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Safety risks and environmental implications associated with Lauzoua manganese mining activities (South-west of Côte d'Ivoire)

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ABSTRACT: The current work deals with the monitoring and control of exploration and exploitation activities at the Lauzoua manganese mining (LMM) located in the Guitry department, in the southwestern tip of Côte d'Ivoire. In order to prevent and reduce the risk of accidents associated with the mine's activities, we undertook a safety audit of the working environment, i.e. to identify the inadequacies and dangerous situations present during exploration and mining activities. Our work focused first on identifying and listing the mine's activities through a field survey and visual observation, and then on assessing the risks associated with these activities using the Failure Modes, Effects and Criticality Analysis (FMECA) method. Our study reveals different risks of which we have categorized them in order of dangerousness, i.e. dramatic, serious and limited risks, with a serious risk percentage of 80% for exploration activities, compared with 28.57% for operating activities. The results show that the highest unsafe risk encountered during exploration campaign are caused by the injury or fracture in the event of a fall into the deepest shafts, and the highest unsafe risk encountered during operational activity are caused by driver distraction or lack of adequate lighting on site are the highest. These results clearly show that exploration and mining activities are not risk-free, and need to be carried out in accordance with strict safety monitoring and preventive measures. A strict environmental and safety assessment should therefore be carried out prior to mining activities, to prevent any risks that could impact and compromise the successful completion of the work.

KEYWORDS: exploration, mining activity, manganese mining, environmental impact, risk assessment.

1 INTRODUCTION

Occupational accidents are a major problem in the work environment. Mining is one of the industrial activities most affected by this problem, and pays the heaviest price. The mining sector has some unenviable statistics when it comes to occupational injuries and illnesses (Fig. 1). Indeed, the mining group ranks 1st among the target groups with the highest number of compensated work-related accidents and illnesses in Quebec in 2000-2002, with a prevalence of 23.6%, while the "mining services" group ranks 3rd, with a frequency of 18.2% [3]. This is also the case in Ontario and British Columbia, where this industry is among the eight economic sectors responsible for almost half of all indemnified work-related trauma fatalities and serious injuries between 2000 and 2002 [4]. All forms of mining have the potential to cause accidents and environmental damage, unless carefully managed. But even when carefully managed, mines pose significant risks to both mine workers and local communities. When mines open, local populations are often forced to relocate for safety or environmental reasons.

The metal manganese (Mn) is relatively widespread in the earth's crust, where it ranks 12th with a Clarke of 0.1% [5], with global manganese reserves estimated at 5-6 billion tonnes, and the market value of high-grade manganese fluctuating between 50 and 70% of global production and 80% of global exports (Fig. 2) [15]. It is indispensable to the steel industry (90% of steel production is based on manganese) due to its ability to bind sulfur, its antioxidant properties and its suitability for alloying, mainly in the form of ferroalloys. As an alloying additive, manganese makes steel harder and improves many of its mechanical properties. However, manganese mining activities have significant safety and environmental implications due to the risks associated with working in mines that need to be carefully considered. The extraction of manganese can lead to various safety hazards for workers, such as cave-ins, exposure to harmful chemicals and physical dangers in the mining process. Ensuring the safety of miners through proper training, equipment, and safety protocols is crucial to prevent accidents and injuries. Additionally, the environmental impact of manganese mining includes deforestation, habitat destruction, soil erosion and water pollution, and potential harm to local ecosystems. The use of heavy machinery, chemicals, and explosives in mining operations can lead to the contamination of soil, water sources, and air quality in the surrounding areas. Proper safety protocols and environmental regulations are essential to mitigate these risks and ensure responsible mining practices.

To produce manganese for export, Littoral Mining Company (LMC) has set up a number of activities, including exploration and exploitation. Since mining is a hazardous activity, safety is an essential aspect of mining practices, and therefore of these activities, which must be assessed in order to take suitable protective measures for workers. Risk appraisal can be used to underpin decision-making, and can supply an essential basis for developing a balance between ostensibly conflicting concerns, such as safety and costs [12]. This work outlines a survey of the global problems associated with manganese mining, including frequent accidents, occupational illness and environmental impact. The main objective is to assess the risks and deficiencies of mining activities, with a view to optimizing safety conditions in the work methodology. More specifically, the aim is (1) to draw up an inventory of exploration and mining activities; (2) to assess the risks associated with these activities; and (3) to propose a qualitative approach to reduce unsafe risks.

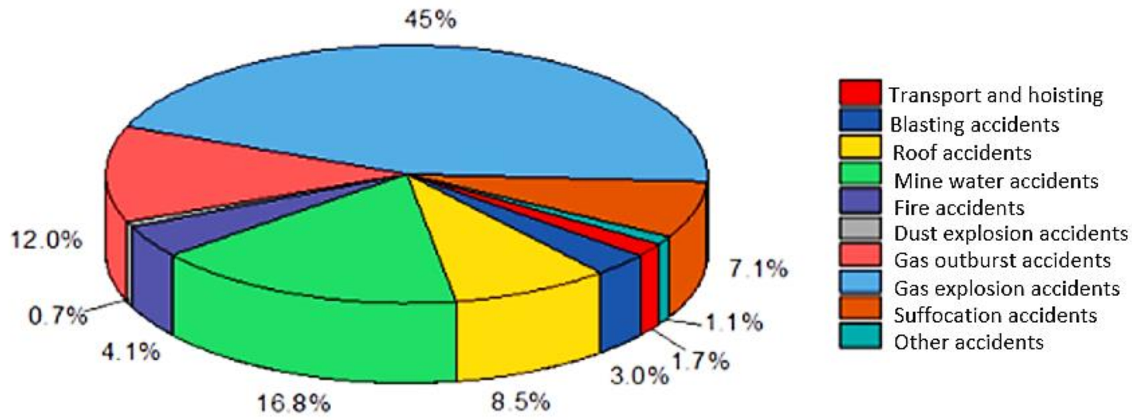

Fig. 1. Occurrence of different types of accidents occur in mining activity [2]

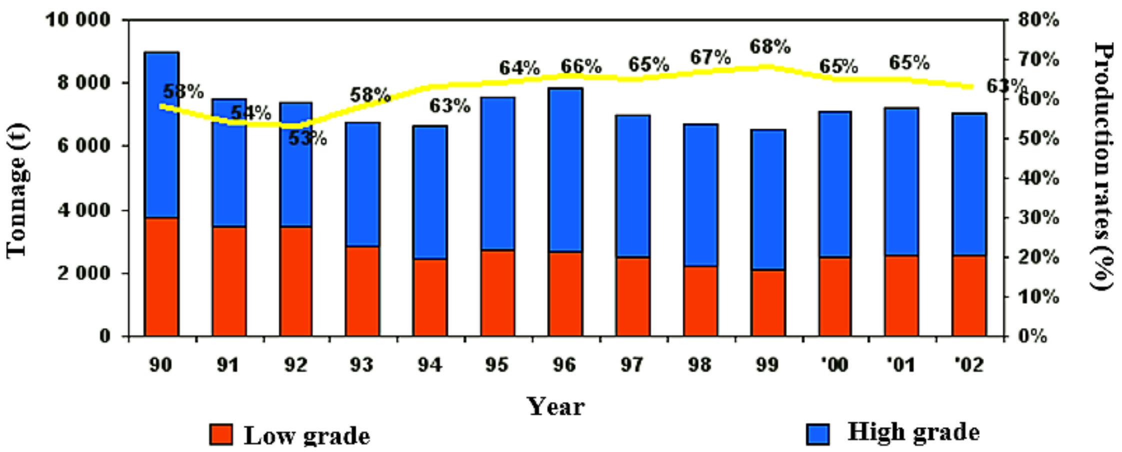

Fig. 2. Global manganese ore production by grade

2 OVERVIEW OF THE STUDY AREA

The Lauzoua manganese mine (LMM) is located in southwest Côte d'Ivoire, in the Lauzoua sub-prefecture, Guitry department, precisely at the edge of the sedimentary basin. It lies some 53 km northwest of Grand-Lahou, including 7 km of track between the "coastal" road and the old MOKTA mine. It is covered by the 100 km2 exploitation permit PE 36 of the former MOKTA permit and the new 88.6 km^2 research permit PR 248 (Fig. 3).

The Guitry department has a humid equatorial climate. Average annual rainfall is between 1100mm and 1700mm. Temperatures range from 24°50 C to 27°C. Vegetation cover is dominated by dense rainforest. It is dotted with large village and industrial cash crop plantations such as palm, rubber, coffee and cocoa. The Lauzoua (Guitry) relief is located in south-west Côte d'Ivoire, and is dominated by a chain of hills running north-east-south-west, with peaks ranging from 103 m to 144 m from south-west to north-east.

The soils of the Guitry region are derived from volcano-sedimentary materials. This region belongs to the zone of moderately leached ferralitic soils. The soils are predominantly silty, with pH levels below 5.5. Organic matter and base cations are low. Low organic matter levels, low pH values and low exchangeable bases could constitute essential risks to good agricultural productivity.

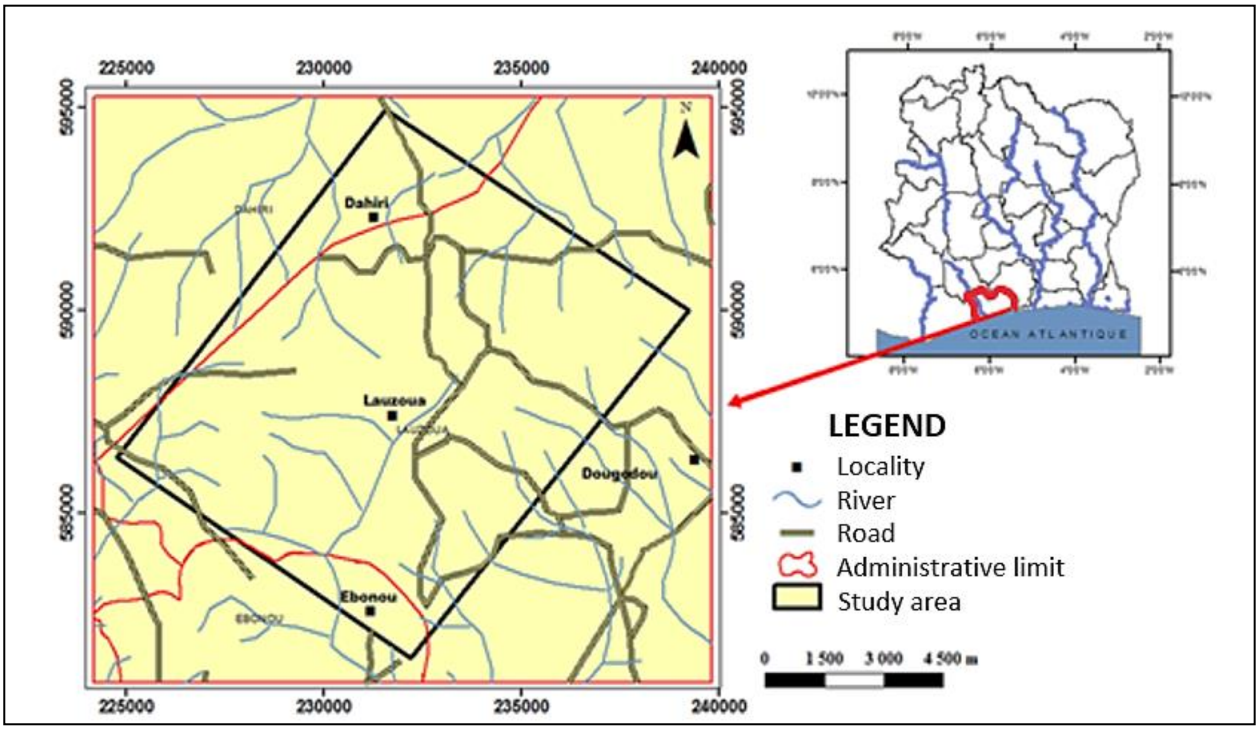

Fig. 3. Location map of the study area

3 Materials And Methods

3.1 Study Design

The current study was carried out on the MML to appraise the environmental and safety risks resulting from the mine's activities. On this basis, a methodological approach driven by research questions was ideally tailored to this study, as more data sources yield more insightful data to answer all the research queries. The study adopted stratified, random and purposeful sampling methods [1]. The sample size covered Lauzoua, Ebonou, Dahirl and the surrounding mining villages. Quantitatively, the study involved 945 interview respondents, including 278 miners, 642 stakeholders, 11 senior mine officials, 6 government representatives, 3 workers' unions and 5 members of community health services. The suggested sample size is derived from the respondents' proximity to the mining sites and their degree of suffering as a result of the direct impact of mining activities.

3.2 Data Collection

The data collected derives from two main sources (Fig. 4). We reviewed primary data from reports and documents relating to exploration and operating activities at the mine. This phase involved making an inventory of exploration and operating activities, analyzing (identifying hazardous situations, assessing and preventing) the risks associated with these activities, and proposing methods for enhancing working conditions at the mine. We then drew up technical data sheets, mainly risk assessment forms, to be used for collecting data in the field during discussions with workers in the various exploration and operating departments, as well as with the population surrounding the mine (secondary data). Finally, we carried out a field investigation in order to establish a correlation between the information collected from the two above-mentioned sources.

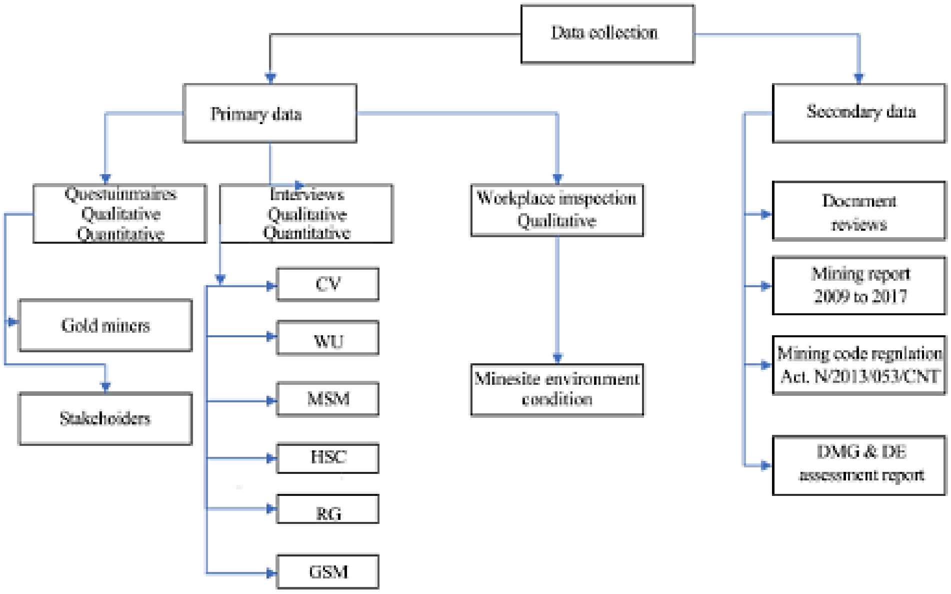

Fig. 4. Data collection process flowchart. WU: Workers union; CV: Chief of the village; MSM: Mining site manager; HSC: Health Service community; RG: Government representatives; GSM: General supervisor of mining

3.3 Data Analysis

The gathered information was carried out for analysis. The software Microsoft Excel spreadsheet was used to input information in both (primary and secondary) to developed frequency distribution tables' charts, graphs among others. The risk level was assessed using a risk level matrix based on the FMECA (Failure Mode, Effect and Criticality Analysis) method (Fig. 5). This involves a systematic, proactive risk analysis to identify major failures in complex processes [6]. The mining risk analysis process is shown in Figure 6, and involves potential risks related to mining activities, such as safety and environmental concerns.

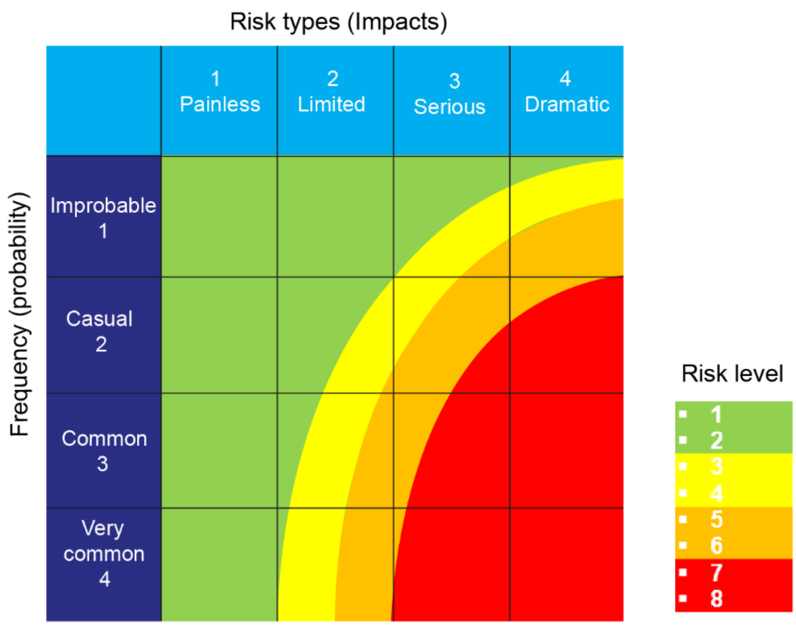

Fig. 5. Risk analysis matrix on 1 to 8 scale using the FMECA method

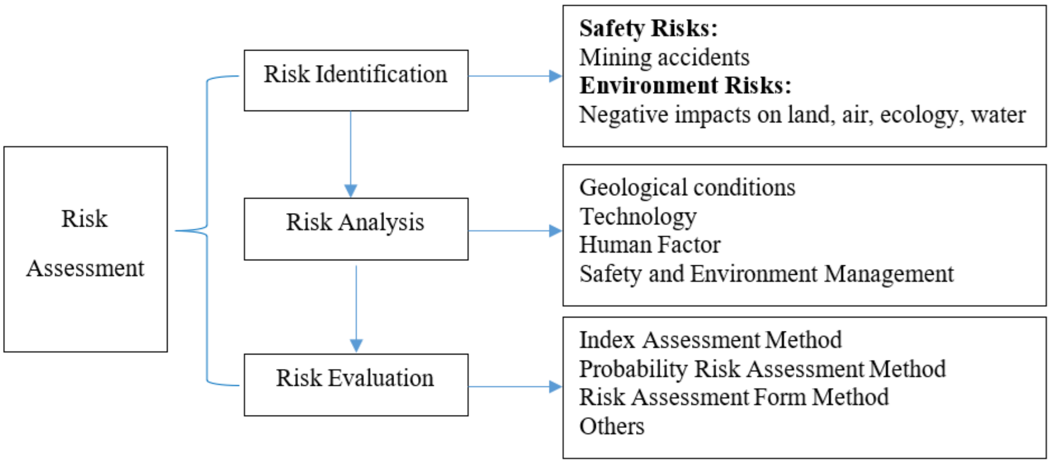

Fig. 6. Steps for mining risk assessment

4 RESULTS

4.1 MAIN MANGANESE MINING ACTIVITIES AT LMM

4.1.1 EXPLORATION ACTIVITIES

Exploration is an important activity at LMM, as it has enabled us to identify the potential existence of a manganese deposit, and to estimate the quantity of manganese present in the area. We will now focus on activities that might have an impact on the mine's safety environment.

- **Layering activity**

The manganese deposits are laid out in a NE-SW direction. The basic layon is set parallel to the NE-SW direction, with a magnetic declination of 7°NM. Layering is carried out using a compass, machete and stakes, following a network that includes a base line and transverse lines arranged perpendicular to the base line. It includes sighting, staking (Fig. 7a), clearing and chaining (Fig. 7b). The aim of these steps is to use the compass to align the stakes in order to represent a layon.

- **Shaft sinking**

Shafts drilled in the study area are either circular or rectangular, with a length (L) = 1.20 m and width (W) = 0.80 m, and a depth (D) of up to 9 m (Fig. 7c). This facilitates sinking and work in the shafts (sampling and description). Shafts are positioned in the direction of the transverse layons, i.e. the length of the shaft follows the direction of the transverse layons and the width follows the direction of the base layon. The wells are positioned perpendicular to the base plies, with the aim of intersecting the anomaly of interest, i.e. the Manganese lens.

- **Trench sinking**

Trenches are long, narrow excavations in the ground. Trenches are also rectangular in shape, but differ from shafts in their length. With a width of 0.80 m (sinking by well-diggers) or 1.20 m (sinking by mechanical shovel) (Fig. 7d). Trench lengths vary from 2.40 to 150 m, with depths ranging from 2 m. Trenches are always perpendicular to the direction of the manganese lens. They are in fact the extension of several shafts to follow the lens line. Some larger trenches can be excavated using a hydraulic shovel. Shaft sinking serves the same purpose as trenching, the only difference being that the anomaly is checked at greater depth. It enables us to verify the vertical evolution of mineralization in the alteration profile.

Fig. 7. Layering work. staking (a), Cleared area (b), Well (c) and trench (d) made during prospecting work

4.1.2 OPERATING ACTIVITIES

Manganese mining at the Lauzoua mine is an open-pit operation. It consists in extracting the ore from the ground, taking into account the 30% cut-off grade. The work is carried out by the mining department. The various mining activities carried out in the area are: clearing, stripping (creation of access roads, development of areas for the installation of equipment and storage of rejects), extraction, screening, stockpiling and transportation.

- **Clearing**

Clearing is a stage in the mining process during which all plant species occupying the area to be mined are destroyed (Fig. 8a, b).

- **Stripping**

Stripping consists of removing the sterile layer of earth above the manganese deposit to expose the mineralized layer and ease its extraction. To carry out stripping work, the mining department relies on the information available on the various panels of the map of the area to be mined, drawn up by topography and cartography. The panels are outlined on the ground by stakes. This information highlights the thicknesses of waste rock to be stripped, as well as the thicknesses of ore to be excavated and their different grades. Once this information has been obtained, a shovel is used to start the stripping work (Fig. 8c).

- **Extraction**

Extraction is the mining process used to extract manganese ore from the face of the mine. It starts when the shovel attacks the face with its bucket, extracting the ore by depositing it in a cone-shaped heap. The heap of excavated ore is fed to the screen by loaders (Fig. 8d).

- **Screening**

Screening is the granulometric separation of coarse from fine particles in manganese ore. It begins when the screen is fed. Once fed, the screen's grizzly, which contains an 80mm mesh, will separate the largest blocks (the +80mm) from the bulk material. Once these have been separated, the 80mm mesh is conveyed by conveyor belt to the 2 meshes: one 25mm above and one 8mm below. Together, the rejects from the 25mm mesh and the passings from the 80mm mesh form the 25-80mm. The combination of the 8mm mesh rejects and the 25mm mesh pass-throughs forms the 8-25mm. The 0-8 mm: the 8-mm grid passes are called "rejects" and do not enter production (Fig. 8e, f).

- **Destocking**

This involves dumping the various heaps obtained after screening onto a prepared platform where loading and transportation activities will take place (Fig. 8h). The 8/25 mm and 25/80 mm are destocked and mixed by loaders to form the 8/80 mm. This process is carried out in order to obtain a well mineralized manganese ore pile. The +80mm is also destocked. After destocking, information such as the heap circumference obtained, and the length L1 and L2 are taken in order to determine the volume of the various destocked heaps.

- **Ore transport**

Once the manganese ore has been destocked, a loader is used to dump it into dump trucks for transport to the processing plant (Fig. 8g).

Fig. 8. Field photographs of activity. a, b: Clearing using a hydraulic shovel; c: Stripping with shovel; d: Photography showing manganese ore mining; e, f: Heap of screened manganese ore of different grain sizes; g: Loading and transporting manganese ore; h: Manganese ore destocking L1: first measured length; l2: second measured length

4.2 Environmental Concerns Of Lmm's Activities

Mining activities can have a negative impact on water quantity. We have observed the toxic effluents used in ore processing, and the accidental spillage of fuels and other products during drilling. All these practices have a major impact on the region's hydrogeological reservoir. The hydrological process comprises two interdependent phases: surface water and groundwater. Surface water can replenish groundwater, and any damage to surface water can adversely affect groundwater in the future, and conversely.

We noted high dust and CO2 gas emission from machine activities. Air emissions from mining operations can impact not only local air quality, but also regional air health. Particulate emissions, such as dust from mining operations, are the main contributor to air quality problems at a mine site. Other air pollution factors are gaseous emissions, odorous emissions, volatile organic compounds from fuels or solvents, and emissions from motor vehicles and mining equipment. Air quality is highly vulnerable because air, unlike other wastes, cannot in practical terms be reprocessed in a central location and then dispensed for reuse [14].

An ecological assessment was performed to understand the fauna of the study area. The ecological impacts of mining encompass deforestation, loss of both vegetation and habitats, and reduced water quality, all of which impact the livelihoods of large and small animals, birds and fish. The deforestation is very harmful to people, animals and property [13]. The landscape changes created by mining activities do not enable many animal species to accommodate, so the modification shrinks their living space.

4.3 Risk Analysis

This involves identifying, assessing and mitigating the risks associated with the mine's exploration and operating activities. Risk evaluation is a scientific process that characterizes the occurrence, the magnitude and nature of health risks on humans, the negative impacts on ecology and others that may affect the environment. Tables 1 and 2 describe the risk management of manganese mining activities.

Table 1. Exploration risk management and evaluation using the FMECA method

Work unit	Dangerous situations	Staff concerned	Risk description	Risk assessment				Preventive measures
				IP	P	Niveau du risque		
Prospecting Layering	Presence of dangerous animals	Geology staff	Snake bites and insect bites when moving through the bush	3	3	6		Be equipped with a first-aid kit and wear safety shoes
	Presence of unmarked wells		Serious injury or fracture in the event of a fall into the deepest shafts (9m)	4	3	7		Flag wells with recognition signals
Well and trench sinking	Agents sinking shafts and trenches with cutting equipment	Manual workers	Injury caused by working equipment	2	2	4		Work with the glove and do not work in the precipitation
	Gas release during well sinking	Manual workers	Asphyxiation, casualties due to late intervention	3	3	6		All workers in shafts must be equipped with a hip rope for rapid evacuation and a breathing mask.
	Working in confined spaces	Manual workers	Landslide due to well instability	4	2	6		Checking wells before sinking
	Well water outlet	Manual workers	Flooding of well, risk of drowning	3	2	5		Plan a rapid evacuation using a rope or harness

PI: Potential Impact; P: Probability

Table 2. Operational risk management and evaluation using the FMECA method

Work unit	Dangerous situations	Staff concerned	Risk description	Risk assessment				Preventive measures
				IP	P	Risk level		
Stripping Extraction Screening Destocking	Lack of signs at the entrance to extraction sites	Machine operators, senior technicians and the local population	Accident to personnel, vehicles and the local population	4	2	6		Post signs to indicate activity in a zone
	Shovel activity in confined areas	Shovel operator, loader, screen operator, local population	Landslide	4	2	6		Avoid mining in confined spaces
	Night activity without lighting		Accident caused by driver distraction or lack of adequate lighting on site	4	3	7		Provide several lighted signs on the sites for night activities and compulsory wearing of chasuble
	Moving near unstabilized bleachers		Slope collapse	3	1	4		Prohibit unauthorized access to extraction areas and stabilize slopes with angles of more than 75%.
	Screen unclogging without proper equipment		Serious injury caused by sudden start-up of the screen	2	2	4		Check that the screen is switched off before unclogging, mandatory wearing of PPE
	Falling ore blocks during loading	Agents working on the site	Falls, injuries (broken bones)	3	2	5		Define a safety zone around the block loading area
	Dust generation during ore loading		Operator respiratory and lung infections	2	2	4		Regularly sprinkle loading areas, Insist on wearing nose protectors
	Hazardous waste disposal area	Shovel operator, loader, screen operator, local population	Discharge onto roads, machinery, pollution of watercourses and destruction of vegetation	3	3	6		Planning the waste repository for each operating site
Transport	High slope for dump trucks in some areas	Truck driver	Dump truck overturns	4	2	6		Reduce steep slopes
	Restricted route	Driver, local resident	Accident, injury or loss of life, road deviation	4	3	7		Enlarge the restricted lanes on the site
	Overloading of trucks	The local population, truck drivers	Accident due to ore spillage on road, injury, road closure, loss of human life	3	2	5		Raising drivers' awareness of bucket number limits
	Dust emissions during ore transport	Employees working on the site and external users (local population)	Respiratory and lung infections, impaired vision during ore transport	2	2	4		Regular watering of transport routes
	Lack of signposting		Accident (Collision of machinery, Running off the road)	4	2	6		Install warning signs at all intersections and high-risk turns
	Steep downhill		Truck drop	4	2	6		Reducing slopes

IP: Potential Impact; P: Probability; PPE: Personal Protection Equipment

4.4 CHART OF MINING ACTIVITIES-RELATED RISKS

In terms of exploration activities, we obtain 6 risks: 4 serious risks, 1 limited risk and 1 dramatic risk, giving respectively (80% serious risks, 10% limited risks and 10% dramatic risks) (Fig. 9). In terms of operating activities, there are 14 risks: 8 serious, 4 limited and 2 dramatic, respectively (57.14% serious, 28.57% limited and 14.29% dramatic) (Fig. 9).

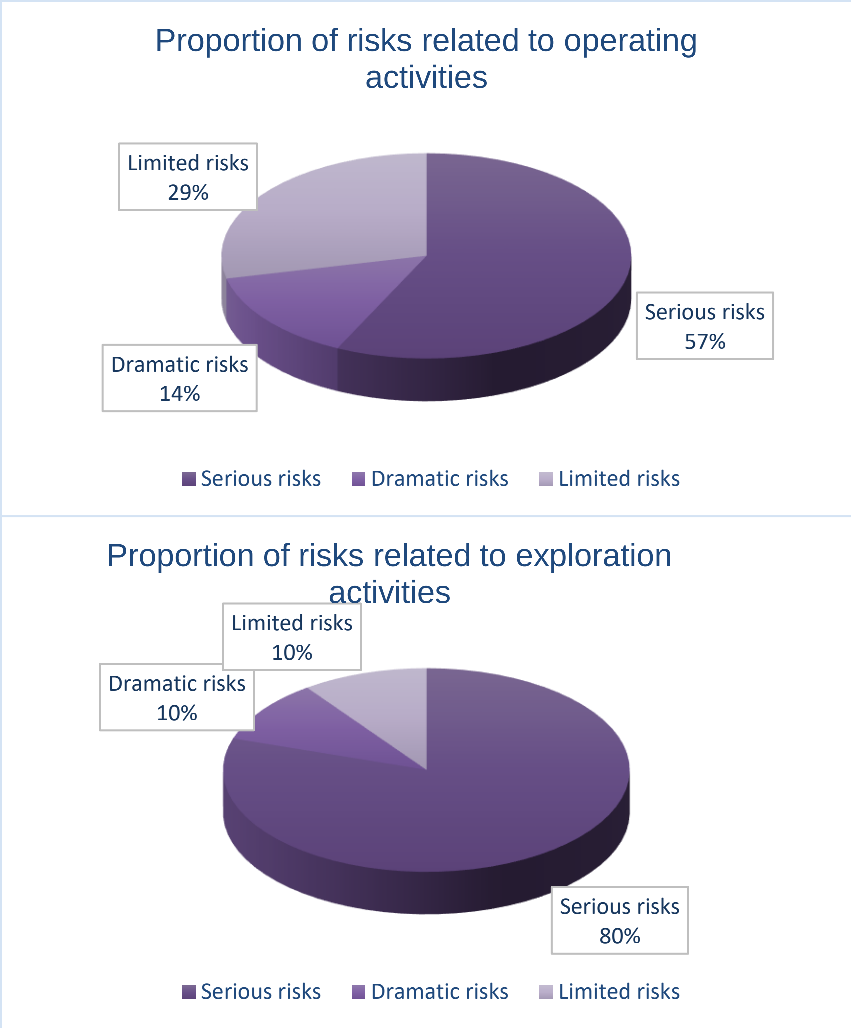

Fig. 9. Risk chart for exploration and operating activities

4.5 Mitigation Measures

According to the research described above, a series of actions are foreseen for good management and stewardship following the national biodiversity conservation and sustainable resource use strategy's implementation at two levels of intervention. The first is the conservation of environmental resources in their biodiversity; the second is the sustainable management of environmental resources and international cooperation. The first approach involves conserving biological, physical and human environments by safeguarding species, habitats, ecosystems and the atmosphere. The company must use renewable and non-renewable natural resources in a sustainable approach; collect, store and properly handle all waste likely to cause environmental or health damage, which can help reduce the risk of contamination; backfill extraction pits where possible, or reforest fast-growing species on waste rock or in compensation areas.

In order to improve exploration activities within the mine, a CA-1510 logger should be used to determine CO2 and humidity levels in the shafts before each sinking to avoid the risk of asphyxiation. It is necessary to ensure that the jacker is equipped with a rescue harness fitted with safety ropes connected to a point located outside for faster evacuation in the event of dangerous situations, and finally the wearing of breathing apparatus and suitable personal protective equipment.

In the case of mining operations, a design must be carried out before the work is performed, and suitable geotechnical studies must be conducted for slope stabilization in the case of work at greater depths and in confined spaces. Light vehicles and machinery should circulate on separate lanes, and all equipment and vehicles used to load materials should comply with the specifications and safety requirements of national legislation.

5 Discussion

The monitoring and control of LMM's activities enabled us to assess the risks to mine personnel associated with these activities. Initially, our work focused on the inventory of activities linked to exploration and operating, and then we assessed the risks associated with these activities. The results were serious risks, dramatic risks and limited risks. According to our study, serious risks are those which have a fairly serious impact on the individual, and are likely to occur less frequently than limited risks within the mine. These include landslides. These results are in line with those of [7] and [8]. Indeed, according to their studies, rockfalls are the most frequent accidents in mining operations, and this type of accident threatens the physical integrity of miners as it takes the form of falling blocks from the roof, collapsing casings and collapsing working faces. In some cases, these landslides can take the form of falling ore due to the collapse of unstabilized slopes during mining operations, or falling earth on well-diggers during exploration operations. These risks represent a percentage of 80% for exploration activities and 57.14% for operating activities. In terms of limited risks, which are generally related to inhalation of manganese dust particles, our results contradict those of [11]. For him, ordinary accidents in mines cause more deaths than explosions. Moreover, he reported that dust inhaled during mining operations caused an average of more than (19.35 deaths / million tonnes of ore extracted) each year. These results contradict our own, because according to our studies, the limited risks at the Lauzoua mine could not have resulted in the deaths of workers in the various departments. Moreover, according to [10], accidents can range from the minor to the major (serious or dramatic), and for him, it's sometimes a simple incident or negligence that degenerates into a catastrophe, such as the untimely extinguishing of a lamp that the worker tries to relight himself to save precious time, and which spreads fire to the gases present; the obstruction of a ventilation shaft by a landslide, resulting in the asphyxiation of many workers. In terms of dramatic risks, our studies reveal that it is the risks associated with the most dangerous situations that have the highest impact - generally collisions between mine vehicles or machinery. These results are in line with those of [9], who indicate that traffic accidents account for nearly three-quarters of all fatalities.

6 Conclusion

This work was prompted by the need to monitor and control all stages of exploration and mining operations at LMM (Guitry department). The aim of this study was to evaluate the exploration and mining activities of the LMM in order to identify the risks and shortcomings of these mining activities with a view to optimizing their safety conditions in the work methodology. This study was made possible thanks to one of the most widely used methods for analyzing the risks associated with failures in an activity, namely the FMECA method. The risk parameters studied are its severity and the probability with which it can occur over time. After study, we obtained dangerous situations associated with risks that can be dramatic, serious (fractures or infections) or limited (injuries, scratches). We highlighted the difficulties as well as the risks encountered in these activities. These difficulties can be the lack of protective equipment, failure to comply with safety instructions or normal work methodology. These risks are due to complex geological conditions, failure to implement technologies, human factors, insufficient financial investment and ineffective management of safety and the environment. It is necessary to prior monitor exploration and exploitation activities, to gain a clear idea of how they operate on all fronts; to carry out a thorough environmental impact assessment prior to mining, and to ensure that any major risks identified are sufficiently mitigated. However, preventive measures have been proposed to reduce serious risks in these different departments. With regard to dramatic risks, a geotechnical study will have to be carried out to stabilize the slopes of mining operations, and a suitable area for depositing the tailings will have to be defined for each extraction site, to avoid the risk of landslides. With regard to exploration activities, well-diggers will be required to wear gas masks and appropriate personal protective equipment.

Acknowledgments

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