difference in mass of a substrate between the initial weighing and the final weighing (ΔM_x for the substrate x used and ΔT_y for the substrate y used as a control),

$$Q_x = \Delta M_x - \overline{\Delta T}$$

n the number of control substrates used (in general $n \geq 3$)

- The mass of particles Q_x (in mg) collected from substrate x is given by the formula

$$C_p = \frac{Q_x}{V}$$

- The weight concentration of the sampled atmosphere Cp (in mg/m^3) is given by the formula:

(V is the volume of air sampled expressed in cubic meters)

Noise pollution measurement

Noise pollution was measured using a sound level meter (Voltcraft, model SL-200). The distance between the source and the measurement point was between 1.2 and 2 m maximum for workshops and equipment, and between 2 and 7 m for machinery. During the measurement, the device was held at the operator's ear level. The duration of a measurement was between 5 and 20 minutes during periods of activity. The noise sampling points are summarized in Table 1 and the analytical parameters in table 2

Research and measurement of various parameters

The water samples collected were used to evaluate physicochemical parameters, trace metals, and other chemical contaminants (oil, grease, hydrocarbons). Thoracic and alveolar dust were evaluated in dust samples (Table 2)

Analytical techniques

The various parameters were evaluated using different analytical measurement techniques in different matrices. Trace metals were measured using ICP-MS according to the technique described by the Quebec Center of Expertise in Environmental Analysis **(CEAEQ)**[13]**.** Ions and hydrocarbons were measured by UV-Visible spectrophotometry. Physicochemical parameters were evaluated by electrometry (Table 3).

Table 3: Methods used for parameter analysis.

Parameters	Methodology					
	Electrometry	**Titrimetry**	**Spectrophotometry UV-Visible**	**ICP***	**Gravimetry**	**Sound measurement**
PH	X					
Temperature	X					
Conductivity	X					
Total dissolved solids (TDS))	X					
Turbidity	X					
Suspended solids (SS)					X	
Sulfates (SO_4^{2-})			X			
Biological Oxygen Demand (BOD)	X					
Chemical Oxygen Demand (COD)		X				
Oils and fats					X	
Total Hydrocarbons			X			
Arsenic (As)				X		
Cadmium (Cd)				X		
Chrome VI (Cr^{6+})				X		
Total chrome (Cr)				X		
Copper (Cu)				X		
Total iron (Fe)				X		
Manganese (Mn)				X		
Mercury (Hg)				X		
Nickel (Ni)				X		
Lead (Pb)				X		
Chest dust (PM 10)					X	
Alveolar dust (PM 2.5)					X	
Noise						X

***ICP :** inductively coupled plasma analysis method

III. Results

Physicochemical parameters of water and other contaminants.

Analysis of the parameters revealed water with a high content of suspended solids with values ranging from 85.4 to 19,619.4 mg/L. These suspended solids values are well above the Ivorian standards set at 150 mg/L[14]**.** Turbidity and conductivity exceeded the WHO standards of 50 NTU and 400 µs/cm, respectively [15]**.** These values decrease in the direction of the flow of mine wastewater. The BOD5 and COD values at the Slurry dam pumping station, which are 50.1 and 113 mg/L respectively, exceed the standards recommended by the WHO. The water was contaminated with oils and fats. The oil and fat content at the washing plant and the pH value of the water collected at the dam inlet also exceeded the standards. All other parameters analyzed were within normal ranges (Table 4).

Table 4: Results of physicochemical parameters and other contaminants

Parameters analyzed	Sampling points			Ivorian standards*	WHO standards
	Laundry section	Dam entrance upstream of the site	Slurry dam pumping station		
pH	5.87	**5.02**	6.02	5,5 – 8,5	6.5-8.5
Temperature (°C)	30.52	30.54	31.27	< 40 °C	<30°C
Conductivity (µs/cm)	10180	6780	849		400
Turbidity (NTU)	30 826	2 853	833		50
Suspended solids (SS) (mg/L)	4 915	19 619.40	85.40	150	<20
Sulfates (SO_4^{2-}) (mg/L)	22.19	53.48	8.14		250
Biological Oxygen Demand (BOD5)(mg/L)	0.1	0.1	50.1	150	<30
Chemical Oxygen Demand (COD) (mg/L)	10.80	6.9	113	500	<90
Oils and fats (mg/L)	**15.3**	8.1	0.63	30	
Total Hydrocarbons (mg/L)	1.63	N.D	N.D	10	

*Guideline limits for wastewater and effluent at Cote d'Ivoire [14]**.**

Parameters analyzed
Trace elements of metals in water

Among the metals sought, only cadmium, copper, iron, and manganese were found in the water.Taking into account Decree No. 01164/MINEEF/CIAPOL/SDIIC of November 4, 2008, regulating discharges and emissions from facilities classified for environmental protection, all trace metal values comply with the established limits [14] (Table 5).

Table 5: Trace metals in water discharges
LOD : Limit of detection

Parameters	Sampling points				Standards	
	Slurry dam pumping station	Dam entrance upstream of the site	Laundry section		Cote d'Ivoire	WHO
Arsenic (As) mg/L	<LOD	< LOD L	< LOD		0.01	0.01
Cadmium (Cd) mg/L	< LOD	0,04	0,04		0.003	0.003
Total chrome (Cr) mg/L	< LOD	< LOD	< LOD		0.5	
Copper (Cu) mg/L	< LOD	< LOD	0,012		0.5	
Total iron (Fe) mg/L	< LOD	0.33	< LOD		5	≤ 0,3
Manganese (Mn) mg/L	0.04	0.04	0.05		1	

Dust samples

The concentrations measured reflect the inhalable dust present in the air in the work premises (thoracic and alveolar fractions). The thoracic dust values in all areas (crusher, north and south extraction areas) exceed the standards of 10 mg/m^3 [16]**.** In addition, the alveolar fractions sampled in the crusher area are also above the standard of 5 mg/m^3 (Table 6).

Table 6 : Dust measurement results

Location	Type of dust	
	Thoracic dust : PM10 (mg/m^3)	Alveolar dust: PM 2.5 (mg/m^3)
Crusher	250.5	6.5
North extraction area (K2 screen)	35.8	0.9
Extraction route	11.6	0.30
Reference values (VME) (ANSES, 2020)	10	5

Noise samples

Noise levels measured in the northern areas (screen K1 and screen K2) and at the factory (trommel, screen, classification, and generator room) exceeded the limits set at 85 dBA (Table 7)

Table 7: Noise measurement results

Location		Average measured value (dBA)	Normative value (dBA) *
Zone H North	K1 Screen	87.4 ± 1.20	<85
	K2 Screen	88.08± 1.00	
	Extraction site	81.92± 5.52	
At the factory	Control room	84.76± 0.15	
	Laundry supplies	81.16± 0.71	
	Trommel	94.18± 0.52	
	Screen	94.14 ± 0.57	
	Classification zone	96.08 ± 0.41	
	Generator room	99.14 ± 0.09	

* Upper exposure action value established by European Union Directive 2003/10/EC[17]

IV. Discussion

This study, conducted as part of the monitoring of the environmental impacts of mining operations, assessed various physical, chemical, and noise pollution parameters related to mining activity. In terms of water discharge, the physical, chemical, and toxicological parameters were assessed. The three (03) wastewater sampling points followed the direction of water flow from the mining activity, from the ore washing plant (point 1) to the retention pond (point 2) via the connecting channel (point 3). The samples taken revealed a high concentration of oils, fats, and suspended organic matter. The oils and fats originate from the machinery and products used for manganese extraction and processing. The values of these physical parameters for these discharges were all within the normal range for Ivorian mine wastewater and the guideline values set by the WHO, with the exception of turbidity, conductivity, and suspended solids (SS)[14,15]**.** The high turbidity and electrical conductivity obtained in the laundry section are due to the presence of significant quantities of suspended solids (clay, silt, silica grains, microorganisms) and dissolved salts (chlorides, sulfates, calcium, sodium, magnesium). Several metals, including cadmium, copper, iron, and manganese, were found in the wastewater discharges at levels within the recommended limits. These low levels of metals in wastewater discharges confirm that this activity generates very few of these elements. However, the infiltration and accumulation of these metals in the subsoil can contaminate the water table and have a very significant negative impact on various ecosystems and biodiversity. Open-pit mining is one of the activities that exposes workers to high levels of dust particles[18,19,20]**.** The concentrations of PM10 and PM2.5 measured in the extraction and crushing areas exceed the established occupational exposure limits, which are 10 mg/m^3 and 5 mg/m^3 respectively for dust in mines and quarries [16]**.** Workers in this mine are at risk of health problems due to exposure to dust particles. The toxicity of dust particles emitted is influenced by their size, concentration, and nature[5]**.** Fine particles (PM 2.5) reach the pulmonary alveoli and cause respiratory diseases (pneumoconiosis, silicosis), heart disease, and cancer[4,5,21]**.** The toxicity of dust particles emitted is influenced by their size, concentration, and nature [5]. Fine particles (PM 2.5) reach the pulmonary alveoli and cause respiratory diseases (pneumoconiosis, silicosis), heart disease, and cancer[4,5,21.] The mining sector also exposes workers to noise emitted by machinery during various activities[22]. This exposure to noise is reflected in the high sound measurements recorded in different areas (crushing, extraction). Certain areas of Zone H North (screen K1, screen K2) and the plant (trommel, screen, classification, generator room) exceed the set limit of 85 dBA over a working day[23,24.] This high level of noise can cause biological effects in workers, resulting in hearing loss, cardiovascular disease, stress, sleep disorders, and decreased cognitive performance[22, 25.] The Lauzoua mine is one of the largest in Côte d'Ivoire, with an estimated 1,631,086 tons, 41.97 % of which is manganese[26].The environmental and health impacts of long-term exploitation will be significant. It would therefore be wise to put in place enhanced prevention and protection measures for workers and to limit the effects on the environment.

V. Conclusion

This study assessed the environmental impact of manganese mining. It found that wastewater from the mine is heavily contaminated with organic matter. Contamination levels from trace metals are acceptable. However, dust from these activities can seriously harm workers' health. In addition, the use of excessively noisy machinery contributes to exacerbating the effects on workers' health. It is therefore necessary to provide protective equipment and biomonitoring, supplemented by atmospheric monitoring. These combined measures will help to control the health and environmental effects of this mining operation.

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