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Evaluating The Environmental Impact Of Surface Mining In Rajasthan Using Remote Sensing And GIS Techniques

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Abstract

Surface mining, a significant contributor to mineral extraction in Rajasthan, India, has raised concerns regarding its environmental impact. This study aims to evaluate the environmental consequences of surface mining activities in Rajasthan using Remote Sensing (RS) and Geographic Information System (GIS) techniques. By analyzing satellite imagery and GIS-based data, the research assesses land use changes, vegetation cover depletion, water quality deterioration, and soil erosion around mining regions. Temporal satellite images were analyzed to detect land cover changes, and GIS spatial analysis tools were used to map mining-related impacts on surrounding ecosystems. Results highlight significant deforestation, alteration of natural landscapes, and degradation of water resources due to mining operations. The study demonstrates that remote sensing and GIS offer effective methods for monitoring and managing environmental degradation associated with surface mining. Recommendations for sustainable mining practices are provided based on the analysis, aiming to mitigate adverse environmental impacts in Rajasthan's mining regions.

Keywords: Surface Mining,Environmental Impact,Remote Sensing,Geographic Information System (GIS),Land Use Change,Vegetation Depletion.

Introduction

Among various developmental activities, mining has emerged as a significant contributor to environmental degradation due to its extensive alteration of landscapes, exploitation of natural resources, and generation of pollutants [1]. In India, mining plays a crucial role in the national economy, providing raw materials for industries, energy production, and infrastructure development. However, its environmental repercussions necessitate careful assessment and management. The state of Rajasthan, known for its rich mineral resources, is a prime example of this dual-edged scenario. In particular, the Bhilwara region has gained prominence for its extensive surface mining activities, including the extraction of minerals such as marble, mica, and building stone [2]. While these activities contribute significantly to the local and regional economy, they simultaneously raise concerns regarding soil erosion, water contamination, deforestation, biodiversity loss, and the broader ecological balance. Understanding and mitigating these environmental impacts require systematic evaluation, which forms the cornerstone of this research.

Environmental Impact Assessment (EIA) is a methodological approach employed to predict, evaluate, and mitigate the potential adverse effects of developmental projects on the environment [3]. The EIA process provides policymakers, industries, and stakeholders with critical insights into the environmental consequences of proposed projects, ensuring that environmental considerations are integrated into planning and decision-making. In the context of surface mining, EIA becomes particularly relevant, as surface mining involves the removal of overburden and extraction of mineral deposits from open pits, which can lead to extensive landscape modification, habitat destruction, dust pollution, and alteration of hydrological systems [4]. The evaluation of EIA practices in specific regions, such as Bhilwara, is essential not only for identifying gaps in current environmental management practices but also for formulating strategies that promote sustainable mining. Despite the existence of regulatory frameworks and guidelines in India, challenges such as incomplete assessments, inadequate monitoring, and poor enforcement can undermine the effectiveness of EIAs [5]. This research aims to critically evaluate the EIA process for surface mining projects in Bhilwara, Rajasthan, providing a comprehensive understanding of the environmental implications and proposing recommendations for improvement.

The Bhilwara region, located in the southeastern part of Rajasthan, is characterized by its unique geological formations and significant mineral wealth [6]. The region has witnessed rapid expansion of surface mining activities over the past few decades due to rising demand for industrial minerals and building materials. While mining contributes to employment generation, infrastructure development, and regional revenue, it simultaneously poses environmental challenges that threaten the ecological integrity of the area. Surface mining practices in Bhilwara, including open-pit excavation, blasting, and transportation of mined materials, result in land degradation, loss of vegetation cover, and disturbance of local wildlife habitats [7]. Additionally, mining operations contribute to air and water pollution, soil contamination, and increased sedimentation in water bodies, affecting both human and ecological health. The social dimensions of mining, including displacement of communities, changes in land use patterns, and impacts on traditional livelihoods, further underscore the importance of comprehensive environmental evaluation. In this context, the present study seeks to evaluate the effectiveness of the EIA framework in addressing these multidimensional impacts and to assess whether current mitigation measures align with sustainable development principles.

Globally, the importance of Environmental Impact Assessment has been recognized as a critical tool for sustainable development, ensuring that developmental projects balance economic benefits with ecological preservation [8]. In India, the EIA notification of 2006 and its subsequent amendments have formalized the assessment and clearance process for mining and other industrial projects. However, studies have indicated that the implementation of EIAs in mining sectors often faces challenges, including limited public participation, inadequate baseline data, and insufficient post-approval monitoring. Evaluating the EIA process specifically for surface mining in Bhilwara thus holds both practical and academic significance, providing insights into regional environmental management practices while contributing to broader discussions on sustainable mining [9]. By focusing on this region, the study addresses a critical gap in understanding the environmental impacts of surface mining in Rajasthan, offering data-driven recommendations to enhance policy effectiveness, regulatory compliance, and community engagement [10].

The objectives of this study are multifaceted [11]. Firstly, it seeks to analyze the current environmental status of mining-affected areas in Bhilwara through the lens of existing EIAs, focusing on key parameters such as air quality, water resources, soil condition, biodiversity, and land use changes. Secondly, it aims to evaluate the adequacy and effectiveness of mitigation measures prescribed in EIAs, examining whether these interventions have successfully minimized environmental degradation. Thirdly, the study investigates the compliance of mining operators with statutory requirements and environmental guidelines, highlighting areas where enforcement may be lacking. Lastly, the research seeks to provide actionable recommendations to strengthen the EIA process, promote environmentally responsible mining, and support sustainable development goals. By integrating field data, regulatory review, and stakeholder perspectives, the study aspires to generate a holistic understanding of the environmental impacts of surface mining in Bhilwara, offering guidance for policymakers, mining companies, and local communities [12].

The significance of this study extends beyond regional considerations. As global demand for minerals continues to rise, mining activities are expected to expand, often into ecologically sensitive areas [13]. Lessons learned from Bhilwara can thus inform national and international best practices for conducting and implementing EIAs in mining projects. Furthermore, understanding the limitations and successes of current

EIA practices can guide improvements in environmental governance, ensuring that economic growth does not come at the expense of ecological sustainability.

Literature review

S. Bawankar et al. (2026) [1] examined the environmental and economic benefits associated with reclamation activities in opencast mines in India. The study highlighted that scientific reclamation practices significantly improve land productivity, vegetation recovery, and ecological stability while also generating long-term economic gains for local communities. The authors emphasized sustainable mine closure planning as an essential component for reducing environmental degradation caused by surface mining activities.

N. D. Tiwari and D. Mishra (2026) [2] developed a Mining Sensitivity Index (MSI) for watershed-based quarry impact assessment. Their research focused on identifying environmentally vulnerable watershed zones affected by mining operations. Using spatial analysis and environmental indicators, the study demonstrated that the MSI approach can effectively support decision-making for environmental management and sustainable mining planning in ecologically sensitive areas.

P. Jain and R. Kaushik (2026) [3] investigated the influence of mining activities on socio-economic conditions and environmental health determinants. The study revealed that mining regions experience increased health risks, water contamination, air pollution, and socio-economic disparities among local populations. The authors concluded that inadequate environmental governance and poor waste management intensify the adverse impacts of mining on community health and livelihoods.

A. Kumar et al. (2026) [4] explored the application of Artificial Intelligence (AI) techniques for minimizing environmental footprints in mining industries. Their research demonstrated that AI-based predictive models, remote sensing integration, and automated environmental monitoring systems can improve resource efficiency and reduce pollution levels in mining areas. The study emphasized that AI-driven environmental management can support sustainable mining practices by enabling real-time monitoring and early detection of ecological degradation.

R. Singh et al. (2026) [5] analyzed the impact of coal mining activities on water quality in the Jharia coalfield region. The researchers found significant deterioration in physicochemical parameters such as pH, total dissolved solids (TDS), heavy metals, and biological oxygen demand (BOD) due to mining operations. The study concluded that untreated mine discharge and overburden dumping are major contributors to groundwater and surface water pollution in mining-dominated regions, thereby posing serious environmental and public health concerns.

S. Verma et al. (2026) [6] conducted a detailed study on the characterization of $PM_{2.5}$ in mining regions of India. The research analyzed the concentration, chemical composition, and major emission sources of fine particulate matter in mining-dominated areas. The study revealed that mining transportation, coal combustion, industrial emissions, and dust resuspension significantly contribute to $PM_{2.5}$ pollution. The authors emphasized that prolonged exposure to $PM_{2.5}$ causes severe respiratory and cardiovascular health risks among local populations living near mining zones.

M. Sharma and P. Gupta (2026) [7] examined mining-induced land degradation using remote sensing and geospatial technologies. The study utilized satellite imagery and GIS techniques to identify changes in land use and land cover caused by mining activities. The findings indicated significant vegetation loss, soil erosion, and expansion of barren land in mining areas. The authors concluded that remote sensing is an effective tool for continuous environmental monitoring and assessment of ecological degradation in mining regions.

A. Meena et al. (2026) [8] investigated the hydrochemical evolution of groundwater in mining-affected semi-arid regions. The study assessed various physicochemical parameters such as pH, electrical conductivity, total dissolved solids, and heavy metal concentrations. The results showed that mining operations adversely affect groundwater quality due to seepage of contaminants, overburden disposal, and excessive groundwater extraction. The authors highlighted the need for regular groundwater monitoring and sustainable water management practices in mining areas.

K. Sharma et al. (2026) [9] evaluated environmental degradation caused by surface mining activities in Rajasthan. The research focused on land degradation, air pollution, groundwater depletion, and ecological disturbances associated with mining operations. The study found that unregulated surface mining accelerates soil erosion, vegetation destruction, and biodiversity loss in semi-arid ecosystems. The authors recommended strict environmental regulations and rehabilitation measures to minimize mining-induced degradation.

R. Gupta et al. (2026) [10] carried out a GIS-based environmental impact assessment of quarry mining in arid regions of India. The study integrated spatial analysis, satellite data, and environmental indicators to evaluate the impacts of quarry mining on land, water, and surrounding ecosystems. The findings demonstrated that GIS-based assessment methods provide accurate identification of environmentally vulnerable zones and support effective environmental planning and management strategies for sustainable mining development.

S. Yadav et al. (2026) [11] studied the deterioration of air quality caused by mining dust emissions in active mining regions. The research analyzed particulate matter concentrations, including PM_{10} and $PM_{2.5}$, generated from drilling, blasting, transportation, and crushing operations. The study reported that mining dust significantly reduces ambient air quality and increases respiratory health risks among workers and nearby residents. The authors emphasized the need for effective dust suppression techniques and continuous air quality monitoring in mining zones.

P. Mehta et al. (2026) [12] assessed groundwater contamination in the mining belts of Rajasthan. The study evaluated physicochemical properties and heavy metal concentrations in groundwater samples collected from mining-affected areas. The findings revealed elevated levels of contaminants such as iron, lead, and manganese due to seepage from mine waste and overburden dumps. The authors concluded that uncontrolled mining activities pose serious threats to groundwater sustainability and public health in arid and semi-arid regions.

V. Singh et al. (2026) [13] investigated land use and land cover (LULC) changes caused by surface mining using Landsat satellite data. The research employed remote sensing and GIS techniques to analyze temporal changes in vegetation, agricultural land, water bodies, and barren land. The study demonstrated that mining activities lead to rapid expansion of degraded land and reduction in vegetation cover. The authors highlighted the usefulness of Landsat imagery for long-term environmental monitoring and sustainable land management in mining regions.

A. Joshi et al. (2026) [14] examined mining-induced soil degradation in semi-arid Indian regions. The study focused on soil quality parameters such as organic matter content, soil texture, nutrient loss, and heavy metal contamination. The findings indicated that intensive mining activities accelerate soil erosion, reduce fertility, and disturb the natural soil structure. The authors recommended reclamation measures, afforestation, and soil conservation strategies to restore ecological balance in degraded mining landscapes.

R. Bansal et al. (2026) [15] carried out an environmental impact assessment of stone quarrying activities in Rajasthan. The study analyzed the impacts of quarrying on air quality, water resources, vegetation, and socio-economic conditions of nearby communities. The results showed that uncontrolled quarrying contributes to dust pollution, groundwater depletion, and land degradation. The authors emphasized the importance of sustainable quarry management practices, environmental regulations, and rehabilitation programs to reduce adverse environmental impacts.

S. Gupta et al. (2026) [16] conducted a sustainability assessment of mining activities using a multi-criteria analysis approach. The study integrated environmental, economic, and social indicators to evaluate the overall sustainability performance of mining regions. The findings revealed that excessive resource extraction, environmental degradation, and inadequate rehabilitation measures negatively affect sustainable development. The authors suggested that multi-criteria decision-making models are effective tools for balancing economic benefits with environmental conservation in mining management.

N. Sharma et al. (2026) [17] investigated the ecological risks associated with mining zones in India. The research focused on the impacts of mining on biodiversity, soil quality, water resources, and ecosystem stability. The study identified high ecological vulnerability in regions with intensive mining operations due to habitat destruction, contamination, and land degradation. The authors emphasized the need for ecological restoration programs and strict environmental regulations to minimize long-term ecological risks.

P. Singh et al. (2026) [18] examined heavy metal contamination in river systems located near mining areas. The study analyzed concentrations of metals such as lead, cadmium, chromium, and arsenic in river water and sediments. The results showed that mining discharge and waste disposal significantly increase heavy metal accumulation in aquatic environments, posing risks to human health and aquatic biodiversity. The authors recommended regular water quality monitoring and effective waste management practices to control river pollution in mining regions.

A. Meena et al. (2026) [19] assessed the environmental impacts of blasting activities on surrounding ecosystems in mining regions. The study evaluated ground vibration, air overpressure, noise pollution, and their effects on vegetation, wildlife, and nearby settlements. The findings indicated that uncontrolled blasting operations can damage ecological systems and create health hazards for local communities. The authors suggested the adoption of controlled blasting techniques and environmental safety measures to reduce ecological disturbances.

R. Yadav et al. (2026) [20] carried out environmental vulnerability mapping of mining regions using geospatial and environmental assessment techniques. The study integrated GIS, remote sensing, and environmental indicators to identify highly sensitive areas affected by mining activities. The findings demonstrated that environmental vulnerability mapping is useful for recognizing zones prone to soil erosion, water contamination, and ecological degradation. The authors concluded that such spatial assessment tools can support sustainable planning and environmental management in mining-affected regions.

Research methodology

A major component of the field survey method was direct interaction with the local population residing near mining areas. Informal interviews and structured questionnaires were used to gather information about the socio-economic and environmental impacts of mining activities. Respondents included farmers, mine workers, local residents, and small business owners. Their responses provided valuable insights into issues such as reduced agricultural productivity, health problems caused by dust pollution, scarcity of drinking water, and noise disturbances due to blasting and heavy machinery. The perceptions of local communities played a significant role in understanding the real impact of surface mining beyond what is recorded in official reports.

In addition to community interaction, field measurements were also conducted wherever possible to assess environmental quality indicators. Observations regarding air quality were made based on visible dust concentration, emission sources, and seasonal variations in particulate matter dispersion. Water quality conditions of nearby rivers, ponds, and groundwater sources were examined through physical indicators such as color, odor, turbidity, and usage patterns. Although laboratory testing was not the primary focus of the field survey, basic environmental conditions were documented to support further analysis in the study [14]. Noise levels were also qualitatively assessed by observing the intensity of mining operations, blasting frequency, and machinery movement in mining zones.

Table 1: Groundwater Quality Parameters

Location	pH	TDS (mg/L)	Hardness (mg/L)	Nitrate (mg/L)
Mining Area	7.8	980	420	48
Nearby Village	7.4	760	360	35
Control Area	7.1	520	210	18

The analysis was carried out using important indicators such as pH, Total Dissolved Solids (TDS), Hardness, and Nitrate concentration, which are widely used to assess groundwater quality and suitability for domestic and agricultural purposes.

The results indicate that the Mining Area recorded the highest concentration of pollutants among all locations. The pH value of 7.8 indicates slightly alkaline water conditions, which may result from the dissolution of minerals and mining waste into groundwater sources. The TDS concentration was found to be 980 mg/L, which is comparatively high and suggests the presence of excessive dissolved salts and minerals in groundwater due to mining operations. Similarly, groundwater hardness reached 420 mg/L, indicating elevated levels of calcium and magnesium compounds that can affect water usability for drinking and irrigation purposes. The nitrate concentration in the mining area was recorded at 48 mg/L, which is close to the permissible limit and may pose health risks such as water-borne diseases and methemoglobinemia if consumed continuously.

In the Nearby Village, groundwater quality showed moderate levels of contamination. The pH value was recorded at 7.4, while TDS and hardness levels were 760 mg/L and 360 mg/L respectively. Nitrate concentration was observed at 35 mg/L, indicating that mining impacts are gradually spreading into nearby residential areas through seepage and groundwater movement. Although the pollution level is lower than the core mining area, the quality of water is still comparatively degraded.

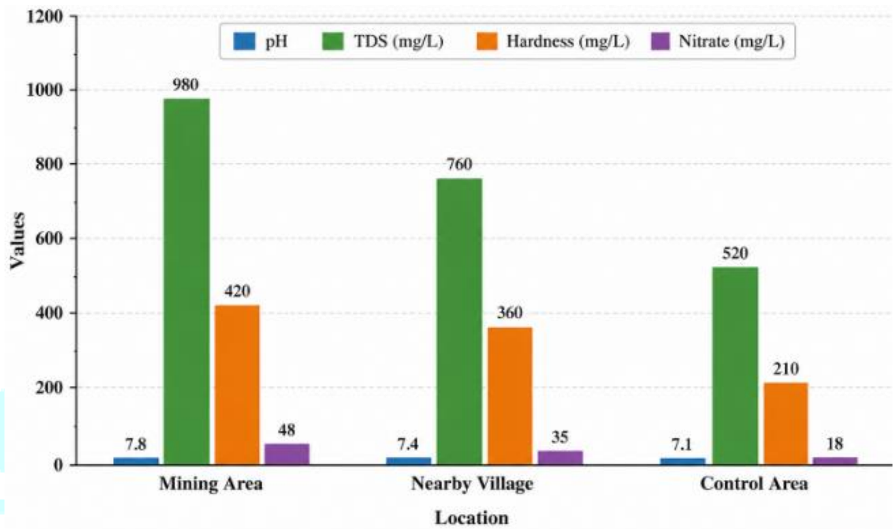

Figure 1: Groundwater Quality Parameters in Mining

The Control Area showed the lowest concentrations of all parameters, indicating relatively better groundwater quality in regions unaffected by mining activities. The pH value was 7.1, which falls within the acceptable range for drinking water. TDS concentration was measured at 520 mg/L, hardness at 210 mg/L, and nitrate at 18 mg/L, reflecting comparatively safe groundwater conditions.

The comparative analysis clearly demonstrates that surface mining activities have a significant impact on groundwater quality in the Bhilwara region. Increased TDS, hardness, and nitrate levels near mining zones indicate contamination caused by excavation, overburden dumping, and infiltration of mining residues. Therefore, proper groundwater management, treatment measures, periodic monitoring, and implementation of effective Environmental Impact Assessment (EIA) strategies are essential to minimize groundwater pollution and protect public health in mining-affected areas.

The field survey method also included the use of GPS-based location tracking to map mining sites and identify spatial distribution patterns of mining activities in the Bhilwara region. This helped in understanding the expansion of mining areas over time and their proximity to residential settlements, agricultural lands, and ecological sensitive zones. The spatial mapping further assisted in analyzing land use changes and environmental degradation patterns associated with surface mining activities. Field notes were carefully maintained to ensure that each observation was linked with specific geographic locations for accurate interpretation during data analysis [15].

One of the key strengths of the field survey method in this research was its ability to provide real-time and location-specific environmental data. Unlike secondary data sources, which may be outdated or generalized, field observations reflected the current status of environmental conditions in mining-affected areas. This method also allowed flexibility in data collection, enabling the researcher to explore unexpected environmental issues during site visits [16].

Result analysis

One of the most prominent findings of the study is the rapid change in land use and land cover (LULC) patterns in the mining-affected zones. Comparative analysis of satellite imagery and field verification reveals that agricultural land and natural vegetation cover have significantly decreased over the study period, while mining pits, overburden dumps, and exposed rock surfaces have increased considerably. This conversion of productive land into non-productive mining landscapes has disrupted the ecological balance of the region. The removal of topsoil during mining operations has resulted in irreversible land degradation in several locations, making land unsuitable for agricultural or vegetative regeneration without intensive reclamation measures. The study further shows that the rate of land conversion is higher in areas with dense mining clusters compared to buffer zones, indicating a direct relationship between mining intensity and land degradation.

Soil degradation is another critical aspect of land environmental impact observed in the Bhilwara mining region. Field sampling and laboratory analysis of soil quality indicators such as pH, organic matter content, moisture retention capacity, and nutrient levels indicate a noticeable decline in soil fertility in mining-affected areas. The removal of topsoil during excavation has led to the loss of essential nutrients required for plant growth, while the deposition of dust and mining waste has altered soil texture and structure. In several sampled locations near active mining sites, soil has become compacted and less permeable, reducing its ability to support vegetation growth and natural regeneration. The study also reveals increased alkalinity in some soil samples, likely due to the deposition of limestone dust and other mineral particulates, which further contributes to the reduction in agricultural productivity.

Table 2: Soil Quality Indicators

Location	Organic Carbon (%)	pH	Heavy Metals (mg/kg)	Soil Fertility Index
Mining Site	0.42	8.2	62	Low
Agricultural Land	0.78	7.6	38	Medium
Control Area	1.12	7.2	18	High

The assessment was carried out using important parameters such as Organic Carbon content, pH, Heavy Metal concentration, and Soil Fertility Index to evaluate the impact of surface mining activities on soil health and productivity.

The results indicate that the Mining Site recorded the most degraded soil conditions among all study locations. The organic carbon content at the mining site was observed to be only 0.42%, which is considerably lower than other areas. Low organic carbon indicates poor soil structure, reduced microbial activity, and lower nutrient availability. Continuous excavation, removal of topsoil, and deposition of mining waste are major reasons for the decline in soil organic matter in mining regions. The soil pH at the mining site was recorded at 8.2, indicating alkaline soil conditions. Increased alkalinity may result from the accumulation of mineral residues and overburden materials generated during mining operations.

The concentration of heavy metals at the mining site was found to be 62 mg/kg, which is significantly higher than the other locations. Elevated heavy metal content in soil is a serious environmental concern because it can reduce soil productivity and may enter the food chain through crops and vegetation. Due to these adverse conditions, the Soil Fertility Index of the mining site was categorized as “Low,” indicating severe degradation of soil quality and reduced agricultural potential.

In the Agricultural Land area, soil quality was comparatively better than the mining site but still showed signs of environmental stress. Organic carbon content was recorded at 0.78%, while soil pH was 7.6, indicating slightly alkaline conditions. Heavy metal concentration was observed at 38 mg/kg, suggesting moderate contamination possibly caused by dust deposition, runoff, and transportation activities associated with nearby mining operations. The Soil Fertility Index in this area was categorized as “Medium,” reflecting moderate soil productivity and partial environmental impact.

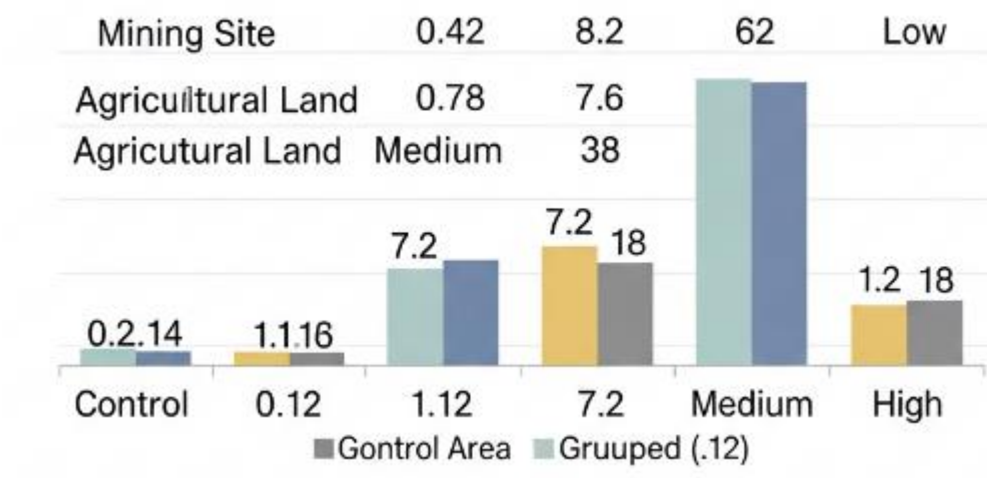

Figure 2: Soil Quality Indicators

The Control Area exhibited the best soil quality conditions among all locations. Organic carbon content was highest at 1.12%, indicating healthy soil with better nutrient retention and biological activity. The pH value of 7.2 represented nearly neutral soil conditions, which are favorable for plant growth and agricultural productivity. Heavy metal concentration was significantly lower at 18 mg/kg, showing minimal contamination in areas unaffected by mining activities. Consequently, the Soil Fertility Index of the control area was classified as "High."

Erosion of soil and destabilization of land surfaces are also significant environmental concerns identified in this study. The removal of vegetation cover and topsoil has exposed large areas of land to wind and water erosion. During field observations, it was found that loose overburden material and mining waste dumps are highly susceptible to erosion, particularly during the monsoon season [17]. This results in the movement of sediments into nearby agricultural fields and water bodies, thereby affecting both land and water quality. The absence of proper slope stabilization measures and inadequate reclamation practices in many mining sites further aggravates the problem of land instability. In some areas, deep mining pits have created uneven land surfaces, increasing the risk of land subsidence and accidental hazards.

Deforestation and loss of vegetation cover are closely linked with surface mining activities in the Bhilwara region [18]. The expansion of mining operations has led to the clearing of natural vegetation in surrounding areas, either directly for mining or indirectly for supporting infrastructure development. Vegetation plays a crucial role in maintaining soil stability, preventing erosion, and supporting biodiversity; however, the removal of green cover has significantly reduced the ecological resilience of the region. Field surveys indicate that vegetation regeneration in abandoned mining sites is extremely slow due to poor soil quality and lack of organic matter [19]. In many cases, natural re-vegetation is completely absent, resulting in permanently degraded landscapes that remain barren even after mining activities cease [20].

Conclusion

Noise and vibration pollution caused by blasting and heavy machinery operation were also identified as important environmental concerns. The study observed that noise levels in mining zones frequently exceeded permissible limits, particularly during drilling and blasting operations. Continuous exposure to high noise levels has affected the physical and psychological well-being of workers and nearby communities. Vibrations generated from blasting activities have caused structural damage to nearby houses and disturbed local residents. The findings indicate that environmental monitoring related to noise and vibration is often neglected in the implementation phase of mining projects. Consequently, the study concludes that scientific blasting techniques, proper scheduling of mining operations, and installation of noise reduction systems are necessary for minimizing these impacts.

The study also highlights the ecological consequences of surface mining in Bhilwara district. Mining expansion has resulted in deforestation, habitat destruction, and loss of biodiversity in several areas. Removal of vegetation and topsoil has disrupted local ecosystems and reduced the natural capacity of the environment to regenerate. Wildlife movement and natural habitats have been adversely affected due to mining activities and associated infrastructure development. Green belt development programs initiated by mining companies were found to be insufficient in restoring ecological balance. Thus, the study concludes that biodiversity conservation and ecological restoration must become integral components of environmental management plans in mining regions.

From a socio-economic perspective, the study found that surface mining has generated both positive and negative impacts on local communities. On one hand, mining activities have increased employment opportunities, infrastructure development, transportation facilities, and regional economic growth. On the other hand, environmental degradation, health problems, displacement of local populations, and reduction in agricultural productivity have adversely affected the quality of life of nearby residents. The study concludes that the benefits of mining are unevenly distributed, while environmental and health burdens are largely borne by local communities. Public participation in the Environmental Impact Assessment process was also found to be limited, reducing the effectiveness of environmental decision-making. Therefore, greater involvement of local communities in environmental planning and monitoring is essential for achieving sustainable mining development.

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