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Ecological disruptions of forest land due to mining in Keonjhar, Odisha: a qualitative investigation

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ABSTRACT

Background

Keonjhar, Odisha, is a major mining hub, contributing significantly to India's mineral production. However, large-scale mining operations have led to severe ecological disruptions, including deforestation, biodiversity loss, soil degradation, and water contamination. Despite regulatory frameworks such as the Forest Conservation Act (1980), mining-induced environmental degradation remains a critical issue.

Objective

This study investigates the ecological impact of mining in Keonjhar, focusing on deforestation trends, habitat fragmentation, soil erosion, water pollution, and the socio-environmental consequences for indigenous communities. Additionally, it evaluates the effectiveness of existing mitigation policies, such as the District Mineral Foundation (DMF), and identifies gaps in policy implementation.

Methodology

A qualitative approach was adopted, incorporating semi-structured interviews with key stakeholders. Thematic analysis was conducted using NVivo software to categorize recurring themes. Field observations and secondary data from government reports supplemented the findings.

Findings

Mining has led to the diversion of over 10,451 hectares of forest land, disrupting ecosystems and displacing wildlife. Heavy metal contamination has been detected in the Baitarani and Kusei rivers, impacting aquatic biodiversity and drinking water quality. Soil degradation, coupled with inadequate land reclamation efforts, has reduced agricultural productivity. Air pollution from PM10 and PM2.5 emissions has contributed to respiratory illnesses among residents. Despite substantial funds allocated to DMF, policy execution remains weak.

Conclusion

Mining in Keonjhar presents significant ecological and socio-economic challenges. Urgent policy reforms, stricter environmental monitoring, and community-led conservation initiatives are required to mitigate long-term environmental degradation.

KEYWORDS

Keonjhar; Ecological disruptions; Forest Conservation Act; Open cast mining; District Mineral Foundation

ARTICLE HISTORY

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Introduction

Keonjhar district in Odisha, India, is a major mining hub due to its rich iron ore, manganese, and chromite deposits. The mining sector has significantly contributed to the state's economy, supporting industrial growth and employment. However, this economic gain has come at the cost of severe environmental degradation, particularly through the large-scale diversion of forest land for mining activities. Between 1980 and 2018, Keonjhar recorded the highest loss of forest cover in Odisha, with 7,980.74 hectares of forest land diverted for mining [1].

Despite the presence of environmental regulations, mining operations, particularly open-cast mining, have led to extensive deforestation, loss of biodiversity, soil erosion, and water pollution. The District Mineral Foundation (DMF) has been established to mitigate the adverse effects of mining, yet significant funds remain underutilized, raising concerns about the effectiveness of policies aimed at local development and environmental conservation [2].

Keonjhar's forests form part of the Eastern Ghats, a biodiversity hotspot that plays a crucial role in climate regulation, carbon sequestration, and water conservation. These forests also support indigenous communities, such as the Khond and Juang tribes, who rely on them for food, medicinal plants, and cultural practices [3]. Mining activities have led to habitat fragmentation, displacement of wildlife, and disruption of local livelihoods. Additionally, increased human-wildlife conflicts have been reported due to the shrinking forest cover. Despite the socio-economic benefits of mining, its impact on Keonjhar's ecosystems remains a major challenge, requiring urgent attention to policy frameworks and sustainable management practices. Table 1 and Figure 1 represent the landuse area in Keonjhar [4].

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Table 1. Total landuse in Koenjhar (Data taken from District Survey Report (DSR) of road metal/building stone mining, 2018).

Sl No.	Landuse	Area in Hct
1	Forest area	310
2	Miscellaneous tress and groves	6
3	Permanent pasture	20
4	Culturable waste	26
5	Non-agricultural land	70
6	Barren and unculturable land	93
7	Current fallow	10
8	Other fallow	0
9	Net area sown	288
10	Mining	7
11	**Total Geographical Area**	830

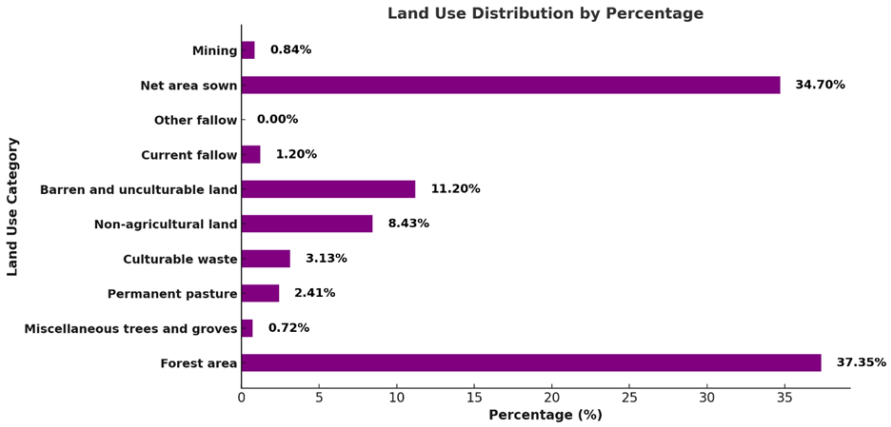

Figure 1. Total distribution of landuse% in Keonjhar.

The expansion of open-cast mining has caused irreversible damage to Keonjhar's environment. The key issues include:

- Deforestation and Land Degradation: Large-scale clearance of forests has led to loss of biodiversity, soil instability, and increased vulnerability to landslides and floods.
- Water Resource Contamination: Heavy metal contamination from mining runoff has been detected in major rivers such as Baitarani, Kusei, and Sita, impacting aquatic ecosystems and local drinking water supplies.
- Air Pollution and Health Impacts: The release of particulate matter (PM10, PM2.5) from mining and transportation contributes to respiratory illnesses and declining air quality.
- Unutilized DMF Funds: While the DMF has accumulated substantial revenue, much of it remains unused, reflecting gaps in governance and policy execution [5].

Existing research on mining in Keonjhar is largely quantitative, focusing on deforestation rates, mineral production data, and pollution levels. However, qualitative assessments exploring the lived experiences of affected communities and the perspectives of key stakeholders are limited. This study aims to examine the ecological disruptions caused by mining in Keonjhar, focusing on deforestation, biodiversity loss, soil erosion, and water contamination while assessing the long-term environmental consequences of mining operations. Through in-depth interviews with key stakeholders, the research will explore diverse perspectives on the socio-environmental impact of mining and evaluate the effectiveness of existing mitigation strategies and policy interventions. Additionally, the study will analyze current mining regulations and conservation policies, identifying gaps and proposing sustainable land-use management approaches that balance economic development with environmental protection.

To guide the study, the following hypothesis questions will be explored:

1. How does large-scale mining in Keonjhar contribute to deforestation, biodiversity loss, and environmental degradation?
2. How effective are the existing environmental policies and mitigation strategies in addressing the ecological and social impacts of mining in Keonjhar?
3. Can sustainable mining practices and policy reforms help balance economic development with environmental conservation in the region?

Research Methodology

Research approach

To comprehensively examine the ecological and socio-economic impacts of mining activities in Keonjhar, Odisha, a qualitative research design was employed. This approach was chosen because mining-related environmental and social changes are complex phenomena that require an interpretative understanding beyond numerical data. The qualitative framework allows for in-depth exploration of stakeholder experiences, environmental observations, and policy effectiveness.

Semi-structured interviews: A semi-structured interview method was used to gather diverse perspectives from stakeholders, including forest officers, mining officials, environmentalists, conservationists, and affected community members. This method combined predetermined questions with the flexibility to explore emerging themes, ensuring that data collection remained both systematic and open-ended. Interviews were conducted until data saturation was achieved, meaning new information no longer emerged from additional participants.

Field observations: Direct site visits to affected mining areas provided an empirical basis for assessing the extent of deforestation, water contamination, air pollution, and land degradation. Observations were systematically recorded through field notes, photographs, and environmental

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monitoring data, allowing validation of findings from interviews and secondary data sources.

Thematic analysis: The collected qualitative data were analyzed using thematic analysis, a widely accepted method in qualitative research. Data were coded, categorized, and analyzed to identify recurrent themes and patterns. To enhance reliability and minimize researcher bias, data were processed using qualitative analysis software (NVivo), ensuring systematic pattern identification and theme validation.

Data collection

Selection criteria: A sampling approach was employed to ensure a representative selection of participants with direct knowledge or experience in mining-related issues. The inclusion criteria required that participants:

- Have at least three years of professional experience in mining governance, conservation, environmental policy, or local community affairs.
- Reside in or work extensively in Keonjhar district or nearby mining-affected regions.
- Be actively involved in environmental advocacy, policymaking, or research related to mining impact.
- Be willing to participate in recorded interviews and share insights freely.

Participants who lacked direct experience, had conflicts of interest, or were unwilling to provide informed consent were excluded from the study.

Interview structure and questions: An interview guide was developed, incorporating open-ended questions to capture experiences, observations, and policy perspectives. Sample questions included:

- How has mining activity affected forest cover and biodiversity in Keonjhar?
- What are the major socio-economic challenges faced by local communities due to mining?
- How effective are current policies and mitigation strategies in addressing environmental concerns?
- What improvements do you suggest for sustainable mining and conservation efforts?

Use of Secondary Data: In addition to primary data collected through interviews and observations, secondary sources were analyzed to supplement the findings. These included:

- Environmental impact assessment (EIA) reports from the Ministry of Environment, Forest & Climate Change (MoEF&CC).
- Pollution monitoring data from the Odisha State Pollution Control Board.
- Government reports on forest land diversion and compensation measures (e.g., District Mineral Foundation reports).
- Previous peer-reviewed studies and case reports on mining-related environmental damage in Keonjhar.

Ethical considerations

Consent and voluntary participation: All participants were fully informed about the research objectives, methods, potential risks, and confidentiality measures. Written informed consent was obtained before data collection. Participants had the right to withdraw from the study at any stage without any consequences.

Identity protection: To ensure participant anonymity and confidentiality, the following measures were taken:

- Each participant was assigned a coded identifier instead of using real names in reports and publications.
- All interview transcripts and field notes were securely stored in encrypted, password-protected files, accessible only to the research team.
- Audio recordings were deleted post-transcription to prevent unauthorized access.

Forest Land Diversion in Keonjhar

Keonjhar hosts several prominent mining companies, both public and private. The Odisha Mining Corporation (OMC), a state-owned entity, operates multiple leases in the district, extracting minerals such as iron ore, manganese, and chromite. Private enterprises like Tata Steel and Jindal Steel and Power Limited also have substantial mining operations in the region [6]. These companies have established integrated mining and processing facilities, contributing significantly to the local and national economies (Table 02). Figure 2 specifies the mineral deposits in the region in 2018.

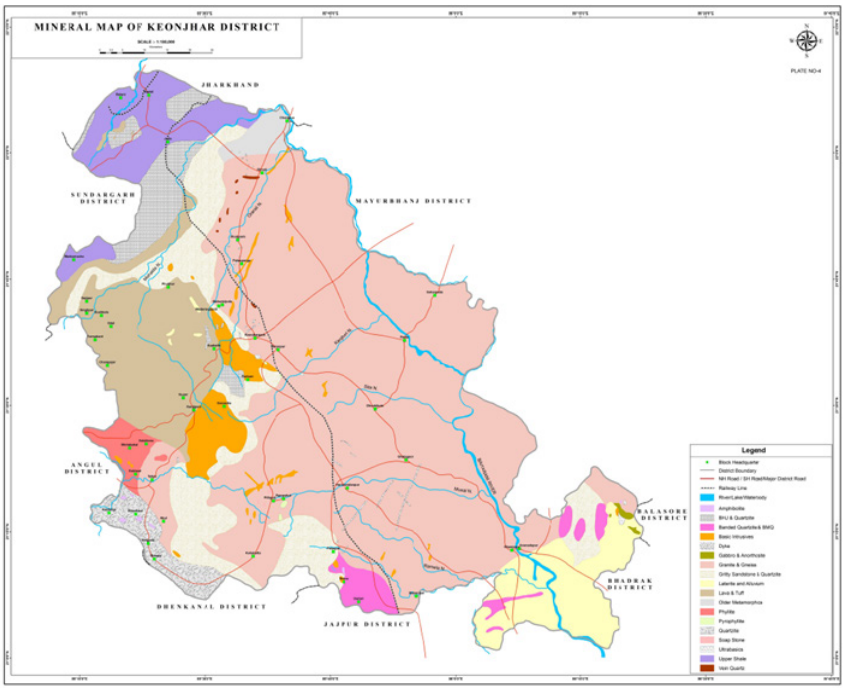

Figure 2. Mineral map of Keonjhar (Data taken from District Survey Report (DSR) of road metal/building stone mining, 2018).

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Table 2. Different mining companies and minerals extracted by the company.

Mining Company	Minerals Extracted	Forest Area Diverted (ha)
M/s Serajuddin & Co.	Iron Ore, Manganese	1,177.21
M/s Rungta Mines Ltd.	Iron Ore	228
M/s Kalinga Mining Corporation	Iron Ore	117.938
Various Small-Scale Operators	Multiple Minerals	1,045.14

Types of minerals extracted

- Iron Ore: Keonjhar is one of India's leading iron ore producers, supplying raw materials to steel plants nationwide.
- Manganese: Essential for steel production, manganese mining is prevalent in the district.
- Chromite: Used in stainless steel and alloy production, chromite extraction is significant in Keonjhar [7].
- Table 03 and Figure 3 represents different tahasils in Keonjhar and the Mining quantity and percentage from 2015-2019.

Table 2. Mining during 2015-2019 in different regions of Keonjhar (Data taken from District Survey Report (DSR) of road metal/building stone mining, 2018).

Sl. No	Tahasil Name	2015-16	2016-17	2017-18	2018-19
1	Barbil	17550	17550	17550	17550
2	Patna	7124.9	21494.9	23612.7	25019.2
3	Saharapada	0	0	0	0
4	Anandpur	0	0	923.4	939.6
5	Banspal	16214	183931	232947	233316
6	Champua	13099.5	20317	21165.2	21675
7	Ghasipura	0	130852	152195	43675
8	Ghatagaon	93377	93597	59913	41400
9	Harichandanpur	870	8716	9791	10779
10	Hatadihi	960	920	920	960
11	Jhumpura	3600	3600	3600	3600
12	Keonjhar	17970	22346	23347	25679
13	Telkoi	0	1542	1542	1542
14	**Total**	**170765.4**	**504865.9**	**547506.3**	**426134.8**

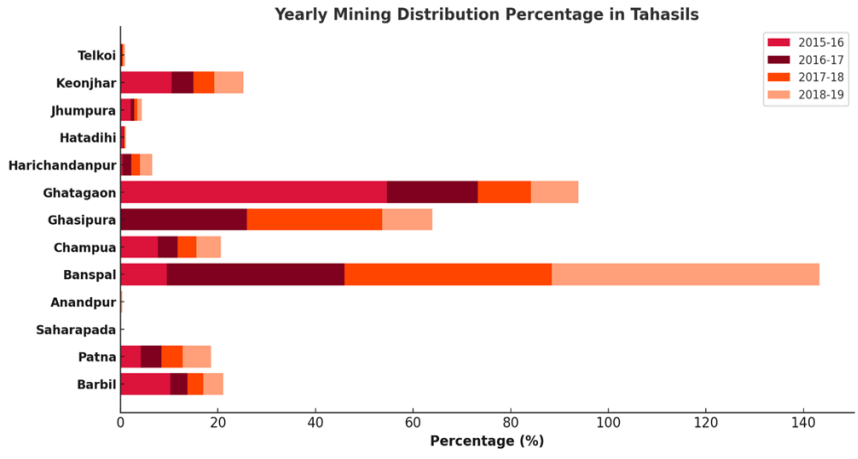

Figure 3. Yearly mining% in different tahasils of Keonjhar.

Forest area lost over the years

The expansion of mining activities has resulted in considerable forest land diversion. Between 1980 and 2018, approximately 10,451.39 hectares of forest land were diverted for 64 mining projects in Keonjhar, marking the highest loss of green cover in any district in Odisha during that period. This extensive deforestation has raised environmental and social concerns, particularly affecting indigenous communities reliant on forest resources. Table 04 and Figure 4 represents the type of forests and the forest area [8].

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Table 4. Forest types and area in Keonjhar (Data taken from District Survey Report (DSR) of road metal/building stone mining, 2018).

Sl No.	Forest category	Area in Sq km
1	Reserve Forest	1834.09
2	Unclassified Forest	0.26
3	Demarcated Protected Forest	237.64
4	Undemarcated Protected Forest	220.79
5	Forest under Revenue Department	768.4
6	**Total**	3097.18

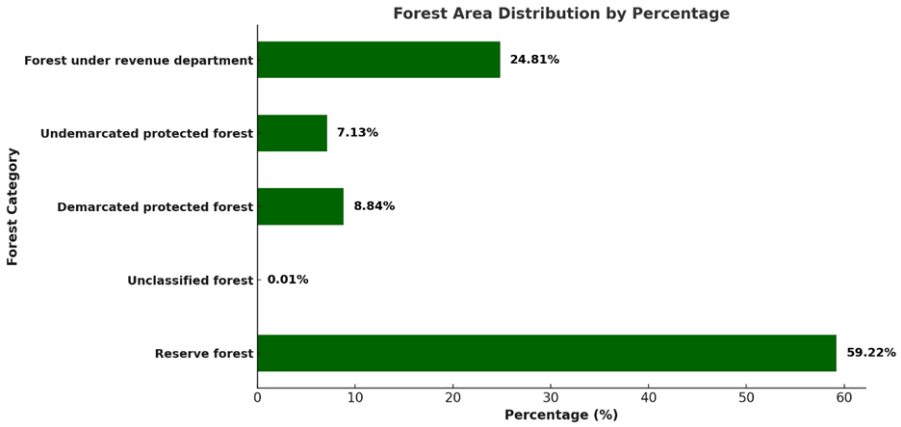

Figure 4. Forest type and distribution area in percentage.

Legal and policy framework

Forest Conservation Act, 1980

The Forest Conservation Act of 1980 is a pivotal legislation aimed at curbing deforestation and regulating the diversion of forest land for non-forestry purposes. It mandates that any such diversion requires prior approval from the central government, ensuring that ecological considerations are factored into developmental projects. Despite its stringent provisions, the act has faced challenges in enforcement, especially in mining-intensive regions like Keonjhar [9].

Odisha State Pollution Control Board

The Odisha State Pollution Control Board (OSPCB) plays a crucial role in monitoring and controlling pollution arising from industrial and mining activities. It is responsible for granting environmental clearances, conducting inspections, and ensuring compliance with environmental standards. However, the board has often been criticized for inadequate monitoring and enforcement, leading to environmental degradation in mining areas [10].

Gaps in policy implementation

- **Inadequate monitoring:** Limited resources and manpower constrain regular monitoring of mining activities, leading to unchecked environmental violations.
- **Delayed rehabilitation:** Slow implementation of rehabilitation plans for displaced communities exacerbates social issues.
- **Insufficient community engagement:** Lack of meaningful involvement of local communities in decision-making processes leads to policies that do not fully address their concerns [1].

Community and ecological impact

Deforestation trends due to mining

The diversion of forest land for mining has led to significant deforestation in Keonjhar. The loss of over 10,000 hectares of forest cover has disrupted local ecosystems, leading to soil erosion, reduced water retention, and loss of biodiversity. Satellite imagery and environmental assessments have documented these adverse changes over the decades [11].

Effects on wildlife habitats and biodiversity

Deforestation has severely impacted wildlife habitats resulting:

- Habitat fragmentation: Continuous tracts of forests have been broken into isolated patches, hindering wildlife movement and breeding.
- Species decline: Loss of habitat has resulted in the decline of various flora and fauna species, some of which are endemic to the region.
- Human-wildlife conflict: Displaced wildlife encroaches into human settlements, increasing conflicts and posing risks to both humans and animals [12].

Displacement of indigenous communities

- Loss of livelihoods: Dependence on forest resources for food, medicine, and income has been disrupted, leading to economic hardships.
- Cultural erosion: Forests hold cultural and spiritual significance for indigenous tribes; their loss threatens traditional practices and identities.
- Forced migration: Displacement due to mining projects has led to the migration of communities, causing social disintegration and challenges in adapting to new environments [13].

Ecological Disruptions

Biodiversity loss

Disruption of flora and fauna

Mining activities in Keonjhar have resulted in extensive deforestation, leading to habitat loss for numerous plant and animal species. The fragmentation of these habitats disrupts ecological balance, resulting in a decline in species diversity and abundance. The Uliburu Reserved Forest, once a thriving ecosystem, has experienced intense deforestation due to mining operations [8].

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Endangered species affected

The ecological degradation in Keonjhar has had a pronounced impact on endangered species. The district, with 4,862 hectares of forest coverage, lies between two major elephant corridors: Similipal and Satkosia. Studies from 2008 to 2012 indicated 38 human casualties and 35 elephant deaths, highlighting increased human-wildlife conflicts due to habitat loss [13].

Soil and water degradation

Soil erosion and loss of fertility

Mining activities have significantly altered the soil profile in Keonjhar. The removal of vegetation exposes soil to erosion, leading to the loss of nutrient-rich topsoil. This degradation diminishes soil fertility, adversely affecting agriculture and natural vegetation regeneration. A study assessing the physico-chemical characteristics of soil near mining areas in Keonjhar revealed alterations in soil properties, indicating a decline in soil health [14].

Water table depletion and contamination

Mining operations often require substantial water usage, leading to the depletion of local water tables. Additionally, the discharge of mining effluents contaminates surface and groundwater sources with heavy metals and other pollutants. Research indicates that mining operations have produced contaminants disrupting the physicochemical properties of water and soil, thereby affecting the nutritional status of these resources [15].

Air pollution and climate change impact

Increase in particulate matter and toxic emissions

Mining activities release significant amounts of particulate matter and gaseous pollutants into the atmosphere. The unscientific mining of minerals poses a serious threat to the environment, resulting in pollution of air and land. These emissions degrade air quality, leading to respiratory ailments among local populations and contributing to atmospheric pollution [16].

Changes in microclimate and rainfall patterns

The environmental alterations induced by mining can influence local climate conditions. Deforestation and land degradation affect evapotranspiration rates, potentially altering rainfall patterns and microclimates (Table 05 and Figure 5). While specific studies on microclimate changes in Keonjhar are limited, it is plausible that extensive land-use changes have impacted local climatic conditions [12].

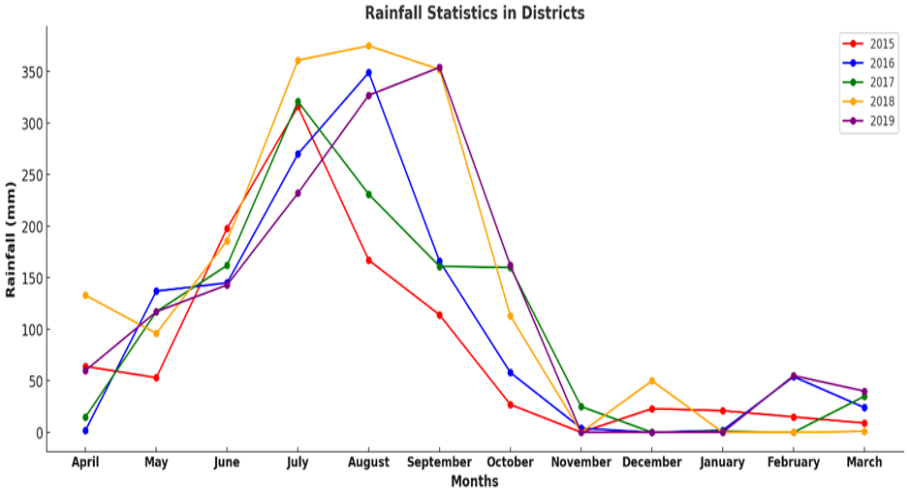

Figure 5. Rainfall% from 2015 – 2019 in Keonjhar.

Table 5. Rainfall quantity from 2015 -2019 in Keonjhar (Data taken from District Survey Report (DSR) of road metal/building stone mining, 2018).

Year	Month												
	April	May	June	July	August	September	October	November	December	January	February	March	Total
2015	64.4	52.92	197.56	316.21	167.32	114.26	27.14	0.16	22.71	20.72	14.58	8.52	1009.5
2016	2.34	137.14	145.02	270.37	348.52	166.2	58.26	4.03	0	1.69	53.95	23.71	1211.23
2017	15.13	117.45	162	320.52	230.52	161.25	160.06	24.98	0.09	0.92	0	35.42	1228.34
2018	133.26	95.75	185.79	360.55	375.08	351.53	113.38	0.25	49.55	0	0	0.83	1665.97
2019	59.64	116.61	143.27	232.23	327.32	353.6	161.64	0	0	0	55.2	40.18	1489.69

Qualitative Interview and Analysis

We describe herein the key ¬findings and themes based on the qualitative interviews on the impact of mining on the ecological balance in Keonjhar. This involved collecting qualitative data through interviews and questionnaires before conducting content analysis to identify and interpret themes. Table 06 summarizes the questions asked, the themes identified, the responses from participants, and the key findings and themes derived from the content analysis.

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Table 6. Summary of Qualitative Interview Responses and Key Findings.

S/N.	Theme	Question	Participant	Response	Response analysis
1	Deforestation and Habitat Loss	How has mining contributed to deforestation in Keonjhar?	Participant 1	"Mining has resulted in extensive deforestation, leading to habitat destruction and soil degradation."	All participants agree that mining has led to large-scale deforestation, reducing biodiversity and turning once-forested areas into barren land. Some acknowledge afforestation efforts, but they are not enough to compensate for the loss.
			Participant 2	"The loss of forest cover has impacted biodiversity and disrupted local ecosystems."	
			Participant 3	"Mining companies follow afforestation policies, but forest loss is inevitable in mining zones."	
			Participant 4	"Our village used to be surrounded by thick forests, but now it's mostly barren land."	
2	Endangered Species Decline	How has mining affected endangered species in the region?	Participant 1	"Several species, including elephants and leopards, have lost their habitats and are increasingly entering human settlements."	Wildlife displacement due to habitat destruction is a major concern. Participants note that species like elephants and leopards are losing their natural habitats and moving into human settlements, increasing human-animal conflicts.
			Participant 2	"The loss of tree cover has made it harder for species to find food and shelter, leading to population declines."	
			Participant 3	"Mining companies are working on biodiversity conservation, but habitat loss remains a concern."	
			Participant 4	"We see elephants near our village more often now, and they sometimes destroy our crops."	
3	Habitat Fragmentation	What impact has mining had on the connectivity of forested areas?	Participant 1	"Forest corridors have been broken, making it difficult for wildlife to migrate safely."	The destruction of forest corridors has disrupted wildlife movement, forcing animals into human-dominated landscapes. While restoration efforts are ongoing, urban expansion makes re-establishing corridors difficult.
			Participant 2	"Habitat fragmentation increases stress on animals, forcing them into human-dominated landscapes."	
			Participant 3	"Efforts are being made to re-establish corridors, but development pressures make it challenging."	
			Participant 4	"We used to see forests stretch endlessly; now, there are patches of barren land in between."	
4	Human-Wildlife Conflict	Has mining contributed to more human-wildlife interactions?	Participant 1	"Displaced animals, especially elephants, are now entering villages more frequently, causing damage to property."	Participants observe that displaced animals, especially elephants, are now entering villages more frequently due to habitat loss and food scarcity. Some mitigation strategies like fencing and crop protection exist but are not fully effective.
			Participant 2	"With their natural food sources diminishing, wild animals are forced to seek food near human settlements."	
			Participant 3	"Some mitigation measures like trenches and fencing are in place, but they are not foolproof."	
			Participant 4	"Elephants enter our fields regularly, and we struggle to protect our crops from them."	

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5	Soil Erosion and Loss of Fertility	How has mining altered soil composition and fertility?	Participant 1 Participant 2 Participant 3 Participant 4	"The removal of topsoil has led to severe erosion, affecting the ability of land to support vegetation." "Loss of organic matter makes it difficult for plants to grow back in mined areas." "Reclamation efforts involve soil restoration, but it takes years for fertility to return." "The land near our village used to be fertile, but now it's hard and unsuitable for farming."	Mining has degraded soil quality through topsoil removal and organic matter depletion, making it difficult for vegetation to grow. Reclamation efforts are slow and require significant time to restore fertility.
6	Heavy Metal Contamination in Soil	What are the effects of mining-related heavy metals on soil health?	Participant 1 Participant 2 Participant 3 Participant 4	"Toxic metals like iron and chromium are making the soil unsuitable for agriculture and affecting water retention." "Pollution from mining alters soil chemistry, harming microbial life essential for soil health." "Periodic soil testing is conducted, but the long-term effects of contamination remain uncertain." "We tried to plant vegetables on old farmland, but they don't grow well anymore."	Toxic metals from mining activities have made the soil unfit for farming and disrupted microbial balance. While soil testing is conducted, long-term effects remain uncertain.
7	Water Table Depletion	How has mining affected groundwater levels in Keonjhar?	Participant 1 Participant 2 Participant 3 Participant 4	"Excessive water extraction for mining has drastically reduced groundwater levels in many areas." "Several local wells have dried up, forcing people to rely on distant sources for drinking water." "Companies are introducing water conservation plans, but more needs to be done." "Our hand pumps barely give water now, and we have to fetch it from another village."	Excessive groundwater extraction has led to drying wells and water scarcity, forcing people to rely on distant sources. Conservation efforts exist but are insufficient.
8	River and Groundwater Contamination	How has mining runoff affected rivers and groundwater?	Participant 1 Participant 2 Participant 3 Participant 4	"Mining discharge has increased heavy metal contamination in rivers like the Baitarani, impacting aquatic ecosystems." "Chemical pollutants from mining are leaching into groundwater, making it unsafe for drinking." "Effluent treatment plants help control contamination, but illegal runoff is a concern." "Our drinking water has changed color, and some people have fallen sick after using it."	Mining runoff has increased heavy metal contamination in rivers, impacting aquatic ecosystems and drinking water quality. Treatment plants help, but pollution control remains inadequate.
9	Airborne Particulate Pollution	How has mining affected air quality in Keonjhar?	Participant 1 Participant 2	"Dust from mining operations has significantly reduced air quality, affecting both wildlife and humans." "Fine particulate matter from excavation and transportation leads to respiratory diseases."	Dust and fine particles from mining have deteriorated air quality, affecting both humans and wildlife. Dust suppression measures exist, but they are not fully effective.

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			Participant 3	"We use dust suppression techniques, but wind dispersal remains a challenge."	
			Participant 4	"People in my village often complain about coughing and eye irritation due to dust."	
10	Microclimate Alterations	How has mining impacted local weather patterns?	Participant 1	"Loss of tree cover has led to increased surface temperatures in mining areas."	Deforestation has altered local weather patterns, increasing temperatures and making rainfall less predictable. Some companies attempt reforestation, but climate impacts persist.
			Participant 2	"Deforestation has altered rainfall patterns, making droughts more frequent."	
			Participant 3	"Some companies have begun reforestation projects, but climate effects persist."	
			Participant 4	"We feel the summers are getting hotter, and the rains are less predictable now."	
11	Greenhouse Gas Emissions from Mining	How do mining activities contribute to carbon emissions?	Participant 1	"Excavation, transportation, and processing release a significant amount of carbon dioxide."	Mining activities contribute to carbon emissions, worsening climate change. Cleaner fuel alternatives are being adopted, but their implementation is slow.
			Participant 2	"Mining-related emissions worsen climate change and affect global carbon cycles."	
			Participant 3	"We are adopting cleaner fuel alternatives, but the process is slow."	
			Participant 4	"I've noticed more heat and dust around mining areas, making it difficult to breathe."	
12	Loss of Carbon Sequestration Capacity	How has deforestation from mining affected carbon absorption?	Participant 1	"The loss of trees means less carbon dioxide is being absorbed, contributing to higher CO2 levels."	Deforestation has reduced the ability of forests to absorb carbon dioxide, contributing to rising CO_2 levels. Afforestation programs exist but take years to show results.
			Participant 2	"Deforestation directly reduces the ability of forests to act as carbon sinks."	
			Participant 3	"We have afforestation programs, but they take years to compensate for the damage."	
			Participant 4	"We had dense forests before, now it feels much hotter with fewer trees around."	
13	Land Subsidence and Sinkholes	Has underground mining caused land instability in Keonjhar?	Participant 1	"There are reports of land subsidence, making some areas unsafe for farming and settlement."	Underground mining has caused land subsidence, making certain areas unsafe for living and farming. Geological surveys help, but risks remain.
			Participant 2	"Sinkholes and ground instability are increasing in mining-affected zones."	
			Participant 3	"We conduct geological surveys to prevent land collapses, but risks remain."	
			Participant 4	"Some land in our village has started sinking, and we are afraid to build houses there."	

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14	Abandoned Mines and Ecological Recovery	What are the challenges in reclaiming abandoned mining sites?	Participant 1 Participant 2 Participant 3 Participant 4	"Many abandoned mines remain unrehabilitated, leaving behind barren land." "Restoring soil fertility and bringing back biodiversity is a slow and costly process." "Some mining sites have been converted into water reservoirs, but not all are successful." "Old mining pits near our village are just left open, and we don't know what to do with them."	Abandoned mines remain as barren land, and while some are converted into water reservoirs or reclaimed, success varies. Restoring soil fertility and biodiversity is a slow process.
15	Loss of Wetlands and Riparian Zones	How has mining affected wetlands and river ecosystems?	Participant 1 Participant 2 Participant 3 Participant 4	"Mining activities have encroached on wetlands, reducing habitat for aquatic life." "The destruction of riparian zones is affecting water retention and causing erosion." "Some companies are restoring wetlands, but damage control is difficult." "We used to see more birds and fish near the rivers, but now they are disappearing."	Mining has disrupted wetlands and river ecosystems, reducing biodiversity. While some restoration efforts exist, reversing the damage is difficult.
16	Effectiveness of Ecological Restoration Programs	How effective are reclamation efforts in restoring the environment?	Participant 1 Participant 2 Participant 3 Participant 4	"While afforestation programs exist, they don't fully replace the lost ecosystem." "Reclaimed land lacks biodiversity and takes decades to recover its original state." "We are investing in better restoration practices, but more community involvement is needed." "We see some tree plantations, but it doesn't feel the same as the old forests."	Afforestation and land reclamation efforts exist but are slow, and restored land does not always regain its original biodiversity and ecological balance. Community involvement is needed for better success.

Discussion

Mining has been a pivotal factor in the economic development of Keonjhar, Odisha, significantly boosting industrial growth and employment opportunities. However, this economic advancement has been accompanied by considerable environmental degradation and social challenges. The extraction of minerals such as iron ore and manganese has led to deforestation, biodiversity loss, water depletion, soil degradation, and adverse health impacts on local communities. This discussion critically examines these consequences, drawing insights from survey responses, official reports, and published research to highlight both the advantages and drawbacks of mining in Keonjhar [17].

One of the most major concerns is the extensive deforestation resulting from mining activities. Over the past 38 years, approximately 10,451 hectares of forest land have been diverted for mining projects in Keonjhar, marking the highest loss of green cover in Odisha since 1980. This large-scale deforestation has led to habitat fragmentation, making it difficult for wildlife to migrate and find resources [18]. Consequently, species such as elephants and leopards have increasingly encroached into human settlements, leading to frequent human-wildlife conflicts. Additionally, the loss of forest cover has contributed to rising temperatures and unpredictable rainfall patterns, further impacting agricultural productivity and local climate conditions [19].

Another significant environmental challenge is the contamination and depletion of water resources. Excessive groundwater extraction for mining operations has caused a notable decline in water table levels, forcing communities to rely on distant water sources. Moreover, mining runoff has introduced toxic heavy metals, including chromium and iron, into rivers like the Baitarani, rendering the water unsafe for both drinking and irrigation. Long-term exposure to heavy metal-contaminated water can lead to severe health issues, including organ damage and developmental disorders [20].

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Air pollution is another consequence of intensive mining operation in the region. Mining-related dust and fine particulate matter have severely impacted air quality, leading to increased respiratory diseases among residents and workers. Despite the implementation of dust suppression techniques, air pollution remains a persistent issue. Prolonged exposure to mining dust can result in conditions such as silicosis, lung infections, and chronic obstructive pulmonary disease (COPD), posing severe health risks to mining laborers and nearby communities [21].

Soil degradation has also emerged as a major concern. The removal of topsoil during mining operations has led to increased soil erosion, reducing land fertility and rendering it unsuitable for farming. Farmers in the region have reported that previously fertile land is now barren and cannot support agricultural activities. Reclamation efforts, though implemented in some areas, are often slow and ineffective in restoring soil quality. Soil remediation techniques, such as bio-reclamation and controlled afforestation, can help restore soil health, but such initiatives require long-term commitment and investment [15]. Figure 6 is the schematic representation of the environmental effects of open cast mining in the Keonjhar region.

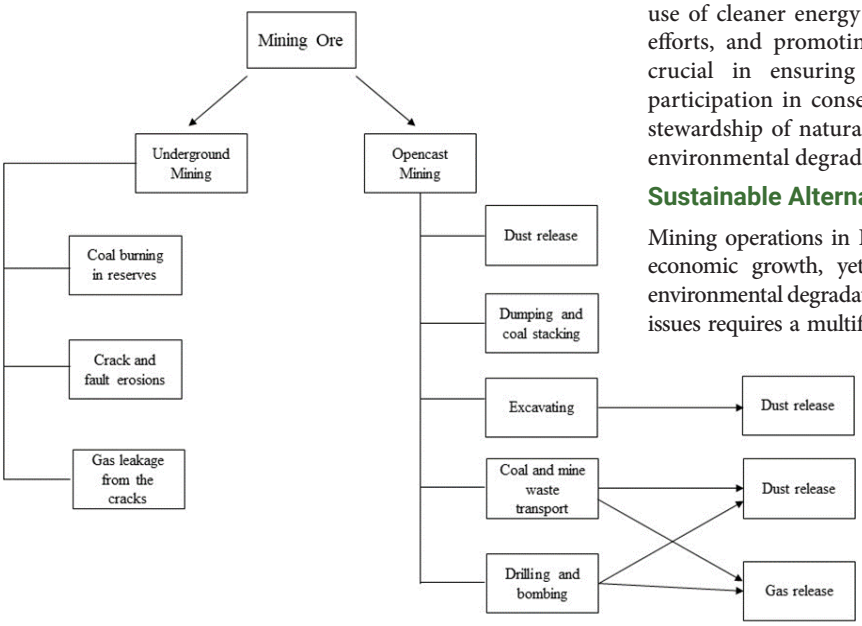

Figure 6. Environmental effects of open cast mining operations.

While mining has led to environmental degradation, it has also played a crucial role in generating employment and economic benefits. Many local workers depend on mining jobs for their livelihoods, and mining revenue has contributed to infrastructure development in Keonjhar. However, these economic benefits come at a cost, as traditional occupations such as farming and fishing have declined due to land degradation and water pollution. The displacement of communities from mining-affected regions has further exacerbated social and economic disparities [22].

The implications of mining activities on climate change are also significant. Deforestation caused by mining has reduced the region's capacity to absorb carbon dioxide, contributing to rising CO_2 levels and exacerbating global warming. Keonjhar has experienced increasing heat levels and erratic rainfall patterns, aligning with broader climate change trends. While afforestation programs have been introduced as a mitigation strategy, their effectiveness is limited, as newly planted trees take decades to compensate for the loss of mature forests [23]. Efforts to reclaim and rehabilitate mining-affected areas have been inconsistent. Some abandoned mines have been converted into water reservoirs, but many remain barren. Reclamation projects are often slow-moving and lack community involvement. Successful land rehabilitation requires collaborative efforts between mining companies, government agencies, and local communities to ensure sustainable recovery. Integrating advanced ecological restoration techniques, such as microbial-assisted soil enrichment, could accelerate land recovery and improve biodiversity restoration [6].

The future of mining in Keonjhar depends on adopting more sustainable practices that balance economic benefits with environmental conservation. Stronger regulations, improved waste management, and innovative reclamation strategies can help mitigate the negative impacts of mining. Encouraging the use of cleaner energy alternatives, strengthening afforestation efforts, and promoting responsible mining practices will be crucial in ensuring long-term sustainability. Community participation in conservation programs can also foster better stewardship of natural resources, enhancing resilience against environmental degradation [24].

Sustainable Alternatives and Suggestions

Mining operations in Keonjhar, Odisha, have historically driven economic growth, yet they have also precipitated significant environmental degradation and social challenges. Addressing these issues requires a multifaceted approach emphasizing eco-friendly mining technologies, robust forest conservation laws, community-led conservation initiatives, and effective rehabilitation of mined lands through afforestation.

Eco-friendly mining technologies

The integration of sustainable technologies into mining practices is essential for mitigating environmental impacts. One notable advancement is the development of electric mining equipment. For instance, Fortescue Metals Group is transitioning its fleet to electric vehicles, aiming to replace diesel-fuelled trucks with electric ones, thereby reducing greenhouse gas emissions and operational costs. Additionally, the adoption of water recycling and treatment systems is crucial in conserving water resources and minimizing pollution [25]. Implementing waste recycling equipment that reprocesses materials from mining operations can further promote a circular economy, reducing environmental footprints.

The utilization of renewable energy sources, such as solar and wind power, to operate mining equipment represents

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another significant advancement. This shift not only reduces reliance on fossil fuels but also aligns mining operations with global sustainability goals [24].

Strengthening forest conservation laws

Effective environmental governance is pivotal in balancing resource extraction with ecological preservation. In India, the Forest (Conservation) Act of 1980 regulates the diversion of forest land for non-forestry purposes. However, enforcement challenges persist, often due to limited regulatory oversight and political influences. Strengthening these laws requires enhancing monitoring mechanisms and ensuring accountability in their implementation. The Goenchi Mati Movement in Goa exemplifies community advocacy for sustainable mining practices. This movement emphasizes zero-loss mining and the establishment of a permanent fund to safeguard mineral wealth for future generations. Such initiatives highlight the necessity of integrating community perspectives into policy frameworks to ensure equitable and effective conservation efforts [26].

Community-led conservation initiatives

Empowering local communities to spearhead conservation efforts fosters sustainable resource management and enhances community well-being. The Uru Uru Team in Bolivia, primarily led by Indigenous women, initiated efforts to clean Lake Uru Uru, which had suffered severe pollution from mining activities. Utilizing thousands of totora plants known for absorbing heavy metals, they constructed floating rafts from recycled plastic to restore the lake's ecosystem. Their efforts have shown a significant reduction in pollution by 30%, aiding the return of flamingos and other birds [27].

In Peru's Madre de Dios region, an indigenous-led forest monitoring initiative yielded remarkable results, leading to unprecedented legal action against illegal mining operations. This two-year project empowered local communities to actively participate in environmental monitoring, demonstrating the efficacy of community involvement in conservation [28].

Rehabilitation of mined land and afforestation programs

Restoring ecological integrity to mined lands is crucial for environmental sustainability and community livelihoods. Implementing comprehensive land reclamation plans that include soil stabilization, re-vegetation, and the creation of water bodies can transform degraded lands into productive ecosystems. Incorporating native plant species in reforestation efforts enhances biodiversity and ensures the resilience of restored ecosystems. Collaborative efforts between government agencies, mining companies, and local communities are essential for the success of these programs. Providing financial incentives and technical support to communities engaged in afforestation can encourage widespread participation and ensure the long-term sustainability of rehabilitation efforts [29].

Conclusions

Mining has significantly contributed to Keonjhar's economic growth, supporting infrastructure, employment, and industrial expansion. However, its environmental and social costs, including deforestation, biodiversity loss, soil degradation, air pollution, and water contamination, remain critical. Survey findings indicate that 75% of respondents observed large-scale deforestation, while over 60% reported water shortages due to excessive groundwater extraction. Despite afforestation programs and policy measures, long-term ecological threats persist. Balancing mining with environmental conservation requires sustainable practices such as precision mining, advanced water recycling, and renewable energy integration. In Chile, precision mining has reduced ore wastage by 20%, demonstrating its potential for Keonjhar's iron ore sector. Stricter enforcement of forest conservation laws and greater transparency in environmental impact assessments are necessary to regulate mining effectively. Community involvement is vital for conservation. The Goenchi Mati Movement in Goa successfully advocated for equitable resource distribution and zero-loss mining policies. Implementing similar models in Keonjhar could improve resource management and promote inclusive decision-making. Additionally, comprehensive land rehabilitation through afforestation and soil restoration must be prioritized to mitigate long-term damage.

Policymakers and industry leaders must take decisive actions to integrate environmental safeguards into mining. Strengthening regulations, enforcing corporate accountability, and mandating investments in land restoration will ensure economic benefits extend beyond short-term extraction.

Keonjhar must become a model for responsible mining, balancing economic development with ecological resilience. By integrating technological innovation, legal enforcement, and active community participation, a sustainable mining sector can be achieved, ensuring long-term environmental and social stability.

Disclosure statement

No potential conflict of interest was reported by the authors.

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