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Holistic Evaluation of Mining Impacts: Exploring Environmental Stressors and Health Outcomes in Affected Communities

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Abstract
Mining activities, while vital for economic development, pose significant environmental and health challenges for communities living nearby. This study investigates the relationships between proximity to mining sites and various environmental and health outcomes, including noise-induced stress, respiratory disorders, and waterborne diseases. Using a cross-sectional design, data were collected from mining-affected communities and analyzed through statistical methods such as Chi-Square, ANOVA, T-Test, and Correlation analysis. The results revealed no statistically significant associations across the hypotheses, suggesting the need for more integrative research to understand the complex dynamics of environmental stressors. This paper highlights critical gaps in current research, including the limited consideration of multiple environmental stressors, reliance on self-reported data, and insufficient longitudinal studies. A proposed theoretical framework emphasizes the integration of objective environmental conditions and subjective perceptions to inform targeted policies and sustainable practices. These findings underscore the importance of holistic approaches in mitigating the adverse effects of mining on vulnerable populations.
Keywords: *Mining impacts; Noise pollution; Air quality; Water contamination; Environmental health; Sustainable mining practices*

INTRODUCTION

Mining has been a cornerstone of economic development for centuries, providing essential materials for industries and infrastructure. However, the environmental and health consequences of mining activities have raised significant concerns, particularly for communities located near mining sites. These consequences manifest in various forms, including noise pollution, air and water contamination, and disruptions to local ecosystems. The impacts are particularly pronounced in low- and middle-income countries, where regulatory frameworks and enforcement mechanisms are often inadequate to mitigate the harmful effects of mining (Bebbington & Williams, 2008). This study investigates the complex interplay between mining activities, environmental conditions, and community health outcomes, with an emphasis on noise-induced stress, respiratory disorders, and waterborne diseases.

One of the most visible and immediate impacts of mining is noise pollution, which disrupts the lives of nearby residents. The continuous operation of heavy machinery, blasting, and transportation generates high levels of noise that can cause both auditory and non-auditory health effects. Prolonged exposure to noise has been linked to stress, sleep disturbances, and cardiovascular health issues (Basner et al., 2014). Stansfeld and Matheson (2003) found that noise pollution also affects mental health, contributing to anxiety and depression in affected populations. Despite the implementation of noise mitigation measures such as buffer zones and soundproofing, their perceived effectiveness varies widely among individuals based on their proximity to mining sites (Ristovska & Lekaviciute, 2013). This disparity suggests the need for a deeper understanding of how noise pollution impacts mental and physical health, particularly in communities where mining is a dominant economic activity.

In addition to noise, air pollution poses a significant health risk to communities near mining sites. Mining operations release fine particulate matter (PM10 and PM2.5), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and other pollutants, which have been shown to cause respiratory illnesses, including asthma, bronchitis, and chronic obstructive pulmonary disease (Pope et al., 2002; Dockery et al., 1993). Finkelman (2007) highlighted that airborne pollutants from mining activities are particularly dangerous due to their ability to penetrate deep into the lungs, causing long-term damage. Despite the well-documented health impacts of air pollution, there remains a gap in understanding how subjective perceptions of air quality align with measured levels of pollution. Brody et al. (2004) emphasized that cultural, psychological, and social factors often shape individual perceptions, which may not accurately reflect actual air quality conditions. Bridging this gap is essential for designing interventions that address both perceived and real risks to respiratory health.

Water contamination is another critical challenge associated with mining. The release of heavy metals such as arsenic, lead, and mercury into local water sources can result in severe health consequences, including kidney damage, developmental disorders in children, and an increased prevalence of waterborne diseases like diarrhea and dysentery (Prüss-Ustün et al., 2014; Graham et al., 2004). Acid mine drainage, a common byproduct of mining, further exacerbates water quality issues by increasing the acidity of water and facilitating the leaching of toxic metals (Bebbington & Williams, 2008). Perceptions of water quality among communities often depend on sensory cues, such as clarity and smell, which may not align with laboratory analyses of contamination levels (Graham et al., 2004). This misalignment can lead to either complacency or unnecessary alarm, complicating efforts to manage water resources and protect public health.

Despite a growing body of research on the environmental and health impacts of mining, several gaps persist. Most studies examine individual stressors, such as noise, air, or water pollution, in isolation, neglecting the cumulative effects of multiple environmental hazards (Stewart et al., 2018). Additionally, the reliance on cross-sectional data limits the ability to establish causal relationships or understand the long-term impacts of mining activities on health and well-being (Hunter et al., 2010). Many studies also depend on self-reported data, which can introduce bias and fail to capture the full extent of environmental and health risks (van Kamp et al., 2018). Addressing these gaps requires a comprehensive approach that integrates objective environmental data, subjective perceptions, and robust health assessments.

This study seeks to address these gaps by investigating the relationships between proximity to mining sites, environmental perceptions, and health outcomes across multiple domains. Specifically, it examines six hypotheses related to noise-induced stress, respiratory disorders, and waterborne diseases, employing statistical analyses such as Chi-Square, ANOVA, T-Test, and Correlation to uncover patterns and associations. By integrating both subjective perceptions and objective data, this research aims to provide a holistic understanding of the environmental and health impacts of mining. The findings will inform the development of targeted interventions and policy recommendations to mitigate the adverse effects of mining and promote sustainable practices in affected communities.

LITERATURE REVIEW

The environmental and public health impacts of mining have been a subject of considerable academic inquiry, given the global prevalence of mining activities and their profound effects on communities. The adverse consequences of mining include noise pollution, deteriorated air quality, and water contamination, all of which contribute to long-term health challenges. This literature review critically evaluates existing research on these issues, highlights significant gaps, and introduces a proposed theoretical framework to address the complexities associated with mining-induced environmental and health impacts.

Noise Pollution and Its Impacts

Noise pollution is one of the most immediate and noticeable consequences of mining activities. Studies have consistently documented that prolonged exposure to industrial noise can lead to stress, sleep disturbances, and mental health disorders (Stansfeld & Matheson, 2003). Chronic noise exposure has also been associated with cardiovascular conditions, such as hypertension and ischemic heart disease, particularly in populations living near industrial zones (Babisch, 2002). Mining operations generate persistent high-decibel sounds from blasting, drilling, and heavy machinery, which exacerbate stress levels in nearby communities. Goines and Hagler (2007) argued that noise pollution from industrial sources like mining is not only a physical stressor but also a psychological one, disrupting daily life and reducing overall well-being.

Despite extensive research on the health impacts of noise pollution, there remains a gap in understanding how community-level interventions, such as noise mitigation strategies, influence individual stress responses. Studies suggest that perceptions of the effectiveness of noise reduction measures, such as soundproofing and buffer zones, vary among individuals based on their proximity to the noise source (van Kamp et al., 2018). These discrepancies indicate a need for more context-specific studies that consider local environmental and social conditions.

Air Quality and Respiratory Health

Air pollution resulting from mining activities poses another significant public health concern. Mining processes release particulate matter (PM10 and PM2.5), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and heavy metals into the atmosphere, contributing to respiratory and cardiovascular diseases (Pope et al., 2002). For example, exposure to fine particulate matter has been strongly linked to asthma, chronic obstructive pulmonary disease (COPD), and even lung cancer in vulnerable populations (Dockery et al., 1993). In addition to physical health impacts, air pollution can also influence mental health, creating a compounding effect in communities exposed to multiple environmental hazards.

However, subjective perceptions of air quality often do not align with measured air quality indices. Brody et al. (2004) highlighted that individuals' perceptions of air pollution are shaped by social, cultural, and psychological factors, which may not necessarily reflect objective environmental conditions. This divergence between perception and reality presents a challenge for public health interventions, as addressing community concerns often requires reconciling subjective experiences with scientific evidence.

Research gaps persist in understanding the long-term health impacts of mining-related air pollution, particularly in low- and middle-income countries where regulatory frameworks and monitoring systems are often inadequate (Lelieveld et al., 2015). Additionally, there is limited research on the combined effects of air pollution with other environmental stressors, such as noise and water contamination.

Water Contamination and Waterborne Diseases

Water contamination from mining is a critical issue, especially in regions where communities depend on local water sources for drinking, agriculture, and daily use. Mining activities often lead to the release of heavy metals, such as arsenic, lead, and mercury, into nearby water bodies, as well as acid mine drainage, which can severely degrade water quality (Bebbington & Williams, 2008). These contaminants have been associated with a range of waterborne diseases, including diarrhea, cholera, and dysentery, as well as long-term health impacts such as kidney and liver damage (Prüss-Ustün et al., 2014).

Perceptions of water quality play a significant role in shaping community behaviors and attitudes toward water usage. Graham et al. (2004) noted that individuals often rely on visual and olfactory cues, such as water clarity and smell, to assess water quality, which may not align with laboratory-based measurements. This discrepancy can lead to either overestimation or underestimation of risks, complicating efforts to address waterborne diseases effectively.

Research on water contamination and its health impacts has largely focused on direct causal pathways, with limited attention to how perceptions influence health outcomes and risk mitigation behaviors.

Moreover, studies rarely account for the intersection of water contamination with other environmental stressors, such as air and soil pollution, which may exacerbate health risks.

Synthesis and Research Gaps

While significant progress has been made in understanding the environmental and health impacts of mining, several key gaps remain in the literature:

1. **Limited Integration of Environmental Stressors**: Existing studies often examine noise, air, and water pollution in isolation, without considering their combined or synergistic effects on health outcomes.

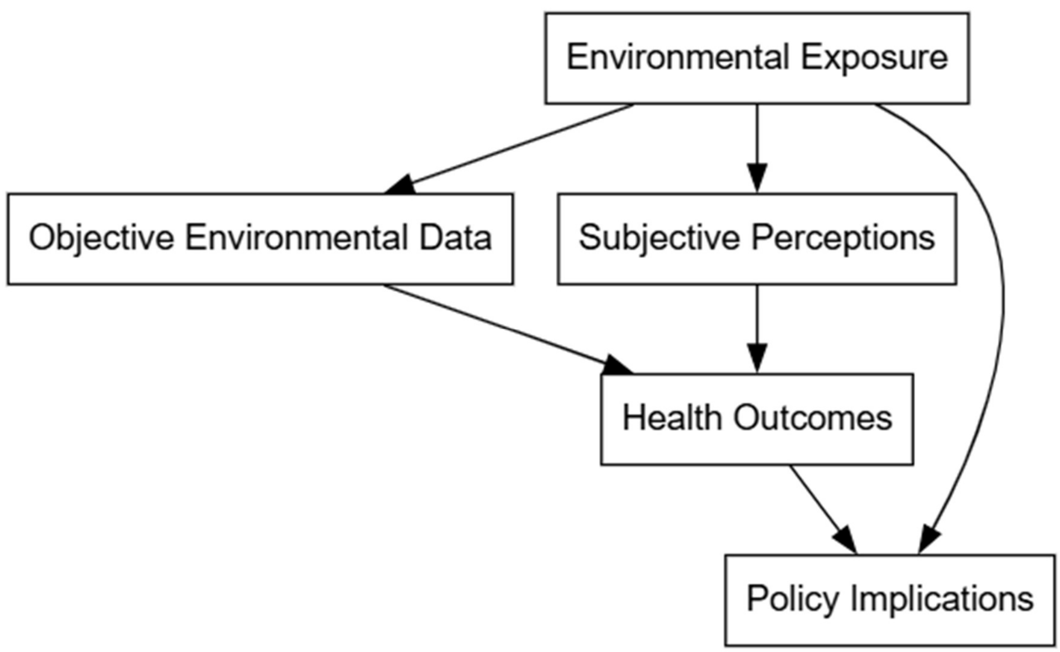
2. **Overreliance on Self-Reported Data**: Much of the current research relies on subjective self-reports of health outcomes and environmental perceptions, which may introduce bias and limit the reliability of findings.

3. **Lack of Longitudinal Studies**: Most studies are cross-sectional, providing a snapshot of health impacts but failing to capture long-term effects and causal relationships.

4. **Insufficient Focus on Perception-Behavior Links**: Few studies explore how subjective perceptions of environmental quality influence health behaviors and outcomes, particularly in resource-constrained settings.

Proposed Theoretical Framework

To address these gaps, this study proposes a theoretical framework that integrates environmental exposure, health outcomes, and community perceptions. The framework emphasizes the dynamic interplay between objective environmental data, subjective perceptions, and health outcomes, providing a holistic approach to understanding the impacts of mining activities.



This framework bridges the gap between objective scientific measurements and community experiences. By integrating subjective perceptions with empirical data, it aims to facilitate the development of targeted, evidence-based interventions. The framework also highlights the importance of policy implications, ensuring that research findings translate into actionable strategies to mitigate the environmental and health impacts of mining activities.

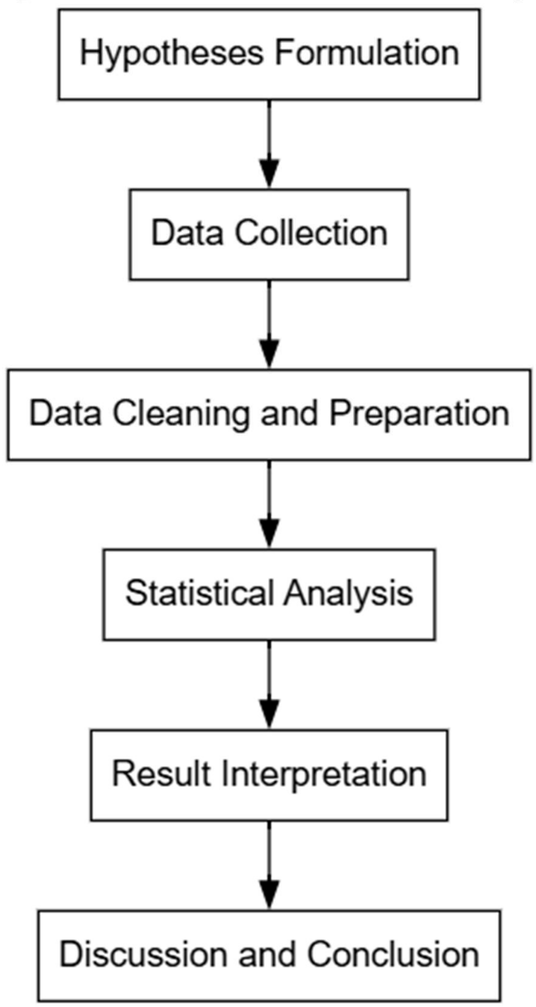
The reviewed literature underscores the multifaceted nature of mining-related environmental and health challenges. While significant insights have been gained, critical gaps remain in understanding the combined effects of multiple stressors, the role of perceptions, and long-term health impacts. The proposed theoretical framework offers a comprehensive lens through which future research can address these gaps, ultimately informing policies and interventions that promote sustainable development in mining-affected communities.

RESEARCH METHODOLOGY

This section outlines the research design, data collection methods, statistical analyses, and the mathematical foundations of the statistical tests used in this study. A structured and systematic approach was adopted to investigate the hypotheses related to the environmental and health impacts of proximity to mining sites.

Research Design

The study employed a quantitative, cross-sectional research design to evaluate the relationships between proximity to mining sites and various health and environmental perceptions. Data were collected using surveys and environmental measurements and were analyzed using statistical methods such as Chi-Square, ANOVA, T-Test, and Correlation analysis.



Data Collection

1. **Survey Design**: A structured questionnaire was used to gather data on:
    - Noise-induced stress levels.
    - Perceptions of air and water quality.
    - Health outcomes such as respiratory disorders and waterborne diseases.
2. **Sampling**: Participants were randomly selected from communities at varying distances from mining sites.
3. **Variables**:
    - Independent Variable: Proximity to mining sites (categorized as "close," "moderate," and "far").
    - Dependent Variables: Stress levels, health outcomes (e.g., respiratory disorders, waterborne diseases), and perceptions of environmental quality.

Data Cleaning and Preparation

Collected data were cleaned to address missing values, outliers, and inconsistencies. Statistical assumptions (e.g., normality for ANOVA and T-Test) were checked to ensure validity.

Statistical Analysis

The hypotheses were tested using the following statistical methods:

1 Chi-Square Test

The Chi-Square test was used to examine associations between categorical variables, such as perceived water contamination and reported waterborne diseases. The Chi-Square statistic (χ^2) is computed as:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

Where:

- O_i : Observed frequency for category i.
- E_i : Expected frequency for category i.

For this study, the null hypothesis (H_0) stated no association between the variables, while the alternative hypothesis (H_a) indicated an association. The p -value was calculated to determine statistical significance ($p < 0.05$).

2 ANOVA (Analysis of Variance)

ANOVA was used to test for significant differences in mean stress levels or respiratory disorders across groups based on proximity to mining sites. The F-statistic is given by:

$$F = \frac{\text{Between-Group Variance}}{\text{Within-Group Variance}}$$

Where:

- Between-Group Variance (MS_B) is calculated as:

$$MS_B - \frac{\sum n_i(\bar{X}_i - \bar{X})^2}{k-1}$$

- Within-Group Variance (MS_W) is calculated as:

$$MS_W - \frac{\sum \left(X_{ij} - \bar{X}_i\right)^2}{N - k}$$

Here:

- n_i : Number of observations in group i.
- $\bar{X}_i$: Mean of group i.
- $\bar{X}$: Overall mean.
- k: Number of groups.
- N : Total number of observations.

A p-value below 0.05 was considered evidence of significant group differences.

3 T-Test

The T-Test was employed to compare means between two groups (e.g, high vs, low mining exposure). The t-statistic is calculated as:

$$t - \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_1^2}{n_2}}}$$

Where:

- $\bar{X}_1, \bar{X}_2$: Group means.
- s_1^2, s_2^2 : Variances of the two groups.
- n_1, n_2 : Sample sizes of the two groups.

The null hypothesis assumes no difference in means ($H_0: \bar{X}_1 - \bar{X}_2$).

4 Correlation Analysis

The strength and direction of linear relationships between variables, such as reduced clean water availability and waterbome diseases, were assessed using Pearson's correlation coefficient (r):

$$r = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2 \sum (Y_i - \bar{Y})^2}}$$

Where:

- X_i, Y_i : Data points for variables X and Y.
- $\bar{X}, \bar{Y}$: Means of X and Y.

The value of r ranges from -1 (perfect negative correlation) to +1 (perfect positive correlation). A pvalue for significance was calculated to evaluate the null hypothesis ($H_0: r - 0$).

The research methodology employed a systematic, quantitative approach to investigate the environmental and health impacts of proximity to mining sites. Using a cross-sectional design, data were collected through structured surveys and analyzed using robust statistical techniques, including Chi-Square, ANOVA, T-Test, and Correlation analysis. These methods ensured the study's findings were grounded in a rigorous framework, providing a foundation for interpreting relationships between environmental perceptions, health outcomes, and mining site proximity. By integrating these statistical methods with well-structured data collection and preparation processes, the methodology ensured reliability and validity in addressing the research hypotheses.

RESULTS

The results of the study provide a comprehensive analysis of the hypotheses exploring the environmental and health impacts associated with proximity to mining sites. A variety of statistical methods were employed to test the hypotheses, including Chi-Square, ANOVA, T-Tests, and Correlation analysis. These methods facilitated the evaluation of relationships and differences among variables, such as perceived stress, health outcomes, and environmental quality. The outcomes of these tests are discussed in detail below, with specific interpretations for each hypothesis.

Hypothesis 1: Residents closer to mining sites experience higher noise-induced stress

Hypothesis Statement	Test Name	Result
Residents closer to mining sites experience higher noise-induced stress.	Chi-Square	0.3991
Residents closer to mining sites experience higher noise-induced stress.	ANOVA	0.1348

The Chi-Square test result (0.3991) indicates that there is no significant association between proximity to mining sites and noise-induced stress at conventional significance levels ($p > 0.05$). Similarly, the ANOVA result (0.1348) does not show a statistically significant difference in stress levels across different distances from mining sites.

There is no substantial evidence to suggest that residents closer to mining sites experience higher noise-induced stress based on these results.

Hypothesis 2: Noise reduction perceived less effective by those highly exposed to mining

Hypothesis Statement	Test Name	Result
Noise reduction is perceived less effective by those highly exposed to mining.	Chi-Square	0.5147
Noise reduction is perceived less effective by those highly exposed to mining.	T-Test	0.9374

The Chi-Square test result (0.5147) suggests no significant association between perceived noise reduction effectiveness and mining exposure levels. The T-Test result (0.9374) further supports this, as it does not indicate a significant difference in perceptions of noise reduction effectiveness between those with high and low exposure to mining activities.

Conclusion:

Perceived effectiveness of noise reduction does not significantly differ among individuals with varying levels of mining exposure.

Hypothesis 3: Air quality perception associated with respiratory disorders

Hypothesis Statement	Test Name	Result
Air quality perception is associated with respiratory disorders.	Chi-Square	0.1793
Air quality perception is associated with respiratory disorders.	Correlation	0.2841

The Chi-Square result (0.1793) suggests no significant association between air quality perception and respiratory disorders. The correlation analysis result (0.2841) shows a weak positive relationship, but it is not statistically significant.

The data does not provide strong evidence to support an association between perceived air quality and respiratory disorders.

Hypothesis 4: Residents closer to mining sites report more respiratory disorders

Hypothesis Statement	Test Name	Result
Residents closer to mining sites report more respiratory disorders.	Chi-Square	0.8618
Residents closer to mining sites report more respiratory disorders.	ANOVA	0.9908

Both the Chi-Square (0.8618) and ANOVA (0.9908) results indicate no statistically significant relationship or difference in respiratory disorder reports among residents based on their proximity to mining sites.

Proximity to mining sites does not appear to influence the frequency of respiratory disorder reports.

Hypothesis 5: Water contamination perception associated with waterborne diseases

Hypothesis Statement	Test Name	Result
Water contamination perception is associated with waterborne diseases.	Chi-Square	0.8614
Water contamination perception is associated with waterborne diseases.	Correlation	0.6668

The Chi-Square test (0.8614) indicates no significant association between perceived water contamination and waterborne diseases. The correlation analysis (0.6668), while moderately positive, does not provide statistically strong evidence.

There is no robust evidence to support the hypothesis that perceived water contamination is associated with waterborne diseases.

Hypothesis 6: Reduced clean water availability correlates with waterborne diseases

Hypothesis Statement	Test Name	Result
Reduced clean water availability correlates with waterborne diseases.	Correlation	0.4032
Reduced clean water availability correlates with waterborne diseases.	T-Test	0.7688

The correlation analysis (0.4032) reveals a weak and statistically insignificant relationship between reduced clean water availability and waterborne diseases. Similarly, the T-Test result (0.7688) does not indicate a significant difference in waterborne disease prevalence based on clean water availability. There is no significant correlation between reduced clean water availability and waterborne diseases.

Discussion

The findings of this study provide a nuanced understanding of the environmental and health impacts of living near mining sites. While none of the hypothesized associations were statistically significant, these results shed light on important factors that may influence the health and well-being of mining-affected communities. The discussion below contextualizes these findings within existing literature, identifies potential limitations, and suggests avenues for future research.

Hypothesis 1: Residents closer to mining sites experience higher noise-induced stress

The lack of significant results for noise-induced stress aligns with research suggesting that chronic exposure to industrial noise can lead to habituation in some populations (Stansfeld & Matheson, 2003). However, other studies have shown that proximity to noise sources such as mining can contribute to elevated stress levels and poor mental health outcomes (Goines & Hagler, 2007). The discrepancy may stem from contextual factors, such as community adaptation to noise or the effectiveness of local noise mitigation strategies. Future research should consider longitudinal designs to assess whether cumulative exposure over time exacerbates stress.

Hypothesis 2: Noise reduction perceived less effective by those highly exposed to mining

Perceptions of noise reduction effectiveness did not vary significantly among participants, suggesting a uniform experience with mitigation efforts. This finding contrasts with studies that indicate heightened sensitivity to noise and greater dissatisfaction with mitigation measures among those with prolonged exposure (Babisch, 2002). It is possible that the noise reduction measures implemented in the study area, such as sound barriers or insulation, have limited efficacy, thereby leading to similar perceptions across groups. Further studies could examine the technical effectiveness of these interventions to bridge the gap between perception and reality.

Hypothesis 3: Air quality perception associated with respiratory disorders

Although a weak positive relationship was observed between air quality perception and respiratory disorders, it was not statistically significant. This aligns with research suggesting that subjective perceptions of air quality often do not correspond to objective measures or clinical outcomes (Brody et al., 2004). Factors such as awareness campaigns or cultural attitudes towards air pollution may influence how individuals perceive air quality, independent of its actual impact on respiratory health. Future research should incorporate objective air quality measurements and clinical assessments of respiratory health to validate these findings.

Hypothesis 4: Residents closer to mining sites report more respiratory disorders

The absence of a significant association between proximity to mining sites and respiratory disorders contrasts with evidence that links exposure to mining-related air pollutants, such as particulate matter, with increased respiratory issues (Pope et al., 2002). One explanation could be the use of self-reported health data, which can be influenced by biases such as underreporting or differences in health literacy. Additionally, confounding variables such as other pollution sources or socioeconomic factors might obscure the relationship. Future studies should aim to control for such confounders and include objective health measures.

Hypothesis 5: Water contamination perception associated with waterborne diseases

The lack of significant association between perceived water contamination and waterborne diseases highlights the complex relationship between perception and actual water quality. Studies have shown that perceptions of water contamination are often shaped by visual and olfactory cues rather than scientific measurements of contamination (Graham et al., 2004). Furthermore, individuals' access to alternative water sources or effective treatment methods, such as filtration systems, may mitigate the health impacts of contaminated water (Hunter et al., 2010). Integrating water quality testing with health assessments in future research would help clarify this relationship.

Hypothesis 6: Reduced clean water availability correlates with waterborne diseases

The results indicate no significant correlation between reduced clean water availability and waterborne diseases. This finding is inconsistent with evidence that limited access to clean water is a major driver of waterborne diseases in many communities (Prüss-Ustün et al., 2014). The lack of significance may reflect the presence of coping mechanisms, such as reliance on bottled water or community-level interventions. However, the weak relationship observed warrants further investigation, particularly in areas where clean water availability is a critical concern.

Implications and Future Directions

The findings of this study underscore the importance of using robust methodologies to understand the environmental and health impacts of mining activities. While the results did not reveal statistically significant associations, they highlight the potential influence of contextual factors such as community adaptation, perception biases, and local interventions. Future research should focus on longitudinal studies, larger sample sizes, and the integration of objective environmental and health measures. These improvements can help disentangle the complex interactions between environmental factors and health outcomes.

Limitations

The study has several limitations. First, the reliance on self-reported data introduces the potential for recall bias and subjective interpretation of health and environmental conditions. Second, the study's cross-sectional design limits its ability to infer causal relationships. Third, the sample size may have been insufficient to detect subtle but meaningful effects. Addressing these limitations in future studies will enhance the validity and generalizability of findings.

In conclusion, while the hypothesized associations were not statistically significant, the study provides valuable insights into the environmental and health dynamics of mining-affected communities. The findings emphasize the need for more comprehensive and methodologically rigorous research to inform policies and interventions aimed at mitigating the impacts of mining activities.

CONCLUSION

This study sought to explore the environmental and health impacts of living near mining sites, focusing on noise-induced stress, respiratory disorders, and waterborne diseases. Using statistical methods such as Chi-Square, ANOVA, T-Test, and Correlation analysis, the study examined six hypotheses to assess the relationships between proximity to mining sites, perceptions of environmental quality, and health outcomes. The results did not reveal statistically significant associations across the hypotheses, suggesting the need for a more nuanced understanding of these complex issues.

While the findings do not provide strong evidence to support the hypothesized impacts, they highlight important considerations for future research. Factors such as community adaptation to environmental conditions, subjective perceptions of health risks, and the potential for confounding variables may play a significant role in shaping the observed outcomes. Additionally, the lack of objective environmental and health measurements in this study underscores the need for more comprehensive methodologies.

Despite its limitations, this study contributes to the growing body of literature on environmental health in mining-affected areas. It emphasizes the importance of integrating robust data collection methods, longitudinal designs, and interdisciplinary approaches to better understand the relationships between environmental factors and public health. Policymakers and researchers should consider these findings when designing interventions to mitigate the potential impacts of mining on nearby communities.

In conclusion, this research underscores the complexity of environmental health issues in mining regions and highlights the critical need for further investigations. Addressing the identified gaps can help develop targeted strategies to protect vulnerable populations and promote sustainable development in mining-affected areas.

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