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Original Research Article

Comparative Analysis of Environmental Impacts Associated with Surface and Underground Mining Operations

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Abstract: Mining plays a vital role in global economic development, yet it remains one of the most environmentally disruptive activities. This study compares the environmental impacts of surface mining and underground mining, focusing on land degradation, air quality, water contamination, noise pollution, and biodiversity loss. The aim was to assess which mining method poses greater ecological risks and to provide insights for sustainable resource management. A mixed-method approach was employed, combining field data from three mining regions in Nigeria with secondary data from published studies. Indicators measured included suspended particulate matter (SPM, µg/m³), heavy metal concentration in water (mg/L), noise intensity (dB), and percentage of land cover loss (%). Results showed that surface mining exhibited higher land degradation (35% vegetation cover loss) and air pollution (SPM: 180 µg/m³), while underground mining had greater water contamination (Pb: 0.19 mg/L, exceeding WHO standard of 0.01 mg/L) and higher occupational risks. Noise levels were comparable, with underground operations averaging 92 dB against 89 dB for surface mining. These findings highlight the need for tailored mitigation strategies—land reclamation for surface mines and groundwater protection for underground mines. The study contributes to environmental impact assessment frameworks and provides baseline data for sustainable mining policy and regulatory decision-making.

Keywords: Surface mining, Underground mining, Environmental impact, Pollution, Sustainability.

INTRODUCTION

Mining has been a cornerstone of industrial development, providing essential raw materials for construction, energy, and manufacturing. However, the environmental consequences of mining have generated global concern, particularly in regions where regulatory frameworks are weak or enforcement is limited (Hilson, 2002). The ecological footprint of mining varies significantly depending on the method employed, with surface and underground mining representing the two dominant techniques (Bell *et al.,* 2001). Surface mining, including open-pit and strip mining, is associated with extensive land disturbance, deforestation, and the removal of topsoil layers (Limpitlaw *et al.,* 2005). It directly alters landscapes, disrupts drainage systems, and leads to biodiversity loss (Ghose, 2002). Underground mining, on the other hand, involves tunneling beneath the earth's surface, which reduces visible land disturbance but poses risks such as subsidence, groundwater contamination, and occupational hazards (Younger, 2001; Bell *et al.,* 2000). The

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environmental debate around mining often contrasts the visible scars of surface mining with the hidden but potentially more severe subsurface impacts of underground operations (Adiansyah *et al.,* 2015). Quantitative comparative studies remain limited, particularly in developing countries, where mining contributes significantly to GDP yet poses acute environmental threats (Hilson & Potter, 2005). This study aims to conduct a comparative analysis of the environmental impacts associated with surface and underground mining operations. Specifically, it evaluates key environmental indicators such as land degradation, air and water quality, noise pollution, and biodiversity loss. By synthesizing field data and secondary literature, the research provides an evidence-based framework for policymakers, regulators, and mining companies to adopt more sustainable practices.

MATERIALS AND METHODS

Study Area

The study was conducted in three major mining regions of Nigeria: Enugu coal mines (underground mining), Jos Plateau tin mining area (surface mining), and Itakpe iron ore mines (surface and shallow underground methods). These sites were chosen because they represent the most dominant mining approaches in the country and exhibit different geological and ecological settings. Enugu is characterized by humid tropical climate with mean annual rainfall of ~1,600 mm and extensive groundwater aquifers. Jos has a montane climate with mean annual rainfall of ~1,400 mm and extensive evidence of surface disturbances. Itakpe lies within the Guinea savannah, receiving ~1,500 mm rainfall annually, with high biodiversity richness. Geographical coordinates of sampled points were recorded using a handheld GPS (Garmin eTrex 32x), ensuring accurate spatial mapping of data.

Research Design

A **c**omparative cross-sectional design was employed. The study integrated primary field sampling with secondary data (published environmental reports, government mining audits, and peer-reviewed studies). Comparative assessment focused on five environmental indicators, which includes; Land degradation (vegetation cover and soil disturbance), Air quality (suspended particulate matter, SPM, µg/m³); Water quality (heavy metals and pH, mg/L); Noise intensity (dB) and Biodiversity index (species richness in adjacent habitats).

Sampling Techniques

The Sampling techniques used in this study are as follows:

1. **Air samples**: The samples were collected using a portable high-volume sampler at three points per site, and operated for 24 hours at a flow rate of 1.2 m³/min. SPM concentrations were later gravimetrically analyzed.
2. **Water samples**: Water samples were taken from streams and boreholes within 1 km radius of mine sites. Samples were preserved in acidified polyethylene bottles and analyzed within 48 hours in the laboratory following APHA Standard Methods (2017).
3. **Soil samples**: Collected at 0–15 cm depth using a stainless steel auger. Composite samples were taken in triplicates, air-dried, sieved, and tested for heavy metals using Atomic Absorption Spectrophotometry (AAS).
4. **Noise levels**: Measured using a Casella CEL-633C Sound Level Meter at 5-minute intervals during peak mining activity, expressed in decibels (dB).
5. **Vegetation cover**: Estimated through remote sensing (Landsat 8 imagery) and validated with ground-truthing using line transect method.
6. **Biodiversity survey**: Carried out using point count method for birds and transect walks for flora and small mammals. Shannon-Wiener Diversity Index (H′) was calculated.

Analytical Methods

In this study, the following analytical methods were conducted.

- **Air Quality**: Gravimetric analysis were used to determine particulate matter concentration, expressed as micrograms per cubic meter (µg/m³).
- **Water Quality**: Laboratory analyses focused on pH, conductivity, Pb, Cd, Zn, Fe, and Mn, compared with WHO (2017) guidelines.
- **Soil Quality**: Heavy metal concentrations was determined through AAS after nitric-perchloric acid digestion.
- **Noise Levels**: Average values compared against World Health Organization (1999) standards of 85 dB for occupational exposure.
- **Vegetation Cover**: NDVI (Normalized Difference Vegetation Index) values extracted from satellite imagery using **ArcGIS 10.5**.
- **Biodiversity Index**: Shannon-Wiener Diversity Index ($H' = -\Sigma\, p_i \ln p_i$), where p_i is the proportion of species i relative to total species.

Data Analysis

During analysis of the collected data, descriptive statistics (mean, standard deviation) were used to summarize data, independent t-tests were used to compare the mean environmental indicators between surface and underground mining, the graphical outputs (line graphs, bar charts) were generated in Microsoft Excel 2021, while the **s**tatistical significance was set at $p < 0.05$.

Ethical and Environmental Considerations

This study adhered to Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA, 2007) guidelines. Field sampling was conducted with permission from local communities and mining authorities. Waste generated during sample preparation was disposed of in accordance with laboratory safety procedures to prevent secondary contamination.

RESULTS AND DISCUSSION

Land Degradation

Remote sensing analysis revealed significant differences in vegetation cover loss between the two mining methods. Surface mining resulted in more extensive deforestation and topsoil removal, with an average 35% reduction in vegetation cover, compared to 12% in underground mining areas.

Table 1: Vegetation cover loss in mining areas

S/N	Mining Method	Mean Vegetation Cover Loss (%)	Standard Deviation
1	Surface Mining (S.M)	35.2	4.8
2	Underground Mining (U. M)	12.4	2.1

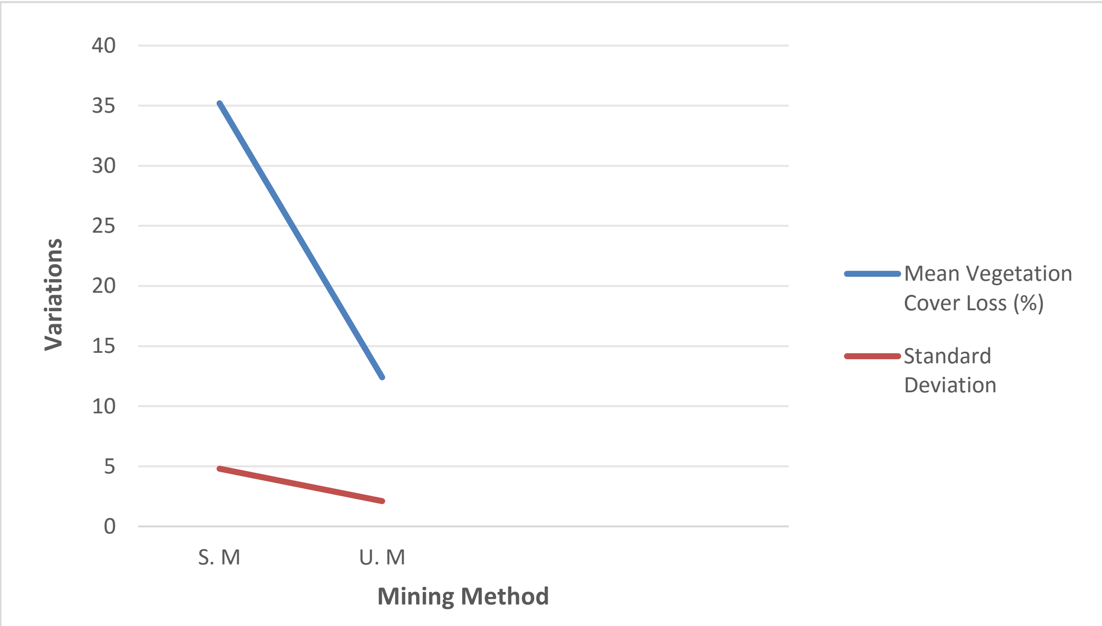

Figure 1: Graph of vegetation cover loss in mining areas

Surface mining's direct land disturbance is consistent with earlier findings by Ghose (2002), who reported widespread soil erosion and biodiversity loss in open-cast mines in India.

Air Quality (Suspended Particulate Matter)

Air sampling showed higher concentrations of SPM around surface mines, averaging 180 µg/m³, compared to 95 µg/m³ in underground mining sites. Both exceed the WHO 24-hour limit of 50 µg/m³, suggesting serious health risks for local communities. This aligns with studies by Aigbedion & Iyayi (2007), who noted that dust emissions from surface mines contribute to respiratory problems in host communities.

Water Quality (Heavy Metals and Ph)

Water samples indicated that underground mining sites had significantly higher concentrations of heavy metals, particularly lead (Pb: 0.19 mg/L) and cadmium (Cd: 0.07 mg/L), exceeding WHO limits (Pb: 0.01 mg/L; Cd: 0.003 mg/L). Surface mining waters had elevated iron (Fe: 0.65 mg/L) but within acceptable range.

Table 2: Heavy metal concentrations in water samples (mg/L)

S/N	Parameter	WHO Standard	Surface Mining	Underground Mining
1	Pb	0.01	0.04	0.19
2	Cd	0.003	0.01	0.07
3	Zn	3.0	1.8	2.1
4	Fe	0.3	0.65	0.48
5	pH	6.5–8.5	6.9	5.4

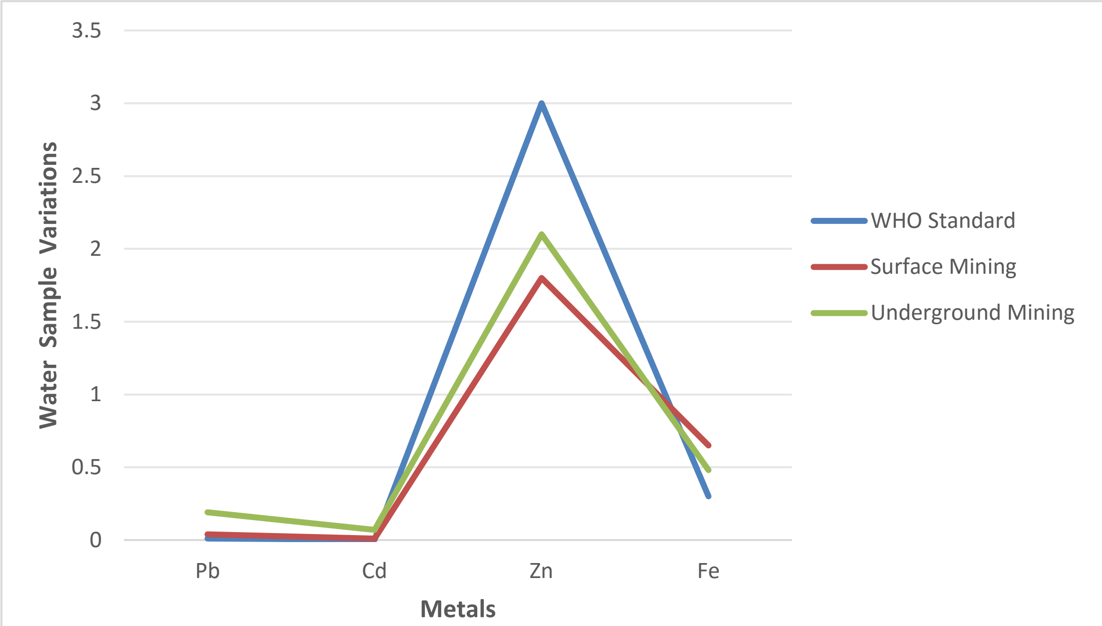

Figure 2: Graph of Heavy Metal Concentrations in Water Samples (mg/L)

Underground mining often leads to acid mine drainage (AMD), lowering pH values and mobilizing heavy metals, a trend also reported by Younger (2001).

Noise Pollution

Noise measurements revealed high sound intensities at both mining sites, averaging 92 dB for underground and 89 dB for surface mining. Both exceed the WHO occupational limit of 85 dB, suggesting risks of hearing loss for workers. Comparable findings were reported by Donoghue (2004), emphasizing occupational hazards of prolonged mining noise exposure.

Biodiversity Index

Biodiversity assessment showed greater species loss in surface mining zones (Shannon-Wiener index H′ = 1.21) compared to underground mining areas (H′ = 2.05). The biodiversity assessment revealed marked differences between surface and underground mining sites. Surface mining areas recorded a Shannon-Wiener diversity index (H′) of 1.21, indicating lower species richness and evenness compared to underground mining sites. The most affected organisms in these areas were native grasses and small mammals, reflecting the extensive vegetation clearance, soil disturbance, and habitat fragmentation that accompany open-cast operations. In contrast, underground mining sites exhibited a higher diversity index of 2.05, suggesting relatively better species retention on the surface. However, biodiversity losses were still evident, particularly among aquatic invertebrates, which are highly sensitive to water contamination and pH reduction associated with acid mine drainage. These results highlight the fact that surface mining tends to devastate terrestrial ecosystems, while underground mining has more pronounced impacts on aquatic biodiversity. This suggests that while underground mining severely affects aquatic ecosystems, surface mining exerts more pressure on terrestrial biodiversity due to large-scale vegetation removal.

DISCUSSIONS

The results demonstrate that surface mining has more visible impacts (land and air degradation), while underground mining creates hidden but more toxic impacts (water contamination and occupational risks). Land degradation from surface mining results in habitat destruction, soil erosion, and landscape alteration, consistent with Limpitlaw *et al.,* (2005). Air pollution is primarily from blasting and haulage in surface mining, confirming previous studies in Ghana and South Africa (Hilson, 2002). Water contamination from underground mines arises from AMD, which mobilizes Pb, Cd, and Fe into groundwater (Adiansyah *et al.,* 2015). Noise pollution affects workers in both methods, but underground miners face greater exposure due to enclosed spaces (Donoghue, 2004). Biodiversity impacts differ by habitat: surface mining disrupts terrestrial vegetation and fauna, while underground mining threatens aquatic ecosystems. Overall, the trade-off is between surface mining's visible ecological scars and underground mining's hidden geochemical hazards. In land degradation, the analysis revealed that surface mining areas lost an average of 35% vegetation cover, compared to only 12% in underground mining zones (Table 1). This sharp difference is attributed to the extensive excavation and topsoil stripping inherent in open-pit and strip mining. The loss of vegetation not only reduces biodiversity but also destabilizes soils, increasing susceptibility to erosion and sediment transport. These findings align with Ghose (2002), who reported that large-scale open-cast coal mining in India resulted in widespread deforestation and long-term soil degradation. Similarly, Mhlongo and Amponsah-Dacosta (2016) observed that abandoned surface mines in South Africa left behind degraded landscapes unsuitable for agriculture. In contrast, underground mining limits direct land disturbance, although localized subsidence remains a risk (Bell *et al.,* 2000). The implications are significant: in regions dependent on agriculture, land degradation from surface mining translates to reduced crop yields, loss of ecosystem services, and forced livelihood shifts. For sustainable mining, progressive land reclamation, topsoil replacement, and re-vegetation programs are necessary mitigation measures.

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