

Analysis of occupational safety, health, and psychosocial risk factors influencing workers' performance in artisanal mining operations in Mali : a case study of Touréla

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Abstract

Artisanal mining is a major economic activity in Mali, but it exposes workers to numerous hazards that can adversely affect their occupational health, safety, and job performance. This study aims to analyze the occupational safety, health, and psychosocial risk factors influencing workers' performance in artisanal mining operations, using the Touréla mining site as a case study. A descriptive and analytical cross-sectional study was conducted among 200 workers using structured questionnaires, semi-structured interviews, and direct field observations. Data were collected on socio-professional characteristics, occupational safety conditions, workers' health status, psychosocial risks, and performance indicators. Statistical analyses were performed using Microsoft Excel and IBM SPSS Statistics. The findings reveal that workers are highly exposed to occupational accidents, musculoskeletal disorders, respiratory diseases, dust, excessive noise, and psychosocial constraints related to excessive workload, stress, and income insecurity. The lack of personal protective equipment (PPE), limited access to occupational health and safety training, and poor working conditions significantly contribute to reduced worker performance. Conversely, strengthening preventive measures, improving working conditions, promoting occupational health, and addressing psychosocial risks are associated with increased productivity and a lower incidence of occupational accidents. This study provides valuable scientific evidence to support the development of prevention policies and promote safer, more productive, and sustainable artisanal mining practices in Mali.

Keywords : *artisanal mining, occupational safety, occupational health, psychosocial risks, worker performance.*

Résumé

Analyse des facteurs de risque en matière de sécurité, de santé et de facteurs psychosociaux influençant la performance des travailleurs dans les opérations minières artisanales au Mali : une étude de cas de Touréla

L'exploitation minière artisanale est une activité économique majeure au Mali, mais elle expose les travailleurs à de nombreux risques susceptibles de nuire à leur santé, leur sécurité et leur productivité au travail. Cette étude vise à analyser les facteurs de risque liés à la sécurité, à la santé et aux aspects psychosociaux qui influencent la performance des travailleurs dans les opérations minières artisanales, en prenant le site minier de Touréla comme étude de cas. Une étude transversale descriptive et analytique a été menée auprès de 200 travailleurs à l'aide de questionnaires structurés, d'entretiens semi-structurés et d'observations directes sur le terrain. Les données recueillies portaient sur les caractéristiques socioprofessionnelles, les conditions de sécurité au travail, l'état de santé des travailleurs, les risques psychosociaux et les indicateurs de performance. Les analyses statistiques ont été réalisées à l'aide de Microsoft Excel et d'IBM SPSS Statistics. Les résultats révèlent que les travailleurs sont fortement exposés aux accidents du travail, aux troubles musculo-squelettiques, aux maladies respiratoires, à la poussière, au bruit excessif et aux contraintes psychosociales liées à une surcharge de travail, au stress et à la précarité des revenus. Le manque d'équipements de protection individuelle (EPI), l'accès limité à la formation en santé et sécurité au travail et les mauvaises conditions de travail contribuent significativement à la baisse de la performance des travailleurs. À l'inverse, le renforcement des mesures préventives, l'amélioration des conditions de travail, la promotion de la santé au travail et la prise en compte des risques psychosociaux sont associés à une productivité accrue et à une diminution de la fréquence des accidents du travail. Cette étude apporte des données scientifiques précieuses pour appuyer l'élaboration de politiques de prévention et promouvoir des pratiques minières artisanales plus sûres, plus productives et plus durables au Mali.

Mots-clés : *exploitation minière artisanale, sécurité au travail, santé au travail, risques psychosociaux, performance des travailleurs.*

1. Introduction

Artisanal and small-scale mining (ASM) is a major economic activity in many developing countries, particularly in West Africa, where it represents an important source of employment and income for rural communities [1]. In Mali, artisanal gold mining makes a significant contribution to the national economy and plays a key role in poverty reduction. However, the sector is characterized by poor working conditions, low levels of mechanization, and inadequate occupational risk prevention measures [2, 3]. Workers are exposed daily to numerous occupational hazards, including pit collapses, falls, mineral dust, excessive noise, vibration, toxic substances, and heavy metals such as mercury, cyanide, and sulfuric acid, in addition to significant ergonomic constraints [4 - 6]. These hazards substantially increase the incidence of occupational accidents and occupational diseases (OA/OD), directly affecting miners' health and safety [7, 8]. Furthermore, difficult working conditions, unstable incomes, long working hours, and the lack of social protection contribute to the emergence of psychosocial risks that may impair workers' cognitive and physical capacities, leading to occupational illnesses and mental health disorders [9 - 11]. These constraints negatively affect workers' efficiency, productivity, well-being, and the overall performance of artisanal mining operations [12, 13]. Despite numerous international initiatives aimed at promoting responsible mining practices, scientific evidence regarding the interactions among occupational safety, occupational health, psychosocial risks, and

workers' performance remains limited in the Malian context [14 - 16]. A better understanding of these relationships is essential for guiding public policies, improving occupational risk management practices, and enhancing the sustainability of the artisanal mining sector [17, 18]. Against this background, the present study aims to analyze the occupational safety, occupational health, and psychosocial risk factors influencing workers' performance in artisanal mining operations in Mali. The findings are expected to provide evidence-based recommendations for improving working conditions, preventing occupational risks, and enhancing the long-term performance and sustainability of artisanal mining activities.

2. Material and methods

2-1. Study area

This study was conducted at the Touréla artisanal mining site, located in the rural municipality of Sanankoroba, Kati Cercle, Koulikoro Region, Mali. Touréla is one of the major artisanal gold mining centers in southern Mali, attracting thousands of workers daily from different regions of the country as well as neighboring West African countries. The rapid expansion of mining activities is primarily driven by the gold-rich geological formations of the West African Craton, making Touréla a strategic location for artisanal gold extraction. Gold mining at the site relies mainly on traditional mining methods, including the manual excavation of shafts that may reach several tens of meters in depth, ore extraction using rudimentary tools, followed by crushing, grinding, and washing of the ore, sometimes involving the use of chemical substances. The lack of adequate equipment, including mining machinery, personal protective equipment (PPE), and appropriate safety systems, exposes workers to numerous occupational hazards, such as shaft collapses, falls, mechanical injuries, musculoskeletal disorders, and chemical intoxication [19]. The Touréla mining site is also characterized by a high concentration of workers operating in an environment with excessive dust, noise, vibrations, high temperatures, and largely informal work organization. These working conditions increase not only the occurrence of occupational accidents and occupational diseases (OA/OD) but also psychosocial risks associated with physically demanding work, income insecurity, production pressure, and poor living conditions [20, 21]. From an environmental perspective, abandoned excavations, land degradation, the absence of mine site rehabilitation, and unplanned mining activities further increase risks for both workers and surrounding communities. Recent studies conducted at the Touréla site have highlighted the progressive deterioration of the geotechnical properties of the soil, which significantly increases the likelihood of excavation instability and shaft collapse [22, 23]. The selection of Touréla as the study area was justified by its major economic importance in Mali's artisanal gold production, its large active workforce, the diversity of mining activities carried out on the site, and the high frequency of occupational accidents and health problems reported among workers. These characteristics make Touréla an appropriate setting for investigating the relationships among occupational safety, occupational health, psychosocial risks, and workers' performance, with the ultimate goal of proposing effective strategies to improve working conditions and strengthen occupational risk prevention in artisanal mining operations in Mali.

2-2. Study period and practical implementation of the research activities

The present study was conducted at the Touréla artisanal mining site over a six-month period, from January to June 2025. This timeframe was selected to ensure the completion of all stages of data collection while taking into account the mining activity schedule and the favorable climatic conditions for access to the study site. The practical implementation of the study was carried out in four successive phases. The first phase consisted of a comprehensive literature review on occupational safety and health in artisanal mining, psychosocial risks, and the factors influencing workers' performance. This stage facilitated the identification of the study variables, the development of data collection instruments, and the definition of the research

methodology. The second phase involved fieldwork. Preliminary site visits were conducted to obtain the necessary authorizations from site managers and to inform mine operators about the objectives of the research. Direct observations were undertaken to identify the various mining activities, workstations, hygiene conditions, existing safety measures, and the main occupational hazards to which workers were exposed. The third phase focused on data collection. Information was gathered through structured questionnaires administered to workers, semi-structured interviews with site managers, and direct observations conducted at the workplaces. The collected data covered workers' socio-professional characteristics, occupational safety conditions, occupational health status, psychosocial risks, occupational accidents, occupational diseases, and individual performance indicators. The fourth and final phase consisted of data validation, processing, and statistical analysis. The results were used to assess the relationships among occupational safety factors, occupational health conditions, psychosocial risks, and workers' performance. Based on these findings, evidence-based recommendations were formulated to improve working conditions and promote sustainable occupational risk management in artisanal mining operations at the Touréla site.

2-3. Data collection and research instruments

This study was based on both primary and secondary data to investigate the occupational safety, occupational health, and psychosocial factors influencing workers' performance at the Touréla artisanal mining site. The integration of multiple data sources enhanced the reliability and validity of the findings through a data triangulation approach. Primary data were collected directly from workers using structured questionnaires, semi-structured interviews, and field observations. The questionnaires gathered information on workers' socio-demographic characteristics (age, sex, educational level, years of experience, and job position), working conditions, use of personal protective equipment (PPE), occupational accidents, occupational diseases, psychosocial risks, and individual performance indicators. Secondary data were obtained from scientific literature, technical reports, administrative documents from mining authorities, national statistical databases, and publications issued by international organizations specializing in occupational safety and health. These sources provided valuable information for characterizing the context of artisanal mining in Mali and for comparing the study findings with those reported in similar settings. The main data collection instruments included direct observation checklists, a structured survey questionnaire, a semi-structured interview guide, and an occupational safety and health assessment checklist. Field observations focused on work organization, workers' safety behaviors, the availability and use of personal protective equipment, workplace hygiene conditions, mining processes, and hazardous situations likely to result in occupational accidents or diseases. Data processing and statistical analyses were performed using both spreadsheet and statistical software. Microsoft Excel was used for data entry, coding, cleaning, and database management, while IBM SPSS Statistics was employed to conduct descriptive and inferential statistical analyses, including descriptive statistics, chi-square tests, correlation analyses, and multiple regression models to identify the factors influencing workers' performance. Tables and figures were generated using Microsoft Excel to facilitate the presentation and interpretation of the results.

2-4. Methods

This study employed a mixed-methods approach (qualitative and quantitative) using a descriptive and analytical research design to evaluate the occupational safety, occupational health, and psychosocial factors influencing workers' performance in the artisanal mining operations of Touréla. This approach made it possible to examine the relationships between the independent variables (occupational safety, occupational health, and psychosocial risks) and the dependent variable (workers' performance) using field data collected from the study population [24].

2-4-1. Study design

This research was based on an observational, cross-sectional, descriptive, and analytical study conducted among 200 workers employed at the Touréla artisanal mining site in the Koulikoro Region of Mali. This methodological design enabled the assessment, at a single point in time, of workers' characteristics, working conditions, and the occupational safety, health, and psychosocial factors likely to influence their job performance [25, 26]. A cross-sectional approach is particularly appropriate for occupational health research because it allows the simultaneous assessment of workers' exposure to various occupational hazards and the corresponding effects on their health, safety, and work performance. It also provides an opportunity to identify associations among multiple variables without altering the actual working conditions under which mining activities are carried out [27]. This type of study is widely used in occupational safety and health research, particularly in sectors characterized by high exposure to occupational accidents and work-related diseases, such as artisanal and small-scale mining (ASM) [28]. The descriptive component of the study aimed to provide a comprehensive overview of working conditions at the Touréla mining site. It included the description of workers' socio-demographic characteristics, occupational hygiene and safety conditions, preventive practices, the use of personal protective equipment (PPE), the frequency of occupational accidents, work-related diseases, and the main psychosocial risks encountered by workers. This stage constituted an essential prerequisite for identifying occupational risk factors and understanding the organizational context of artisanal mining activities [13]. The analytical component was designed to investigate the relationships between the explanatory variables namely occupational safety conditions, occupational health, and psychosocial risks and the dependent variable, workers' performance. Statistical analyses were conducted to identify the factors significantly influencing productivity, work quality, individual performance, and absenteeism while highlighting the interactions among the different dimensions of occupational safety and health [14]. The selection of this methodological approach was further justified by its ability to provide reliable information within a relatively short period and at a reasonable cost while enabling the simultaneous investigation of multiple occupational risk factors. It is currently widely recommended in public health, occupational safety, and occupational epidemiology research for assessing working conditions in the informal sector, particularly in artisanal and small-scale mining.

2-4-2. Study population and sampling

The study population consisted of all workers engaged in mining activities at the Touréla artisanal mining site in the Koulikoro Region of Mali. This population included workers involved in the various stages of the gold production chain, including shaft diggers, drillers, crushers, mill operators, ore washers, transporters, material handlers, ore buyers, and mining team supervisors. Owing to the diversity of mining tasks and working conditions, these workers are exposed to a wide range of occupational hazards, including physical, chemical, ergonomic, biological, and psychosocial risks that may adversely affect their health and safety [29, 30]. Considering the large workforce operating at the mining site and the associated logistical constraints, it was not feasible to survey the entire target population. Therefore, a representative sample was selected to obtain reliable information on occupational safety, occupational health, psychosocial risks, and workers' performance. The use of sampling is recommended in occupational health and epidemiological studies when surveying the entire population is impractical [8]. Participants were selected using a simple random sampling technique, ensuring that each eligible worker had an equal probability of being included in the study. This sampling strategy minimized selection bias, improved the representativeness of the sample, and enhanced the validity of the findings. Particular attention was paid to ensuring adequate representation of the major occupational categories involved in mining activities at the site [9, 10]. Eligible participants were workers aged 18 years or older who were regularly engaged in mining activities at the Touréla site and had sufficient

work experience (measured in months or years) to assess their working conditions and occupational risk exposure. Participation in the study was entirely voluntary. All participants received clear information regarding the objectives of the research and provided written informed consent before enrollment. Confidentiality and anonymity were strictly maintained throughout the study. Occasional workers, visitors, temporary workers, and individuals who declined to participate were excluded from the study [7].

2-4-3. Data collection

Data collection was conducted at the study site using a structured approach combining quantitative and qualitative methods. This mixed-methods approach provided a comprehensive understanding of occupational safety conditions, occupational health status, psychosocial risks, and their effects on workers' performance. The combination of several data collection techniques also enabled information triangulation and improved the validity and reliability of the results obtained. Primary data were collected using a structured questionnaire administered through face-to-face interviews with workers. The questionnaire was developed based on recommendations from the International Labour Organization (ILO) and scientific literature related to occupational health and safety in artisanal mining operations. It included both closed-ended and semi-open-ended questions organized into several sections: participants' socio-demographic characteristics (age, sex, educational level, years of experience, and job position), working conditions, use of personal protective equipment (PPE), occupational accidents, occupational diseases, psychosocial risks (workload, stress, fatigue, organizational support, job satisfaction), and workers' performance indicators [31]. In addition to the questionnaires, semi-structured interviews were conducted with site managers, team supervisors, and experienced workers. These interviews provided detailed information on work organization, risk prevention practices, challenges related to occupational safety and health, and the risk management mechanisms implemented at the mining site [16]. Direct observations were also carried out at different workplaces to assess the actual conditions under which mining activities were performed. A standardized observation checklist was used to evaluate compliance with safety practices, the use of personal protective equipment, the condition of mining infrastructures, workers' behaviors, hazardous situations, and environmental factors such as dust exposure, noise, vibrations, and hygiene conditions. This approach made it possible to compare participants' reported information with the actual conditions observed in the field [17]. To ensure the quality of the collected data, the questionnaire was *pre-tested* among a limited number of workers with characteristics similar to those of the target population. The results of this preliminary test were used to improve question wording, assess participants' understanding, and adapt the data collection instrument to the specific context of the Touréla artisanal mining site. Furthermore, field investigators received prior training on interview techniques, questionnaire administration procedures, and compliance with ethical principles of scientific research [18]. All collected data were checked daily to ensure completeness, consistency, and accuracy before coding and entering them into a database for statistical analysis. This quality control procedure helped minimize data entry errors, missing information, and inconsistencies that could affect the reliability of the study results.

2-4-4. Ethical considerations

The present study was conducted in strict compliance with the ethical principles governing research involving human participants. Prior to the beginning of field activities, the necessary authorizations were obtained from the managers of the Touréla artisanal mining site and the relevant local authorities. The objectives, procedures, expected benefits, and potential constraints of the study were clearly explained to participants to ensure their full understanding of their involvement in the research process [6]. Participation in the study was based exclusively on the principle of *voluntary involvement*. Each participant was invited to provide free, informed, and voluntary consent before completing the questionnaire or participating in an interview. Participants were informed that they had the right to refuse participation or withdraw from the study at any

time, without providing justification and without any negative consequences for their professional activities or their relationship with site managers [2]. To ensure the confidentiality of collected information, no names or personally identifiable information were recorded in the database. Questionnaires were anonymously coded, and all collected data were used exclusively for scientific purposes. Access to the database was restricted to members of the research team, in accordance with the principles of confidentiality, personal data protection, and respect for participants' privacy [13]. The investigators also ensured respect for workers' dignity, integrity, and fundamental rights throughout the data collection process. Interviews were conducted in a climate of trust, without any form of pressure, discrimination, or stigmatization. Particular attention was given to the protection of potentially vulnerable individuals and to respecting the cultural and social values specific to the artisanal mining context in Mali [18]. Finally, this research was conducted in accordance with international principles of research ethics in public health, particularly those established by the Declaration of Helsinki, the recommendations of the Council for International Organizations of Medical Sciences (CIOMS), and the guidelines of the World Health Organization (WHO) regarding research involving human subjects. These ethical frameworks ensure the protection of participants' rights, safety, well-being, and confidentiality throughout the research process.

2-5. Data quality control and validation

To ensure the reliability, consistency, and scientific quality of the results, several quality control and validation procedures were implemented throughout the data collection, processing, and analysis stages. These procedures helped minimize measurement errors, observational biases, and inconsistencies that could affect the validity of the study conclusions [22, 23]. Before the beginning of the main survey, the data collection instruments (questionnaire, interview guide, and observation checklist) underwent content validation by specialists in occupational health and safety, public health, and mining sciences. This step made it possible to assess the relevance, clarity, and consistency of the questions in relation to the study objectives and to ensure their suitability for the specific context of artisanal mining operations at Touréla. Subsequently, a pre-test was conducted among a limited group of workers with characteristics similar to those of the target population. This preliminary phase helped identify comprehension difficulties, remove ambiguities, and improve the wording of certain questions before the final data collection process. The feedback obtained contributed to strengthening the quality of the survey instruments and reducing response errors [25]. During the data collection phase, completed questionnaires were subjected to daily quality checks to verify their completeness, internal consistency, and compliance with the recorded responses. Incomplete forms or questionnaires containing inconsistencies were corrected whenever possible in collaboration with the investigators or the concerned participants. This procedure helped reduce missing data and improve the overall quality of the database [19]. After electronic data entry, the dataset underwent statistical validation procedures, including the identification of outliers, detection of duplicate records, verification of coding errors, and assessment of consistency among variables. Preliminary descriptive analyses were also performed to detect potential anomalies before conducting the final statistical analyses [31]. Finally, the reliability of the collected information was strengthened through methodological triangulation, which consisted of comparing results obtained from questionnaires, direct field observations, and interviews conducted with various stakeholders at the mining site. This approach helped confirm the consistency of the collected data and improved the interpretation of findings related to occupational safety factors, occupational health, psychosocial risks, and workers' performance in the artisanal mining operations of Touréla.

3. Results

3-1. Socio-professional characteristics of the surveyed workers

The survey conducted among workers at the Touréla artisanal mining site enabled the characterization of participants' socio-professional profiles and the identification of the main occupational characteristics related to artisanal mining activities. A total of 200 workers were interviewed, representing the different professional categories involved in the artisanal gold mining production chain. The results show a predominance of male workers, reflecting the highly physical and demanding nature of mining activities performed at the site. Although less represented, women are mainly involved in ore crushing, gold washing, gold recovery activities, and certain commercial activities associated with mining operations. The age distribution indicates that the majority of respondents belong to the economically active age groups, mainly between 20 and 45 years, corresponding to the period of highest participation in artisanal mining activities. This relatively young workforce represents an essential labor force for operations requiring significant physical effort, particularly shaft excavation, ore transportation, and mineral processing activities. However, the presence of very young workers in certain positions exposes this category to significant occupational risks related to work intensity and precarious working conditions. Regarding educational level, the results reveal a high proportion of workers with only primary education or no formal schooling. This low educational qualification limits access to information on safety practices, the proper use of personal protective equipment (PPE), and understanding of occupational risk prevention procedures. Workers with secondary or higher education remain a minority and generally occupy organizational, supervisory, or management positions within mining activities. Analysis of professional experience shows that many workers have significant experience in artisanal gold mining, with a considerable proportion having more than five years of work experience. This experience represents an advantage in terms of practical knowledge of mining conditions; however, it may also encourage routine behaviors that are sometimes inconsistent with safety requirements. Newly recruited workers are more vulnerable due to their limited knowledge of mining hazards. Professionally, surveyed workers were distributed among several activity categories, including shaft diggers, ore transporters, crushers, mill operators, gold washers, gold collectors, and team supervisors. Shaft diggers and material handlers represent the groups most exposed to physical hazards due to high physical demands, difficult underground conditions, and the risk of mine collapse. Workers involved in ore processing are more exposed to mineral dust and chemical substances used during gold recovery operations.

3-2. Analysis of occupational safety, health, and psychosocial risk factors influencing workers' performance

The analysis of occupational safety, health, and psychosocial factors identified the main constraints affecting workers and influencing their performance. The findings demonstrate interactions between working conditions, exposure levels to occupational hazards, workers' health status, and factors affecting productivity.

3-2-1. Assessment of occupational safety conditions

The survey results indicate that artisanal mining activities conducted at the Touréla site are characterized by significant exposure to multiple occupational hazards. The main identified risks include shaft collapses, falls from height, injuries caused by manual tools, exposure to mineral dust, noise, vibrations, and chemical substances used during ore processing. The analysis of preventive practices reveals insufficient use of personal protective equipment (PPE). A significant proportion of workers do not have complete protective equipment, such as safety helmets, safety footwear, protective goggles, gloves, or respiratory masks. This

situation is mainly related to the high cost of PPE, limited availability, insufficient awareness of their importance, and inadequate training on occupational risk prevention. The results also indicate that only a small proportion of workers have received specific training in occupational health and safety. The lack of regular training reduces workers' ability to identify hazardous situations and adopt safe behaviors. Recorded accidents at the site are mainly associated with shaft falls, cuts, handling-related injuries, and incidents occurring during extraction activities.

3-2-2. Workers' health status

The assessment of workers' health status highlights several problems associated with artisanal mining working conditions. Respiratory disorders represent one of the main health problems observed due to prolonged exposure to dust generated during ore crushing, grinding, and transportation activities. Workers also reported musculoskeletal disorders affecting mainly the back, shoulders, upper limbs, and lower joints. These conditions are associated with intense physical effort, manual transportation of heavy loads, awkward postures, and repetitive tasks. Exposure to chemical substances, particularly mercury during gold amalgamation processes, represents an additional health concern. Reported symptoms include chronic fatigue, headaches, respiratory irritation, and general health problems associated with difficult working conditions. The results further show that access to healthcare services remains limited at the site, with inadequate availability of medical care, occupational health monitoring, and preventive measures against work-related diseases.

3-2-3. Analysis of psychosocial risks related to artisanal mining work

The analysis of psychosocial risks reveals that Touréla workers are exposed to several factors likely to affect their well-being and work capacity. The main identified factors include production pressure, income uncertainty, long working hours, task difficulty, and insecurity related to mining conditions. A significant proportion of workers reported high levels of physical and mental fatigue, particularly those involved in excavation, transportation, and ore processing activities. The absence of social protection, economic insecurity, and instability of mining activities also represent major sources of occupational stress. Social relationships within work teams are generally considered favorable; however, organizational difficulties were observed, including insufficient communication regarding safety measures, lack of technical supervision, and limited worker participation in decisions related to work organization.

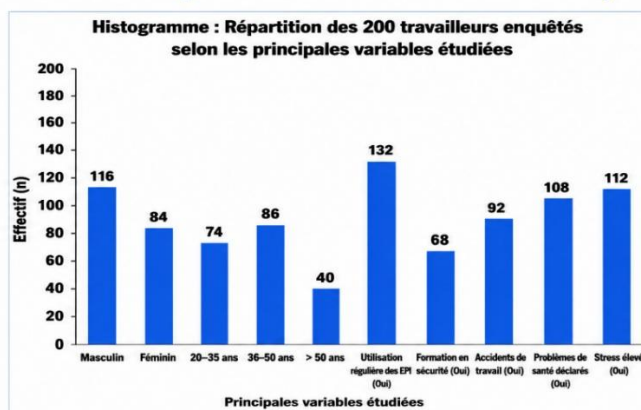
3-2-4. Influence of studied factors on workers' performance

The analysis of the relationship between occupational safety factors, occupational health, psychosocial risks, and performance shows that poor working conditions are major factors limiting workers' effectiveness. Workers exposed to high levels of occupational risks experience greater difficulties related to fatigue, absenteeism, reduced concentration, and decreased productivity. Statistical analysis indicates that regular PPE use, occupational safety training, good health status, and improved organizational conditions are positively associated with better performance. Conversely, frequent accidents, chronic health problems, and high psychosocial constraints are associated with reduced productivity and lower work quality. The analytical model demonstrates that workers' performance in artisanal mining operations depends not only on individual technical abilities but also on the overall working environment, including safety, health, and organizational dimensions. Overall, the results show that Touréla artisanal miners operate in an environment characterized by high exposure to occupational and psychosocial risks. The observed deficiencies in risk prevention, socio-health protection, and work organization directly affect workers' performance. These findings highlight the need for an integrated occupational health and safety management approach to sustainably improve artisanal mining conditions in Mali.

3-2-5. Relationships between the studied variables

The analysis of relationships among the studied variables was conducted to identify occupational safety, occupational health, and psychosocial risk factors significantly influencing workers' performance at the Touréla artisanal mining site. Statistical analyses examined associations between qualitative variables using the Chi-square test, relationships between quantitative variables using the Pearson correlation coefficient (r), and predictive factors of performance through multiple linear regression analysis. The results show a statistically significant association between the availability and regular use of personal protective equipment (PPE) and the reduction of occupational accident frequency. Workers who systematically use PPE demonstrate higher safety levels, fewer occupational injuries, and better continuity in their work activities. The analysis also reveals a positive relationship between participation in occupational health and safety training and professional performance. Workers who received specific training achieved better results in terms of productivity, compliance with safety procedures, and work quality compared with those without training. Regarding occupational health, a significant negative correlation was observed between the frequency of occupational diseases, musculoskeletal disorders, chronic fatigue, and performance indicators. Workers experiencing health problems reported higher absenteeism, reduced productivity, and decreased physical capacity to perform demanding mining tasks. The study also demonstrates that psychosocial risks, particularly occupational stress, excessive workload, and income insecurity, are negatively associated with workers' performance. Increased stress levels are accompanied by reduced concentration, increased handling errors, and decreased daily productivity. The multiple regression model indicates that safety training, PPE use, general health status, and occupational stress level are the main factors explaining variations in workers' performance. Among these variables, regular PPE use and participation in safety training have the strongest positive effects, whereas occupational accidents, work-related diseases, and stress show the most significant negative effects. Overall, the findings demonstrate that workers' performance in Touréla artisanal mining operations depends on a set of interconnected factors. Sustainable improvement requires an integrated approach combining stronger safety measures, prevention of occupational diseases, reduction of psychosocial risks, and improvement of overall working conditions.

Répartition des 200 travailleurs enquêtés selon les résultats de l'étude



Total des travailleurs enquêtés : 200

Synthèse des résultats

Sur un total de 200 travailleurs enquêtés, 58 % sont de sexe masculin et 42 % féminin. La majorité des travailleurs a entre 36 et 50 ans (43 %). Seulement 66 % utilisent régulièrement les EPI et 34 % ont reçu une formation en sécurité. Près de la moitié des travailleurs (46 %) ont déclaré avoir déjà été victimes d'un accident de travail et plus de la moitié (54 %) ont rapporté des problèmes de santé. Enfin, 56 % des travailleurs présentent un niveau de stress professionnel élevé.

Tableau : Répartition des 200 travailleurs enquêtés selon les résultats de l'étude

Variables	Modalités	Effectif (n)	Pourcentage (%)
1. Sexe	Masculin	116	58,0
	Féminin	84	42,0
	Total	200	100,0
2. Âge	20-35 ans	74	37,0
	36-50 ans	86	43,0
	> 50 ans	40	20,0
	Total	200	100,0
3. Utilisation régulière des EPI	Oui	132	66,0
	Non	68	34,0
	Total	200	100,0
4. Formation en sécurité au travail	Oui	68	34,0
	Non	132	66,0
	Total	200	100,0
5. Accidents de travail déclarés	Oui	92	46,0
	Non	108	54,0
	Total	200	100,0
6. Problèmes de santé déclarés	Oui	108	54,0
	Non	92	46,0
	Total	200	100,0
7. Niveau de stress professionnel	Élevé	112	56,0
	Faible/Moyen	88	44,0
	Total	200	100,0
TOTAL GÉNÉRAL		200	100,0

4. Discussion

4-1. Discussion of the main findings

The present study aimed to analyze the occupational safety, occupational health, and psychosocial risk factors influencing workers' performance in artisanal mining operations at Touréla, Mali. The findings show that workers operate in an environment characterized by high exposure to occupational hazards, insufficient preventive measures, and limited occupational health and safety coverage. These conditions contribute to increased occupational accidents, work-related diseases, and psychosocial constraints that may negatively affect workers' performance. These observations are consistent with the conclusions of several studies conducted in artisanal and small-scale mining operations in sub-Saharan Africa [17 - 30]. The analysis of occupational safety factors highlights the limited availability and irregular use of personal protective equipment (PPE) among workers. This situation increases exposure to occupational accidents, including falls, injuries caused by work tools, inhalation of mineral dust, and contact with chemical substances used during ore processing. These findings confirm previous studies [26 - 31], which identified the lack of protective equipment and insufficient safety training as major factors contributing to occupational accidents in artisanal mining operations. The results related to occupational health indicate that musculoskeletal disorders, respiratory diseases, chronic fatigue, and occupational injuries are among the most common health problems affecting workers. These conditions are directly associated with intense physical effort, repetitive manual handling, awkward working postures, prolonged exposure to mineral dust, and, in some cases, mercury exposure during gold processing activities. These findings are consistent with previous studies conducted in Mali, Ghana, and Tanzania on the health impacts of artisanal mining activities [7, 8]. Regarding psychosocial risks, the results demonstrate that work overload, economic insecurity, long working hours, and occupational stress significantly affect workers' well-being. These factors contribute to reduced concentration, increased mental fatigue, and a higher likelihood of operational errors that may result in occupational accidents. These findings are consistent with the recommendations of the International Labour Organization (ILO), which recognizes psychosocial risks as major determinants of occupational health, safety, and work performance [8 - 24]. Finally, statistical analyses indicate that workers' performance is strongly influenced by the quality of safety conditions, health status, and psychosocial factors. Workers benefiting from better protection measures, safety training, and improved working conditions demonstrate higher productivity and lower accident rates. Conversely, workers exposed to higher levels of occupational risks experience a significant decline in productivity. These results confirm that the simultaneous improvement of occupational safety, occupational health, and work organization represents an essential strategy for enhancing performance and promoting sustainable development in artisanal mining operations. An integrated occupational risk management approach, combining prevention measures, worker training, health protection, and psychosocial risk reduction, is therefore necessary to improve working conditions at the Touréla mining site and within artisanal mining activities throughout Mali.

4-2. Practical implications for improving safety and performance in artisanal mining operations

The findings of this study highlight the need to strengthen occupational accident and occupational disease prevention policies in artisanal mining operations in Mali. A first priority is to improve the availability and effective use of personal protective equipment (PPE) adapted to the various mining activities. This measure would significantly reduce occupational accidents and exposure to hazardous agents. Strengthening occupational health and safety training programs also represents a key preventive action. Regular awareness sessions on occupational hazards, safe working practices, and emergency procedures would contribute to developing a genuine safety culture within artisanal mining sites. Furthermore, improving workers' access to occupational health services is essential through periodic medical examinations, monitoring of occupational diseases, availability of first-aid facilities, and implementation of screening campaigns for diseases

associated with mining activities. The results also emphasize the importance of integrating psychosocial risks into national occupational health and safety programs. Improving work organization, reducing excessive workloads, strengthening communication between workers and site managers, and promoting a more supportive working environment would contribute to better mental health, increased motivation, and improved workers' performance. Finally, public authorities, local governments, technical services, and professional organizations should strengthen their inspection, awareness, and technical support activities to promote safer, more productive, and environmentally sustainable artisanal mining practices in accordance with sustainable development principles.

4-3. Study limitations

Despite the relevance of the findings obtained, this study has several limitations that should be considered when interpreting the results. First, the research was conducted at only one artisanal mining site (Touréla). Therefore, the findings cannot be generalized to all artisanal mining sites in Mali, where operating conditions, work organization, and levels of occupational risk exposure may vary considerably. Second, the collected data were largely based on workers' self-reported information obtained through questionnaires and interviews. This data collection approach may introduce recall bias, reporting errors, or social desirability bias, as some participants may have underestimated or overestimated information related to occupational accidents, diseases, or safety practices. Third, the observed associations represent statistical relationships at a specific point in time and do not allow assessment of changes or causal relationships over time. A longitudinal research design would provide a better understanding of the temporal evolution of occupational risks and their effects on workers' health and performance. Finally, some variables potentially influencing workers' performance were not included in the analyses, such as socio-economic factors, climatic conditions, geotechnical characteristics of mining sites, and environmental exposure levels to contaminants. Future multicenter longitudinal studies incorporating environmental measurements, biomedical assessments, and broader socio-economic indicators would provide a deeper understanding of the mechanisms linking working conditions, occupational health, psychosocial risks, and performance in artisanal mining operations in Mali.

5. Conclusion

This study analyzed the occupational safety, occupational health, and psychosocial risk factors influencing workers' performance in artisanal mining operations at Touréla, Mali. The results show that workers are exposed to numerous occupational hazards, including musculoskeletal disorders, respiratory diseases, exposure to mineral dust and chemical substances, as well as significant psychosocial constraints related to demanding tasks and precarious working conditions. Statistical analysis demonstrates that inadequate preventive measures, limited use of personal protective equipment (PPE), insufficient occupational health and safety training, and high levels of occupational stress negatively affect workers' performance. Conversely, improving safety conditions, strengthening prevention strategies, promoting occupational health, and enhancing work organization significantly contribute to increasing productivity while reducing occupational accidents and work-related diseases. This study highlights the need to adopt an integrated occupational health, safety, and psychosocial risk management approach within artisanal mining operations. It also provides a scientific basis for guiding public policies, prevention programs, and strategies aimed at formalizing and improving the sustainability of the artisanal mining sector in Mali. Future research should be conducted across multiple mining sites, incorporating longitudinal monitoring, environmental assessments, and biomedical indicators to better understand the interactions between occupational exposures, workers' health, psychosocial factors, and sustainable performance in artisanal mining operations in Mali.

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