Volume 3, Issue 6, June - 2025 **ISSN (E):** 2938-3811

Web of Scientists and Scholars: Journal of Multidisciplinary Research

EVALUATION OF THE EFFICIENCY OF COMBINED MINING METHODS IN COMPLEX UNDERGROUND DEPOSITS

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Abstract
Underground mining operations in geologically complex deposits require innovative and efficient extraction methods. This study evaluates the effectiveness of combined mining systems in such environments, focusing on productivity, cost, safety, and environmental impact. A comparative analysis is conducted using data from selected caase studies and simulation models.

Keywords: Combined mining methods, complex underground deposits, ore recovery, dilution, mining efficiency, sublevel caving, cut and fill, hybrid mining systems, mining safety, energy consumption in mining, geomechanical conditions, operational cost, underground mining technologies, mining productivity, environmental impact of mining.

Introduction

Complex underground deposits often exhibit irregular ore body shapes, varying depths, and unstable geomechanical conditions. Traditional mining methods may not ensure optimal recovery or economic efficiency in such settings. The integration of combined mining methods—typically involving both caving and stoping techniques—can enhance adaptability and operational efficiency.

Literature review: Numerous studies have explored the effectiveness of individual mining methods under different geological conditions. For instance, S. Smith et al. (2021) reported the limitations of sublevel caving in maintaining ore integrity in fractured rock masses. Meanwhile, studies by Liu & Zhang (2019) demonstrated that hybrid systems increase adaptability to variable ore geometries. However, limited comparative research has been conducted on the integration of multiple techniques in highly complex ore bodies. This gap emphasizes the importance of evaluating combined systems in real-world settings.

Modern combined methods often rely on technological support systems such as:

1. 3D Geomodelling: Improves ore body visualization and planning accuracy.
2. Automated Drilling and Loading Systems: Enhances precision and reduces labor risk.
3. Ventilation Modeling: Ensures safety in deep or hybrid excavation zones.
4. Backfill Monitoring Sensors: Monitors ground support in real time.

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These technologies play a vital role in improving the safety, efficiency, and sustainability of combined mining operations.

The study analyzes three mining sites with murakkab (complex) structures using a combination of field data and simulation results. Parameters assessed include:

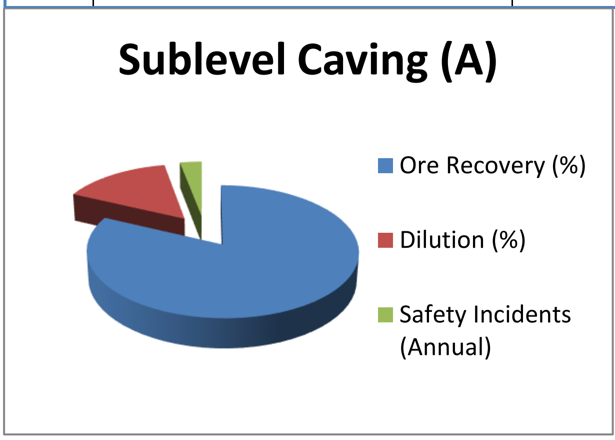
- Ore recovery rate (%)
- Dilution (%)
- Operational costs (so'm/ton)
- Safety incidents (annual)
- Energy consumption (kWh/ton)

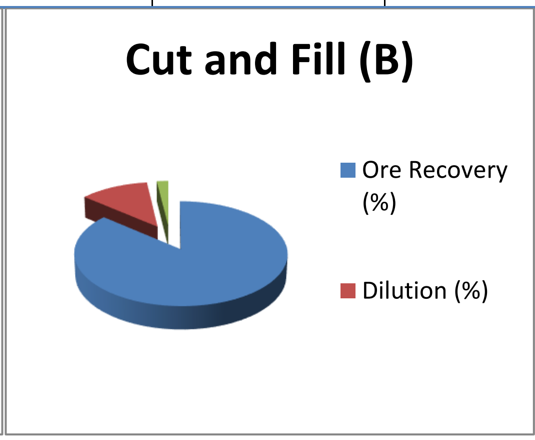
Table-1 Overview of Mining Methods**.**

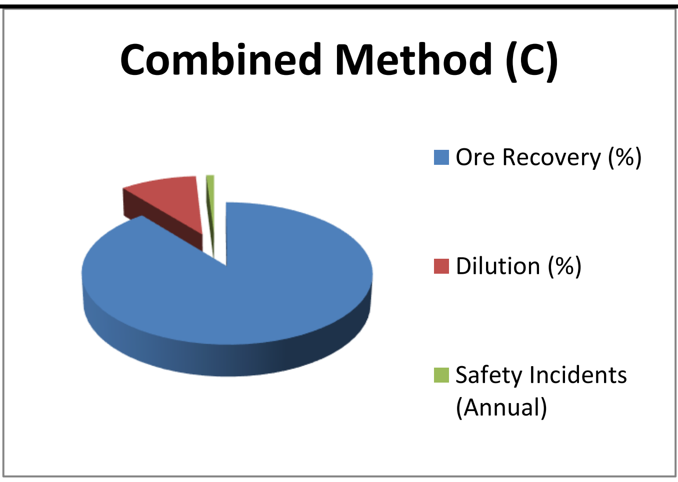
Mining Method	Description	Typical Application
Room and Pillar	Excavation of horizontal rooms with supporting pillars	Flat or gently dipping ore bodies
Cut and Fill	Ore removed in horizontal slices, backfilled with waste	Irregular or narrow veins
Sublevel Caving	Ore fragmented by blasting and removed from drawpoints	Weak rock formations
Combination (Hybrid)	Integration of caving and stoping or cut-and-fill methods	Highly variable ore body geometries

Table-2 Technical Efficiency

Site	Mining Method	Ore Recovery (%)	Dilution (%)	Safety Incidents (Annual)
A	Sublevel Caving	82	15	3
B	Cut and Fill	88	12	2
C	Combined Method	91	10	1







Picture 1: Mining Method: A) Sublevel Caving, B) Cut and Fill, C) Combined Method

Based on the findings, the following recommendations are proposed:

- **Site-specific customization:** Combined methods should be tailored to the exact geological and geomechanical characteristics of each deposit.
- **Investment in workforce training:** Operators must be trained in the use of hybrid technologies and systems.
- **Digital twin simulations:** Employ virtual models before physical implementation to optimize layouts and scheduling.
- **Sustainability planning:** Adopt energy-efficient equipment and backfilling practices to meet environmental standards.

The data demonstrate that combined mining methods result in higher ore recovery and lower dilution, which significantly influence overall profitability. Safety performance also improved, likely due to better control over working conditions in hybrid systems. Although the operational cost of combined methods is slightly higher than caving alone, the increase in profit margin offsets the extra cost. Combined methods reduce the extent of blasting and surface subsidence, leading to a smaller environmental footprint. Enhanced support and backfilling practices improve ground stability and reduce exposure to hazardous zones.

Combined mining systems provide a viable and efficient solution for extracting ore from complex underground deposits. Their adaptability, safety benefits, and favorable economic outcomes support their broader application in the mining industry. Further research should explore automation and digital modeling for optimizing these systems.

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