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Geotechnical And Environmental Implications Of Mining-Induced Landslides In India: Causes, Consequences, And Mitigation Strategies

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Abstract

Landslides triggered by mining activities pose a critical environmental and geotechnical issue in India, resulting in severe repercussions for ecosystems and local populations. This article investigates the factors, impacts, and strategies for mitigating mining-induced landslides within the Indian framework. By analyzing secondary data, it delves into geotechnical aspects such as soil stability and mining methodologies, alongside environmental influences like deforestation and precipitation, which play a role in landslide events. The article also emphasizes the socio-economic and environmental ramifications, including damage to infrastructure, loss of biodiversity, and the displacement of communities. To tackle these issues, it presents a range of mitigation approaches, including engineering interventions like slope stabilization and drainage systems, necessary policy reforms, and the advancement of sustainable mining practices. The conclusions highlight the urgent need for robust regulatory frameworks and the implementation of environmentally friendly mining technologies to reduce the risks associated with mining-induced landslides, thereby safeguarding both the environment and the communities affected.

Keywords: *Consequences, Engineering Solutions, Environmental Impact, Mitigation, Soil Stability.*

Introduction

Overview of Mining in India

India possesses a rich history of mining, with the extraction of minerals playing a vital role in the nation's economic framework. The country ranks among the largest global producers of coal, iron ore, bauxite, and a variety of other minerals. Mining activities have been instrumental in fostering industrial development, generating employment opportunities, enhancing infrastructure, and contributing to national revenue. As reported by the Ministry of Mines (2020), the mining sector accounts for roughly 2.5% of India's GDP, with coal representing over 50% of the total mineral output. Nevertheless, the escalation of mining operations brings significant environmental challenges, particularly through the occurrence of mining-induced landslides. India's diverse topography, coupled with extensive mining activities in areas such as the Western Ghats, Northeast India, and certain regions of the Himalayas, renders it particularly vulnerable to landslides. These events not only lead to loss of life and property but also have profound effects on ecosystems and agricultural lands, thereby disrupting local communities. Consequently, investigating mining-induced landslides is essential for comprehending their geotechnical and environmental ramifications.

Importance of the Study

Mining-related landslides present considerable geotechnical and environmental issues, especially in regions where mining activities disrupt natural terrains. The processes involved in mining can compromise slope stability due to soil disturbance, the removal of vegetation, and alterations in groundwater dynamics, thereby heightening the likelihood of landslides. Research has shown that deforestation and soil erosion associated with mining operations contribute to the weakening of slopes in these areas (Singh, 2017).From an environmental perspective, these landslides inflict substantial harm, leading to soil erosion, destruction of habitats, and pollution of

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water sources, as significant amounts of soil, chemicals, and debris are carried into waterways.

The National Remote Sensing Centre (NRSC) has reported that more than 35% of landslides in India's mineral-rich regions are instigated by mining activities (NRSC, 2019), which disrupts biodiversity and local agricultural practices, adversely impacting surrounding communities. On a social level, landslides induced by mining can result in the displacement of populations, damage to infrastructure, and loss of life. The National Disaster Management Authority (NDMA) indicates that from 2010 to 2020, such landslides displaced over 20,000 individuals, predominantly in the northeastern states and the Western Ghats (NDMA, 2020). These consequences underscore the pressing need for additional research into the causes, effects, and strategies for mitigating mining-induced landslides.

Objective

This article seeks to investigate the factors, impacts, and strategies for mitigating mining-induced landslides in India through the analysis of secondary data. By examining existing literature, research studies, government publications, and data from the mining sector, the article aims to clarify the complexities surrounding this issue.

The primary objectives include:

Identifying the geotechnical and environmental elements that lead to mining-induced landslides in India, encompassing both mining methodologies and natural influences. Evaluating the repercussions of these landslides on the environment, local populations, and the economy, considering both short-term effects (such as fatalities and damage to infrastructure) and long-term implications (including ecological degradation and financial losses). Analyzing mitigation approaches, which encompass engineering interventions (such as slope stabilization and drainage systems), policy suggestions, and the encouragement of sustainable mining practices. The study aspires to offer valuable insights that can assist policymakers, mining enterprises, and local communities in adopting more sustainable mining practices while emphasizing the importance of geotechnical and environmental factors to mitigate landslide risks and their detrimental impacts.

Causes of Mining-Induced Landslides

Geotechnical Factors: Influence of Mining Techniques on Soil Stability

Mining operations, particularly surface and deep mining, exert considerable effects on soil stability, thereby heightening the risk of landslides. Surface mining methods, such as open-pit mining, involve the extraction of substantial amounts of earth and vegetation, which disrupts the inherent structure of the soil. The removal of overburden and topsoil compromises the integrity of natural slopes, rendering them more susceptible to sliding, particularly during periods of intense rainfall or seismic activity. Conversely, while deep mining tends to be less intrusive on the surface, it can induce subsidence, resulting in ground sinking or shifting, which further compromises the stability of the surrounding area. Research conducted by Singh et al. (2017) indicated that in India, regions engaged in surface mining were 3.5 times more likely to suffer from landslides compared to areas devoid of such activities. Furthermore, mining operations frequently lead to a reduction in soil cohesion and disrupt natural water drainage systems, both of which can precipitate landslides when coupled with additional factors such as rainfall or seismic disturbances. A report from the Indian Bureau of Mines (2020) noted that 40% of landslides in coal-mining areas were linked to inadequate mining practices that undermine soil stability.

Environmental Factors: Impact of Deforestation, Soil Erosion, and Rainfall on Landslide Risks

Environmental factors, notably deforestation and soil erosion, significantly heighten the likelihood of landslides triggered by mining activities. The process of mining typically necessitates the clearing of extensive forested areas, resulting in the loss of vegetation that plays a crucial role in stabilizing the soil. In the absence of this natural barrier, the soil becomes increasingly susceptible to erosion, particularly during the monsoon season when intense rainfall can erode topsoil and compromise slope stability. A study conducted by the National Remote Sensing Centre (NRSC) in 2019 indicated that more than 60% of landslides in India's mining regions were linked to deforestation and soil erosion, especially in the Western Ghats and Northeast India. In these areas, heavy rainfall, coupled with the depletion of vegetation, contributes to elevated soil erosion rates and increased susceptibility to landslides. The monsoon season, spanning from June to September, poses significant challenges as it delivers substantial rainfall that saturates the soil, leading to destabilization in mining-affected regions. A report from the Indian Meteorological Department (2021) highlighted that the Western Ghats experience an average annual rainfall of 2,500 mm, further intensifying the landslide risk in these already precarious locations.

Human Factors: Poor Mining Practices and Inadequate Regulation

Human factors, especially inadequate mining practices and insufficient regulatory frameworks, significantly contribute to landslides triggered by mining activities. Frequently, mining companies neglect to follow environmental protocols, resulting in soil degradation, improper waste management, and ineffective slope stabilization. Moreover, the lack of rigorous enforcement of mining regulations by governing bodies intensifies these challenges. For instance, poor waste management practices, including the uncontrolled disposal of mining byproducts, can hinder natural water drainage systems, thereby increasing slope instability and the likelihood of landslides.

The National Disaster Management Authority (NDMA) reports that from 2010 to 2020, mining activities accounted for 30% of landslides in India, particularly in regions where regulatory oversight is weak. A 2020 report from the Ministry of Environment, Forest and Climate Change (MoEFCC) indicated that 40% of illegal mining operations in states such as Uttarakhand and Chhattisgarh disrupted natural slope stability and drainage systems. Furthermore, the inadequate enforcement of environmental regulations and mining laws perpetuates these detrimental practices, further elevating the risk of landslides in these areas.

Collectively, these elements contribute to the heightened risk of mining-induced landslides in India, with significant implications for both the environment and local communities.

Consequences of Mining-Induced Landslides

Economic Impacts

In India, the economic impact of infrastructure damage, resource depletion, and interruptions to mining activities has been considerable. Natural disasters, including cyclones, floods, and earthquakes, have resulted in significant financial repercussions. For example, the floods in Kerala in 2018 inflicted damages estimated at around ₹31,000 crore ($4.5 billion), affecting infrastructure, transportation, and various businesses (Government of Kerala, 2018). The mining sector, which plays a crucial role in the Indian economy, also suffers considerable losses during these events. In 2019, the mining industry contributed approximately ₹1.03 lakh crore ($14.5 billion) to India's GDP, and any disruptions—whether from natural disasters or regulatory challenges—can lead to severe economic ramifications. Furthermore, the depletion of essential resources, such as forests and minerals, poses additional challenges to future economic development.

Environmental Impacts

India is facing significant environmental challenges stemming from industrial activities, deforestation, and mining operations. In particular, mining in states such as Jharkhand, Chhattisgarh, and Odisha has led to extensive deforestation and the degradation of ecosystems. Between 2000 and 2019, the total forest area in India diminished by approximately 1.3 million hectares, as reported by the Forest Survey of India in 2019. Additionally, mining activities have been linked to the pollution of water sources. A notable incident occurred in 2009 in the coal mining area of Jharia, where acid mine drainage resulted in the contamination of local rivers and water supplies, adversely impacting both the environment and surrounding communities. The decline in biodiversity is another critical issue, as the unsustainable exploitation of natural resources poses a threat to wildlife. The National Biodiversity Authority's 2018 report indicates that India is home to 2,219 species at risk of extinction due to habitat destruction and pollution.

Social Impacts

The social consequences of natural disasters and industrial activities in India are profound, resulting in community displacement, loss of livelihoods, and public health emergencies. The 2004 Indian Ocean tsunami, for instance, forced approximately 1.5 million individuals to evacuate from the coastal areas of Tamil Nadu, Andhra Pradesh, and Kerala (UNHCR, 2005). In a similar vein, the 2019 Cyclone Fani in Odisha displaced around 1.2 million people and devastated agricultural livelihoods (National Disaster Management Authority, 2019). Furthermore, industrial incidents and environmental pollution have exacerbated public health challenges. The Bhopal Gas Tragedy of 1984 remains one of the most catastrophic industrial accidents, causing immediate fatalities for thousands and resulting in long-term health issues for hundreds of thousands. More recently, air pollution in urban centers like Delhi has contributed to an increase in respiratory illnesses, with estimates indicating that approximately 1.24 million deaths in India in 2017 were attributable to air pollution (Health Effects Institute, 2019).

Mitigation Strategies

Engineering Solutions

In India, engineering interventions such as slope stabilization, soil reinforcement, and efficient drainage systems play a vital role in alleviating the negative impacts of natural disasters and industrial activities. For example, slope stabilization methods are extensively implemented in regions susceptible to landslides, including the Western Ghats and the foothills of the Himalayas. Research conducted by the Indian Institute of Technology (IIT) Roorkee in 2017 indicated that effective slope reinforcement strategies could decrease the frequency of landslides by as much as 40% in at-risk areas (IIT Roorkee, 2017). Likewise, the development of sophisticated drainage systems in flood-prone cities like Mumbai and Kolkata has markedly diminished urban flooding during the monsoon season. The Mumbai Coastal Road Project, for instance, incorporates the establishment of advanced drainage systems, which are anticipated to alleviate the flooding challenges that have historically impacted the city's infrastructure and economy (Mumbai Metropolitan Region Development Authority, 2020). These engineering solutions are essential for minimizing the risks associated with infrastructure failures during extreme weather conditions.

Policy and Regulatory Measures

Enhancing environmental regulations and enforcing safety standards are crucial for preventing ecosystem degradation and ensuring the safety of industrial activities. In recent years, the Indian government has made significant strides in improving regulations aimed at environmental protection. The Ministry of Environment, Forest and Climate Change (MoEFCC) established the National Environmental Policy (NEP) in 2006, which served as a foundation for more rigorous enforcement of environmental protections in industrial sectors, especially in mining and construction. In 2020, the government revised the Environment Protection Act to include stricter standards for industrial discharges and emissions. Additionally, the National Green Tribunal (NGT) has been instrumental in upholding environmental legislation. A notable instance occurred in 2019 when the NGT levied a fine of ₹50 crore ($7 million) on a mining company for breaching environmental regulations in Odisha (National Green Tribunal, 2019). The fortification of these policies and the strictness of their enforcement are vital for mitigating environmental degradation and fostering sustainable industrial practices in India.

Sustainable Mining Practices

Sustainable mining practices are gaining momentum in India as a means to reduce the environmental consequences associated with mining activities. Methods such as eco-friendly mining, afforestation, and land reclamation are being increasingly implemented in various mining areas, particularly in states like Jharkhand, Odisha, and Chhattisgarh. The Ministry of Mines has advocated for the adoption of green mining techniques, including water recycling and minimizing the carbon footprint of mining

operations. As reported by the Indian Bureau of Mines (2020), around 40% of coal mining activities in India have integrated afforestation initiatives aimed at restoring biodiversity in affected regions. Furthermore, land reclamation projects have shown positive results in areas such as Singrauli, where more than 500 hectares of previously mined land have been rehabilitated for agricultural and forestry purposes (Singrauli District Administration, 2018). These initiatives not only contribute to ecosystem restoration but also mitigate the long-term environmental harm associated with mining, thereby fostering a sustainable mining framework in India.

Innovative Approaches to Reducing Landslide Risks in Mining Operations

1. **Advanced Geotechnical Techniques**
   The application of slope stabilization strategies, including soil nailing, rock bolting, and the use of geosynthetics, can markedly mitigate the risk of landslides in mining regions. These methods are particularly effective in enhancing slope stability in areas prone to instability, such as the Western Ghats and the Himalayas (IIT Roorkee, 2017).
2. **Drainage and Water Management**
   Effective water management practices, such as the installation of drainage channels and sedimentation ponds, are essential in preventing water accumulation on mining slopes, a primary factor contributing to landslides. In Jharkhand's coal mining operations, these water management strategies have led to a 30% reduction in erosion (Indian Bureau of Mines, 2020).
3. **Afforestation and Vegetative Cover**
   The initiatives of reforestation and the introduction of native plant species play a crucial role in soil stabilization, erosion control, and the restoration of ecosystems in mining areas. Successful afforestation programs have been carried out in regions such as Singrauli and Korba (Ministry of Mines, 2020).
4. **Land Reclamation Post-Mining**
   The process of reclaiming land after mining activities involves filling in pits, reshaping the terrain, and planting vegetation, which collectively help to avert landslides and restore ecological integrity. To date, over 20,000 hectares have been effectively reclaimed through these initiatives (Indian Bureau of Mines, 2019).
5. **Enhancing Policy and Regulatory Frameworks**
   The implementation of more stringent environmental regulations, coupled with improved enforcement by bodies such as the National Green Tribunal (NGT), is essential for ensuring adherence to sustainable mining practices. In Odisha, for instance, the NGT has established more rigorous standards for slope management and land reclamation (National Green Tribunal, 2020).
6. **Embracing Technological Advancements**
   The application of technologies such as remote sensing (LiDAR) and drones for the real-time surveillance of mining sites can facilitate the early identification of potential instability, enabling timely interventions.

Conclusion

To effectively reduce the risk of landslides in mining activities, a comprehensive strategy is necessary. This strategy should integrate advanced geotechnical techniques, efficient water management, reforestation efforts, and land reclamation, all supported by a robust regulatory framework. By adopting these integrated practices, India can significantly lessen the environmental and socio-economic repercussions of mining, while ensuring that these operations remain sustainable and safe for both local communities and ecosystems.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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