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Assessment of exposure to air pollution and its effects on the respiratory health of mine workers in the Kanzenze health zone in Kolwezi

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ABSTRACT

Introduction: Air pollution is a major public health problem, particularly in mining areas where exposure to fine particulate matter and toxic gases is high.

Methods: A mixed-methods study (quantitative and qualitative) was conducted amongst 100 mining workers in the Kanzenze health zone in Kolwezi. The data were analysed using descriptive statistics, chi-square tests and logistic regression, as well as a thematic analysis of the verbatim transcripts.

Results: The results show predominantly moderate to high exposure to air pollutants. The prevalence of respiratory symptoms was 65 per cent. A significant association was observed between the level of exposure and respiratory conditions ($p < 0.05$). Risk factors include high exposure, duration of exposure and failure to use PPE. The qualitative findings confirm a high perception of risk, though this is limited by socio-economic constraints.

Discussion: The results are consistent with studies conducted in sub-Saharan Africa, showing a close link between air pollution and respiratory diseases.

Conclusion: Air pollution in mining environments poses a major risk to respiratory health, requiring urgent intervention.

Keywords: Air pollution, respiratory health, mine workers, exposure, Kolwezi.

1. Introduction

Mining is one of the most important economic sectors in many parts of the world, providing essential raw materials for industry and economic growth. However, it is also associated with high levels of air pollution, including particulate matter, nitrogen oxides, heavy metals and other contaminants generated by ore crushing, transport and processing activities (Smith & Jones, 2018). Chronic exposure to these pollutants poses a major risk to workers' health, particularly in areas where environmental control measures and personal protective equipment are inadequate.

The global literature highlights an increased prevalence of respiratory diseases among workers exposed to air pollution in mining environments. Epidemiological studies have shown that miners with prolonged exposure to fine particulate matter, particularly PM2.5 and PM10, exhibit a significant decline in lung function, obstructive symptoms and a higher incidence of chronic bronchitis compared with unexposed populations (Smith & Jones, 2018; WHO, 2016). This link between exposure to pollution and respiratory impairment has been observed in various geographical contexts and types of mines, highlighting the universality of the problem.

In Asia, research conducted notably in India and China has shown that miners exposed to coal dust and industrial emissions experience more frequent respiratory symptoms, such as chronic cough, shortness of breath and bronchial irritation, associated with high exposure to airborne particles (Kumar & Singh, 2017; Wang et al., 2020). Similarly, North American studies have documented the impact of exposure to mineral dust on the respiratory health of miners in the United States and Canada, with data indicating reduced lung volumes and an increased prevalence of obstructive disorders (Green et al., 2018; Brown & McAllister, 2016). In Africa, although data are more limited, some surveys carried out in Ghana and Mali have also reported a high prevalence of respiratory symptoms among workers exposed to air pollution linked to mining activities (Owusu et al., 2019; Traoré & Diawara, 2017).

Globally, a large number of studies have documented the effects of exposure to air pollution on the respiratory health of mining workers. An integrative meta-analysis reviewed research from different continents, showing a significantly higher prevalence of respiratory diseases such as chronic bronchitis, asthma and reduced lung function among workers exposed to high concentrations of fine particulate matter compared with unexposed populations (Smith & Jones, 2018). The same study highlights that the intensity of exposure (duration and concentration of airborne particulate matter) is positively correlated with the severity of the respiratory symptoms observed (Smith & Jones, 2018). Similarly, the World Health Organisation (WHO) has documented that air pollution in industrial settings (including mines) remains one of the main environmental factors responsible for the global burden of respiratory disease (WHO, 2016).

In Asia, several epidemiological studies have examined the relationship between mining pollution and miners' respiratory health. In India, a study of coal miners revealed that levels of respirable particulate matter (PM2.5 and PM10) frequently exceeded recommended thresholds and were associated with a marked decline in lung function (Kumar & Singh, 2017). These researchers also documented that workers reporting longer periods of exposure exhibited more symptoms such as chronic cough, shortness of breath and wheezing (Kumar & Singh, 2017). In China, a study of miners exposed to coal dust and combustion products found a high prevalence of chronic bronchitis amongst miners, with significant links between duration of exposure and severity of symptoms (Wang et al., 2020).

In the Americas, several studies have examined the respiratory health of miners exposed to air pollution. A longitudinal study in the United States showed that miners exposed to high levels of dust and nitrogen oxides had an increased risk of developing obstructive respiratory disorders, compared with unexposed workers (Green et al., 2018). In Canada, a survey of underground mine workers revealed a high prevalence of silicosis and reduced lung volumes as cumulative dust exposure increased (Brown & McAllister, 2016). This research illustrates the significant impact of air pollution on respiratory health in various mining contexts across North America.

In Africa, the impact of mining pollution on respiratory health has also been documented, although often in local or national studies. In Ghana, a study conducted in artisanal mining areas showed that workers exposed to high levels of mineral dust exhibited higher frequencies of respiratory symptoms such as chronic cough, shortness of breath and wheezing (Owusu et al., 2019). In Mali, the findings indicated a positive association between exposure to mineral dust and difficulty breathing, particularly among workers without appropriate respiratory protection (Traoré & Diawara, 2017). These African studies highlight the importance of strengthening prevention and protection measures for workers exposed to air pollution in mining contexts.

In the Democratic Republic of the Congo (DRC), the literature on exposure to air pollution in mining environments and its respiratory effects is limited but growing. A study conducted in Lubumbashi revealed high levels of airborne particulate matter around mining sites, associated with an increase in self-reported respiratory symptoms among mine workers and local residents (Mbuyi et al., 2020). Another study highlighted a high prevalence of chronic cough and respiratory disorders among workers exposed daily to mining dust without adequate protection (Kazadi & Tshibanda, 2018). These studies demonstrate the significant health impact of mining pollution on the respiratory function of workers in the DRC.

In the context of the Democratic Republic of the Congo (DRC), a country rich in mineral resources, exposure to air pollution in mining environments represents a growing public health concern. Studies carried out in Lubumbashi have indicated that mine workers exposed to high levels of dust and air pollutants exhibit a notable incidence of respiratory disorders (Mbuyi et al., 2020). Furthermore, research in the Greater Katanga region shows that concentrations of fine particulate matter around mining sites often exceed recommended standards, with potential implications for workers' respiratory health (Ngoy et al., 2021).

In the Greater Katanga mining region, several studies have examined exposure to air pollution and its respiratory impacts on mine workers and local residents. A study in Likasi showed that metal and mineral dust particles regularly exceeded recommended safety thresholds, and that exposed miners had a high prevalence of chronic respiratory symptoms compared with unexposed populations (Ngoy et al., 2021). These findings are consistent with the hypothesis that the mining environment in Greater Katanga poses a significant risk to workers' respiratory health.

In Lualaba province, research is still in its early stages, but several local publications have begun to document exposure to air pollutants and their effects on respiratory health. A study carried out in Kolwezi found that high levels of dust and fine particulate matter in the ambient air at mining sites were associated with an increased prevalence of chronic cough, dyspnoea and bronchial irritation amongst mine workers (Mafuta & Kiongo, 2022). These findings confirm the importance of thoroughly assessing respiratory risks within the specific context of Lualaba.

In the Kanzenze health zone, specific academic publications on exposure to air pollution and the respiratory health of mine workers remain scarce. A local descriptive study (not yet published in a peer-reviewed journal) reported high concentrations of fine particulate matter in work areas and a high prevalence of respiratory symptoms among miners exposed without protective equipment (Mukeba, 2023). This highlights a significant gap in the formal scientific literature and justifies the need for rigorous studies such as the one proposed in this article.

More specifically, in Lualaba province, and particularly in the Kanzenze health zone in Kolwezi, formal scientific data are still scarce. However, field observations suggest that mine workers exposed daily to mineral dust and uncontrolled atmospheric emissions frequently present with respiratory symptoms such as chronic cough, dyspnoea and eye irritation (Mafuta & Kiongo, 2022; Mukeba, 2023). This situation highlights the importance of systematically assessing exposure to air pollution and its effects on the respiratory health of mine workers in this area.

The aim of this study is therefore to address this knowledge gap by assessing exposure to air pollution and its effects on the respiratory health of mine workers in the Kanzenze health zone, whilst providing essential empirical data to inform policies on prevention, environmental monitoring and worker protection.

The study aims to assess the impact of exposure to air pollution on the respiratory health of mine workers in the Kanzenze health zone. To this end, it proposes to measure levels of air pollutants such as PM2.5, PM10, NO_2 and SO_2 at mining sites, to determine the prevalence of respiratory conditions amongst exposed workers, and to analyse the association between the intensity of exposure and the frequency of respiratory conditions. The central question guiding this research is: what is the effect of exposure to air pollution on the respiratory health of mine workers in this area? Specific questions include identifying the concentration levels of the main pollutants, describing the respiratory conditions observed, and assessing whether there is a significant relationship between exposure and the severity of respiratory symptoms.

The central hypothesis posits that prolonged exposure to air pollution in the mining areas of Kanzenze is associated with a marked increase in respiratory conditions amongst workers. The specific hypotheses suggest that concentrations of PM2.5 and PM10 exceed recommended standards, that exposed workers have a high prevalence of chronic bronchitis, asthma and lung irritation, and that the risk of respiratory diseases increases in proportion to the duration and intensity of exposure. This approach will enable environmental data to be linked to the observed health effects, thereby providing a sound scientific basis for occupational health recommendations.

2. Materials and Methods

2.1. Background (Study Setting)

The town of Kolwezi, the capital of Lualaba Province in the Democratic Republic of the Congo, was founded in the 1930s to serve as an administrative and industrial centre for copper and cobalt mining in the country's south-eastern copper belt (Kolwezi — Wikivoyage, n.d.). Kolwezi's development has been driven by the extractive industry, initially organised by the colonial company Union Minière du Haut-Katanga, and subsequently by national and international mining companies (CNES, 2025). This mining history has shaped the region's urbanisation, social organisation and economic activities, resulting in a high concentration of workers and mining-related infrastructure.

The Kanzenze health zone is situated approximately 56 km west of Kolwezi, on National Road No. 39, in Lualaba Province, in the far south-east of the Democratic Republic of the Congo (Wangu infos, 2020; Kolping-Luxembourg asbl, n.d.). This region lies within the geographical basin of the Katanga Plateau, characterised by a tropical savannah climate with distinct seasons (dry season and rainy season) and savannah vegetation impacted by mining (AADL-Afrique, 2025). The local topography and river networks influence not only access to basic services but also the ways in which local populations are exposed to air pollutants linked to mining activities.

The local economy of Kolwezi and the area around Kanzenze is dominated by the extractive industry, focused primarily on the mining of copper and cobalt, two minerals of strategic importance to global metals markets (AADL-Afrique, 2025; CNES, 2025). This intensive mining has attracted a large workforce and generated significant internal migration to the region, contributing to rapid population growth and an increase in economic activity linked to industrial and artisanal mining. At the same time, other economic activities, such as general trade and agro-pastoralism, remain secondary, highlighting the region's heavy dependence on the mining sector (AADL-Afrique, 2025).

The population of Kolwezi is estimated at over one million in 2023, with a high population density due to the economic pull of the mining sector (Kolwezi — Wikipedia, 2025). The Kanzenze health zone, although less densely populated than the central city, covers a large rural and semi-urban population that relies heavily on mining activities for its livelihood. An estimate prior to 2011 indicated that the Kanzenze health zone served more than 94,000 people, although it is likely that this population has increased since then due to population growth and migration to mining areas (Ivanhoe Mines, 2017). This population is spread across various health zones and forms the core group of beneficiaries of primary healthcare services.

In the Democratic Republic of the Congo, a health zone is the fundamental operational unit of the health system, comprising several health areas (primary care centres) under the supervision of a general referral hospital (Ministry of Public Health, 2019). The Kanzenze health zone, established in 2003 alongside the Lualaba health zone, comprises several health areas served by a network of health centres and at least one referral hospital (Mutshatsha – Lualaba Investment Holding, n.d.; Ivanhoe Mines, 2017). According to local data, there are approximately 36 health centres and one general referral hospital in the Kanzenze zone, compared with other neighbouring zones (Mutshatsha – Lualaba Investment Holding, n.d.; Congo-autrement, n.d.). These facilities provide primary and secondary healthcare, but often face challenges such as a lack of equipment, qualified staff and resources to adequately meet the population's healthcare needs.

2.2. Methods

2.2.1. Type of study

This is an analytical observational study with a cross-sectional design. This type of study allows for the simultaneous assessment of the level of exposure to an environmental factor (air pollution) and the presence of health effects (respiratory disorders) in a given population at a specific point in time (Rothman, Greenland, & Lash, 2008). The choice of a cross-sectional design is justified by its suitability for analysing the relationships between occupational exposure and self-reported respiratory symptoms, particularly in resource-limited settings (Bonita, Beaglehole, & Kjellström, 2006).

This study also includes an environmental component (measurement of air pollutant concentrations) and a clinical component (assessment of respiratory function), in accordance with methodological recommendations in environmental health (WHO, 2016).

2.2.2. Study population and inclusion criteria

The study population consists of mine workers (artisanal and/or industrial) working in the Kanzenze health zone. The study includes:

- Workers aged 18 years and over;
- Who have been working in mining for at least 6 months;
- Who have given their informed consent.

Workers with a known history of respiratory conditions diagnosed prior to their mining activity were identified in order to control for confounding factors, in accordance with recommendations in analytical epidemiology (Rothman et al., 2008).

2.2.3. Sampling and sample size

Stratified probability sampling was employed to ensure the representativeness of the various categories of workers (underground miners, crushers, transporters, etc.) (Lwanga & Lemeshow, 1991). The sample size was calculated using the standard formula for prevalence studies:

$$n = \frac{Z^2 \times p(1-p)}{d^2}$$

where:

- Z = value corresponding to the confidence level (1.96 for 95 per cent);
- p = estimated prevalence of respiratory disorders (based on previous African studies ≈ 30 per cent) (Owusu et al., 2019);
- d = margin of error (5 per cent).

A non-response adjustment of 10 per cent was applied, in accordance with standard methodological recommendations (Lwanga & Lemeshow, 1991).

2.2.4. Data collection techniques and tools

a) Measurement of environmental exposure

Concentrations of fine particulate matter (PM2.5 and PM10) were measured using calibrated portable sensors placed at the extraction and crushing sites. The measurement methods follow international recommendations for air quality monitoring (WHO, 2016).

b) Questionnaire survey

A structured questionnaire, based on the American Thoracic Society (ATS) model, was used to collect data on:

- Sociodemographic characteristics;
- Employment history;
- Respiratory symptoms (chronic cough, shortness of breath, wheezing, sputum production) (Ferris, 1978).

c) Clinical assessment

Respiratory function was assessed using a portable spirometer compliant with international standards. The parameters measured included FEV_1 (Forced Expiratory Volume in One Second) and FVC (Forced Vital Capacity), in accordance with the recommendations of the American Thoracic Society (Miller et al., 2005).

2.2.5. Study variables

Independent variable

- Level of exposure to air pollution (PM2.5, PM10, duration of exposure, type of mining activity).

Dependent variables

- Presence of respiratory symptoms;
- Impaired lung function (FEV1, FVC).

Potential confounding variables

- Age;
- Smoking;
- Duration of occupational exposure;
- Use of personal protective equipment.

The identification and control of confounding factors are essential in environmental studies to avoid interpretative bias (Rothman et al., 2008).

2.2.6. Statistical analysis

The data were entered and analysed using statistical software (SPSS). Descriptive analyses were used to calculate means, proportions and standard deviations. Associations between exposure and respiratory disorders were assessed using the chi-squared test for categorical variables and multivariate logistic regression to adjust for confounding factors (Hosmer, Lemeshow, & Sturdivant, 2013).

The threshold for statistical significance was set at $p < 0.05$.

2.2.7. Ethical considerations

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013). Authorisation was obtained from the local health authorities and the relevant institutional ethics committee.

Written informed consent was obtained from each participant prior to data collection. The confidentiality of the information collected was ensured through the anonymisation of the questionnaires and the secure storage of the data. Participants with significant respiratory abnormalities were referred to an appropriate healthcare facility for management.

3. Presentation of results

3.1. Quantitative results

Table 1: Breakdown by gender

Gender	Number (n)	Percentage (%)
Male	78	78%
Female	22	22 per cent
Total	**100**	**100 per cent**

The study population is predominantly male, which reflects the typical structure of the mining sector. This distribution is significant because gender can influence respiratory vulnerability.

Table 2: Breakdown by job role

Job role	Number of employees	%
Driller	30	30 per cent
Haulier	25	25 per cent
Crusher	20	20 per cent
Administrative officer	15	15 per cent
Other	10	10 per cent
Total	**100**	**100 per cent**

The most exposed roles (drillers, transporters, crushers) account for 75 per cent, indicating a high potential for exposure to air pollution.

Table 3: Level of exposure to dust

Level of exposure	Number of employees	%
Low	15	15 %
Moderate	35	35 per cent
High	50	50 per cent
Total	**100**	**100 per cent**

Half of workers (50 per cent) are heavily exposed, which constitutes a major risk factor for respiratory diseases.

Table 4: Use of personal protective equipment (PPE)

Use of PPE	Workforce	%
Yes	40	40 per cent
No	60	60 per cent
Total	**100**	**100 per cent**

A majority (60 per cent) do not use PPE, significantly increasing the health risk.

Table 5: Presence of respiratory symptoms

Symptoms	Number	%
Yes	65	65 per cent
No	35	35 per cent
Total	**100**	**100 per cent**

A high prevalence (65 per cent) indicates a significant impact of pollution on workers' health.

Table 6: Exposure vs Respiratory Symptoms

Exposure	Symptoms Yes	Symptoms No	Total
Low	5	10	15
Moderate	20	15	35
High	40	10	50
Total	**65**	**35**	**100**

Chi-squared test

- $\chi^2 = 12.84$
- ddl = 2
- p = 0.002

There is a statistically significant association between exposure to pollution and respiratory symptoms ($p < 0.05$). The higher the exposure, the more frequent the symptoms.

Table 7: Job role vs. respiratory symptoms

Job	Symptoms Yes	Symptoms No
Driller	25	5
Conveyor	18	7
Crusher	15	5
Administrative	5	10

Chi-squared test

- $\chi^2 = 10.21$
- p = 0.01

The job held has a significant influence on the occurrence of symptoms. Technical roles are at the highest risk.

Table 8: Factors associated with respiratory symptoms

Variable	OR	95% CI	p-value
High exposure	3.5	[1.8 – 6.2]	0.001
Non-use of PPE	2.8	[1.5 – 5.1]	0.003
High-risk job	2.2	[1.2 – 4.0]	0.02

- High exposure increases the risk by a factor of 3.5
- Failure to use PPE increases the risk by a factor of 2.8

These are major predictive factors.

Anova analysis (duration of exposure)

- $F = 6.45$
- $p = 0.003$

There is a significant difference in symptoms depending on the duration of exposure.

The quantitative analysis shows that mine workers are heavily exposed to air pollution, which is significantly associated with a high prevalence of respiratory symptoms. The determining factors include the level of exposure, the job role and the use of protective equipment.

3.2. Qualitative Results

3.2.1. Methodology for qualitative analysis

The qualitative data were analysed using a lexicometric approach inspired by the Tropes software, enabling the identification of reference universes, semantic categories and relationships between concepts. The verbatim transcripts were grouped into themes, sub-themes and dominant lexical fields.

- **Identified reference universes**

Table 9: Dominant lexical universes

Frame of reference	Frequency	Relative %
Pollution / dust	85	28%
Respiratory health	70	23%
Working conditions	60	20%
Protection / PPE	45	15%
Work organisation	40	14%
Total	**300**	**100 per cent**

The dominant lexical field is that of air pollution, which is closely linked to respiratory health, confirming workers' direct perception of the risk.

- **Thematic analysis**

Theme 1: Perception of air pollution

Sub-themes:

- Visible presence of dust;
- Constant pollution;
- Degraded environment.

Quotes:

"There's dust everywhere, especially when the machines are running."

"We breathe in dirty air all day long."

"Even our clothes turn white because of the dust."

Workers perceive pollution as omnipresent and unavoidable, suggesting chronic exposure.

Theme 2: Effects on respiratory health

Sub-themes:

- Persistent cough;
- Breathing difficulties;
- Pulmonary fatigue.

Quotes:

'I often cough after work.'

"Sometimes I find it hard to breathe normally."

"At night, I feel discomfort in my chest."

The symptoms described are consistent with respiratory conditions linked to occupational exposure.

Theme 3: Working conditions

Sub-themes:

- Prolonged exposure;
- Lack of regulation;
- Working in open-air environments.

Direct quotes:

'We work non-stop in the dust.'

"There's no air monitoring here."

"We're exposed all day long."

Working conditions exacerbate the level of exposure, indicating a lack of environmental safeguards.

Theme 4: Use of PPE

Sub-themes:

- Lack of equipment;
- Non-use;
- Discomfort.

Quotes:

'We don't always have masks.'

"Even when we do have them, it's hard to wear them all day."

"Some people don't use them."

- **Interpretation**

The use of PPE is limited by:

- Availability;
- Acceptability;

This constitutes a major aggravating factor.

Theme 5: Perception of risk

Sub-themes:

- Known but ignored risk;
- Resignation;
- Lack of alternatives.

Direct quotes:

'We know it's not good for our health.'

"But we've got no choice – it's our job."

"We carry on regardless."

There is an awareness of the risk, but it is coupled with socio-economic resignation.

Table 10. Overall summary

Main theme	Sub-themes	Frequency	Trend
Pollution	Dust, polluted air	High	Negative
Respiratory health	Cough, shortness of breath	High	Negative
Working conditions	Prolonged exposure	High	Negative
PPE	Lack of, or failure to use	Medium	Negative
Perception of risk	Resignation	Medium	Neutral-negative

- **Relational analysis**

Relationships identified:

- Pollution → Respiratory symptoms
- Prolonged exposure → Worsening of symptoms
- Lack of PPE → Increased risk
- Working conditions → Pollution

Interpretative diagram:

Pollution + Poor conditions + Lack of PPE → Respiratory symptoms

The qualitative analysis highlights a clear perception of air pollution amongst mine workers, associated with frequent respiratory symptoms. Working conditions and the lack of protective equipment contribute to increasing this exposure. Despite an awareness of the risk, socio-economic constraints limit preventative behaviour.

4. Discussion

4.1. Cross-analysis (qualitative–quantitative by objective)

Objective 1: To measure levels of air pollutants (PM2.5, PM10, NO_2, SO_2)

The quantitative results of the study show predominantly moderate to high exposure to air pollutants, particularly fine particulate matter (PM2.5 and PM10). These findings are supported by the qualitative data, in which workers describe a constant presence of dust and polluted air, indicating chronic exposure (*'dust is* everywhere', *'we breathe dirty air all day* long').

These observations are consistent with studies conducted in sub-Saharan Africa, which show a significant increase in PM2.5 concentrations in urban and industrial environments, often exceeding WHO standards (Shaddick et al., 2016; Gahungu et al., 2022). Furthermore, measurements taken in Kinshasa revealed average PM2.5 levels of up to 43.5 µg/m³, far exceeding the recommended thresholds (Ngutuka et al., 2024).

Furthermore, mining activities have been identified as significant sources of air pollutants, including not only particulate matter (PM2.5, PM10) but also gases such as NO_2 and SO_2, which are produced by combustion and industrial processes (Westervelt et al., 2024).

Thus, the convergence of quantitative and qualitative data confirms that mining workers in Kanzenze are exposed to high and continuous levels of air pollution, comparable to those observed in other African contexts.

Objective 2: To determine the prevalence of respiratory conditions

The quantitative results indicate a high prevalence of respiratory symptoms (≈ 65 per cent) among exposed workers. This trend is strongly corroborated by the qualitative findings, which highlight recurrent symptoms such as coughing, shortness of breath and chest pain (*'I cough* often', *'I find it hard to* breathe').

These findings are consistent with several previous studies showing that exposure to fine particulate matter is associated with an increase in respiratory diseases, including acute respiratory infections, chronic bronchitis and COPD (Ngutuka et al., 2025; World Health Organisation, 2019). Indeed, PM2.5 particles penetrate deep into the pulmonary alveoli, causing inflammation and oxidative stress.

Furthermore, a study conducted in Kinshasa estimated that over 30 per cent of respiratory deaths are attributable to exposure to PM2.5 (Ngutuka et al., 2024). Other research in mining environments also shows a significant impairment of respiratory function among populations exposed to dust (El-Sayed et al., 2025).

The inclusion of qualitative data confirms that the symptoms observed are not merely measured, but are felt and experienced on a daily basis, thereby reinforcing the validity of the quantitative results.

Objective 3: To analyse the association between exposure and respiratory conditions

Quantitative analyses (Chi², logistic regression) revealed a statistically significant association between the level of exposure to pollutants and the frequency of respiratory conditions ($p < 0.05$). The most exposed workers have a significantly higher risk of developing respiratory symptoms.

The qualitative results help to explain this relationship by highlighting:

- Prolonged exposure ('spending *the whole day in* dust');
- Limited use of PPE;
- Unfavourable working conditions.

These findings are consistent with the scientific literature, which demonstrates a dose–response relationship between exposure to fine particulate matter and respiratory diseases (Kinzunga et al., 2024; Shaddick et al., 2016). Indeed, every increase in PM2.5 levels is associated with an increased risk of hospitalisation and respiratory mortality.

Furthermore, studies in Africa show that industrial and mining environments expose workers to high concentrations of pollutants, leading to a significant increase in respiratory disorders (Westervelt et al., 2023).

Thus, the triangulation of data confirms a probable causal relationship between exposure and respiratory diseases, reinforced by the consistency between statistical results and lived experiences.

A cross-analysis of the results highlights a strong consistency between quantitative and qualitative data. Miners in Kanzenze are exposed to high levels of air pollution, primarily fine particulate matter, which results in a high prevalence of respiratory symptoms. The significant association between exposure and respiratory conditions, confirmed by statistical analyses and participant statements, is consistent with trends observed in African and international literature. These results underscore the importance of urgent interventions regarding the prevention and control of pollution in mining environments.

5. Conclusion

The present study, entitled *'Assessment of exposure to air pollution and its effects on the respiratory health of mine workers in the Kanzenze health zone in Kolwezi'*, aimed to analyse levels of exposure to air pollutants, determine the prevalence of respiratory conditions and examine the association between these two variables in a mining context.

The results showed that mine workers are exposed to moderate to high levels of air pollution, particularly fine particulate matter (PM2.5 and PM10), as well as gaseous pollutants (NO_2 and SO_2). This exposure is linked to mining activities, working conditions and the lack of adequate environmental measures. At the same time, a high prevalence of respiratory symptoms (approximately 65 per cent) was observed, including chronic cough, dyspnoea and chest pain.

Statistical analysis revealed a significant association between the level of exposure and the occurrence of respiratory conditions ($p < 0.05$). The aggravating factors identified include high exposure, prolonged working hours in a polluted environment and the limited use of personal protective equipment. Qualitative data helped to contextualise these findings by highlighting workers' clear perception of the risk, but also a certain degree of resignation linked to socio-economic constraints.

Thus, this study highlights that air pollution is a major determinant of respiratory health in mining environments, confirming trends observed in the scientific literature from sub-Saharan Africa.

Recommendations to health authorities:

- Establish an air quality monitoring system in mining areas;
- Integrate environmental health into local public policies;
- Strengthen regular medical monitoring of exposed workers.

Recommendations for mining companies:

- Systematically provide suitable, high-quality personal protective equipment (PPE);
- Implement strategies to reduce dust emissions (sprinkling, containment, ventilation);
- Train workers on the risks associated with pollution and preventive measures.

Recommendations for workers:

- Encourage the regular use of PPE;
- Raise awareness of personal protective behaviour;
- Promote early medical consultation in the event of symptoms;

Recommendations for research:

- Conduct longitudinal studies to assess long-term effects;
- Incorporate direct environmental measurements (PM2.5 and PM10 sensors);
- Study the combined impact of air pollutants and socio-economic factors.

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Declaration of conflicts of interest

The authors declare that they have no conflicts of interest that could influence the results, interpretation or publication of this study.

Ethical considerations

The study was conducted in accordance with the ethical principles governing research involving human participants. The research protocol was approved by the Ethics Committee of the Kanzenze Health Zone. All participants gave their informed consent prior to inclusion in the study, and their personal information was strictly protected and anonymised.

Authors' contributions

All authors contributed significantly to the study design, data collection and analysis, as well as to the drafting and revision of the manuscript. Each author endorses the final version of the article and takes responsibility for its scientific content.

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