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Advanced analysis of mining-induced fragmentation and its correlation with human-elephant conflict: A case study of the Hasdeo Arand Forest

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Abstract
The Hasdeo Arand forest in Chhattisgarh represents one of the final contiguous deciduous ecosystems in Central India, serving as a critical biological bridge for megafauna. However, the intensification of coal mining has triggered a systemic collapse of ecological connectivity. This study investigates the correlation between mining-induced habitat fragmentation and the escalation of Human-Elephant Conflict (HEC). Utilizing data from the Forest Survey of India (FSI, 2021) [1] and the Wildlife Institute of India (WII, 2021) [3], we analyze the transition of forest patches from "Core" to "Periphery" status. The results indicate that fragmentation is not merely a loss of area but a disruption of behavioral ecology. Mining infrastructure creates "Edge Effects" that degrade habitat quality up to 12km beyond lease boundaries (Sonter *et al*., 2017) [9]. The bisection of ancient migratory corridors forces elephants into human-dominated landscapes, increasing crop-raiding and retaliatory encounters (WTI, 2017; Banda *et al*., 2021) [5]. Socio-economic externalities, including the loss of ecosystem services and tribal social capital, are found to outweigh immediate fiscal gains from coal extraction (Kumar *et al*., 2023) [27]. The study concludes that reinstating "No-Go" zones and adopting "Landscape-Level Management" is imperative to prevent irreversible biodiversity loss.

Keywords: Hasdeo arand forest, mining-induced fragmentation, human-elephant conflict (HEC), ecological connectivity

Introduction

Hasdeo Arand is a vital ecological heartland, spanning approximately 170,000 hectares. Recognized as a "Very Dense Forest" (VDF) by the Forest Survey of India (FSI, 2021), it performs essential functions in carbon sequestration and maintains the hydrological integrity of the Hasdeo Bango Dam catchment. Despite its classification as a "No-Go" zone in historical conservation assessments (MoEFCC, 2012) [6], the region has faced increasing pressure from coal block allocations.The primary driver of ecological instability here is Habitat Fragmentation. As defined by Sudhakar *et al*. (2016) [4], mining activities convert vast, unbroken canopies into isolated "Islands of Green." This triggers the "Edge Effect," facilitating the invasion of non-native species and reducing the genetic connectivity of resident species (Wilson *et al*., 2016; Raiter *et al*., 2018) [11, 18]. These ecological "ripples" extend far beyond physical excavation sites, disrupting the infrasonic communication and migratory paths of the Asian elephant (Jha *et al*., 2019; Nayak *et al*., 2020) [15, 16]. Consequently, HEC has emerged as a critical socio-political crisis. When traditional corridors are blocked, elephants adopt the "Path of Least Resistance," leading through agricultural fields and village settlements (Goswami *et al*., 2015; WTI, 2017) [19].

Research Methodology

This study employs a Mixed-Methods Multi-Disciplinary Approach:

- **Spatial Analysis:** Utilizing Remote Sensing and GIS technologies (Kushwaha *et al*., 2015; Satapathy *et al*., 2022) [17, 28], satellite imagery from 2011 to 2021 was processed to calculate the Fragmentation Index and map habitat "Bottlenecks."
- **Statistical Correlation:** Linear regression was used to correlate coal extraction rates (MTPA) with HEC incident data from the Chhattisgarh State Forest Department (2022) [8].
- **Economic Framework:** An Environmental Economics Framework (Kumar *et al*., 2023) [27] was applied to quantify the loss of Non-Timber Forest Products (NTFP) and the "Chronic Fear" among indigenous populations (Das, 2017; Dickman, 2010) [21, 22].
- **Verification:** All findings were cross-referenced with institutional reports from FSI, WII, and MoEFCC.

Comparative Data Analysis: The Quantifiable Impact

Table 1: Transformation of Forest Matrix (2011 vs. 2021) [1]

Landscape Parameter	2011 Status (Pre-Intensive)	2021 Status (Post-Expansion)	Change (%)	Reference
Total Forest Cover (ha)	~1,70,000	~1,58,000	-7.05%	FSI (2021)
Core Area Index (CAI)	82%	64%	-18.00%	Satapathy (2022) [28]
Edge-to-Area Ratio	0.12	0.28	+133.3%	Sudhakar (2016) [4]
Habitat Connectivity	High (Contiguous)	Low (Fragmented)	High Risk	WII (2021) [3]

Table 2: Correlation between Fragmentation and Conflict (HEC)

Incident Parameter	Avg. Annual (2005-2012)	Avg. Annual (2013-2022)	Increase Factor	Reference
HEC Encounters	12-15	45-60	4.0x	CG Forest Dept (2022)
Crop Damage (Acres)	~250	~1,200	4.8x	Banda *et al*. (2021) [5]
Human Casualties	1-2	8-10	5.0x	District Records (2023) [20]
Compensation Paid (INR)	~20 Lakhs	~4.5 Crores	22.5x	CG Forest Dept (2022)

Analysis of Externalities and Socio-Economic Cost

The economic valuation of Hasdeo Arand extends beyond coal revenue. Kumar *et al*. (2023) [27] highlights that the loss of ecosystem services—specifically water table maintenance and carbon storage—presents a long-term deficit. For tribal communities, the forest represents Social Capital. Displacement leads to the erosion of traditional knowledge systems and identity (Das, 2017) [21]. Furthermore, Dash (2021) [26] notes that the collapse of the Mahua and Tendu-based economy has intensified rural poverty, creating a cycle of dependency and social unrest.

Future Research Directions

- **Acoustic Ecology:** Investigating the specific thresholds of industrial noise that trigger elephant aggression.
- **Restoration Potential:** Assessing the feasibility of converting mined-out lands into functional corridors (Satapathy *et al*., 2022) [28].
- **Genetic Resilience:** Studying the long-term impact of isolated "Islands of Green" on the genetic health of the elephant population.

Conclusion and Policy Recommendations

The evidence confirms that fragmentation in Hasdeo Arand is the primary driver of escalating HEC. Following WII (2014), this study advocates for "Landscape-Level Management." It is recommended that:

1. **"No-Go" Policy:** Strictly reinstate the 2012 classification for core ecological blocks.
2. **Infrastructure Mitigation:** Construct eco-bridges and underpasses on transport routes as per IUCN (2020) [25] guidelines.
3. **Community Empowerment:** Implement GIS-based Early Warning Systems (EWS) to foster coexistence.

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