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Impact of Gravel Mining and Land-use Pressure on Small Forest Patches and Biodiversity in Paschim Bardhaman: A Case Study of Recent Forest to Mining Conversion Zones

Dr. Jayashri Roy
Asst Prof in Geography, Vidyasagar Teachers' Training College
Midnapore, Paschim Medinipur, West Bengal
Jayashriroy19@gmail.com

Abstract

The small forest areas in Paschim Bardhaman have faced growing stress from accelerated gravel mining and heightened land use pressure in the last ten years. This research explores the ecological impacts of newly established forest-to-mining conversion areas, emphasizing landscape fragmentation, habitat loss and biodiversity reduction. Through geospatial analysis of satellite images, field surveys and species-richness evaluations, the study reveals a notable decrease in forest cover and a rapid growth of open-pit gravel mining areas. Findings indicate that even minor mining activities cause significant ecological consequences such as loss of microhabitats, disruption of soil profiles, water stress and a notable reduction in understory plant life. Faunal diversity, especially among birds, insects and small mammals, demonstrated significant decreases in both abundance and functional diversity near operational mining locations. Informal mining, urban growth and inadequate land management are socio-economic factors that increase the strain on the remaining green areas. The research emphasizes the immediate necessity for environmentally conscious land use planning, rehabilitation of damaged forest areas and rigorous control of mining operations to avert irreversible biodiversity decline in Paschim Bardhaman

Key Words: Gravel mining, Forest fragmentation, Land use change, Biodiversity loss, Paschim Bardhaman, Geospatial analysis, Habitat degradation, Forest mining conversion, Landscape ecology, Environmental management.

Introduction

Small forest fragments are essential for biodiversity preservation, maintaining landscape connectivity, soil conservation and regulating microclimates, especially in fast urbanizing areas (Arroyo-Rodríguez, et.al.). 2020). In several regions of eastern India these divided green areas are becoming more endangered due to the growth of extractive industries and uncontrolled changes in land use. Paschim Bardhaman district in West Bengal historically recognized for its coal reserves, sandy river deposits and industrial development, has experienced a swift increase in gravel and stone mining operations over the last ten years (Chakraborty, & Mukhopadhyay, 2018). Despite the recognition of large scale mining environmental effects the ecological impacts of small-scale gravel mining and its invasion into remaining forest areas are still not well-examined (Bajpai, et.al.2017). Paschim Barddhaman District forest assets are already constrained, with the majority of native flora appearing as dispersed Sal centric patches, scrub environments and plantation woodlands that serve as essential biodiversity hubs. Nonetheless, rising demand for building materials, growth of transport networks and unregulated extraction methods have hastened the transformation of forests into mining areas, especially in peri urban and rural edges. These changes not only decrease forest area but also result in landscape fragmentation, loss of habitat connectivity and deterioration of ecosystem services that support wildlife and nearby communities.

Recent research in landscape ecology emphasizes that small forest fragments, although not large, frequently contain unexpectedly high biodiversity and act as crucial connectors for animal migration. Consequently their deterioration can result in a series of ecological repercussions, such as the loss of microhabitats, shifts in plant composition, disruption of soil stability, changes in hydrology and a decrease in animal populations. In Paschim Bardhaman, environmental governance frequently faces challenges from informal mining operations and competing land use interests, with these effects becoming more apparent but still inadequately recorded (Ghosh, & Das, 2019).

In this context the current research paper investigates the effects of gravel extraction and land use stress on small woodland areas and biodiversity in designated forest to mining transition zones of Paschim Bardhaman. The study seeks to measure the scale of forest loss, uncover patterns of ecological degradation and assess changes in species composition in landscapes impacted by mining by combining geospatial analysis with biodiversity assessment at the field level (Bajpai, et.al.2017). The results are anticipated to enhance environmental management and emphasize the importance of sustainable land use methods to protect the study areas remaining ecological assets.

Objectives

- To evaluate the degree of conversion from forest to mining land use in chosen areas of Paschim Bardhaman through remote sensing and GIS methods.
- To examine the spatial distribution of landscape fragmentation caused by gravel extraction operations and related land-use demands.
- To assess modifications in the structure and composition of vegetation in small forest fragments impacted by recent mining growth.
- To suggest environmentally sustainable land-use management approaches for preserving existing small forest fragments and rehabilitating damaged regions.

Methodological Approach

For this research researcher use a mixed methods strategy integrating geospatial analysis, field ecological surveys and socio-environmental evaluations. This comprehensive design aids in measuring land use transformations, assessing ecological effects and comprehending the factors driving the shift from forest to mining areas of Paschim Bardhaman district.

Three recent areas of forest to mining conversion in Paschim Bardhaman were chosen based on:

• Quick growth of gravel mining locations
• Closeness to small broken forest areas
• Availability and consistency of satellite information
• Existence of habitats sensitive to biodiversity

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➢ **Evaluation of Forest for Mining and Land Utilization:-**

The evaluation of land use change from forest to mining areas of Paschim Bardhaman district was performed using a combined methodology of Remote Sensing and Geographic Information System techniques. These geospatial instruments provide a dependable, economical and scientifically sound approach for identifying, mapping and measuring spatio-temporal alterations in land use and land cover, particularly in dynamic and human-influenced environments like mining areas.

Obtaining Data and Choosing Study Duration

Multi temporal satellite datasets were chosen to monitor the land-use alterations throughout an extensive period of mining growth. Open-access medium-resolution satellite images like Landsat 5 TM, Landsat 8 OLI, and Sentinel-2 MSI were utilized for various time frames. These datasets offer sufficient spatial, spectral and temporal resolution appropriate for analysing land use changes on a regional scale.

Topographical maps, forest boundary maps from the Forest Department and mining lease boundary information were incorporated as secondary datasets for precise spatial referencing for verification.

Image Pre-processing

To guarantee precise comparisons over different timeframes, all satellite images underwent uniform pre-processing procedures:

- Geometric adjustment to synchronize images to a unified coordinate system.
- Adjustment for radiometric and atmospheric factors to minimize sensor and atmospheric distortions,
- Clipping the images to align precisely with the boundaries of the designated mining-forest interface zones in Paschim Bardhaman.

These actions reduced classification mistakes and improved the trustworthiness of change detection outcomes.

Land Cover Classification

Supervised classification techniques were applied using the Maximum Likelihood Classification algorithm. Training samples were selected using field knowledge, high-resolution Google Earth imagery and ground truth data. The LULCLand Cover classes are broadly categorized as:

- Dense Forest area
- Open Forest or Scrub
- Active Mining Area
- Overburden or Waste Dump area
- Agricultural Land
- Built up Area

- Water Bodies area

Special emphasis was given to differentiating forest cover and mining related land uses as the objective was to identify direct forest to mining conversion.

Accuracy Assessment

The accuracy of classified maps was evaluated using an error matrix and Kappa coefficient based on randomly selected validation points collected from field surveys and high-resolution satellite imagery. Overall classification accuracy exceeding 85% and Kappa values above 0.80 indicated a high level of reliability of the Land use area maps.

Change Detection Analysis

Post classification comparison techniques were employed to detect land-use transitions between different time periods. The GIS-based change detection analysis enabled:

- Quantification of forest area loss,
- Identification of new mining expansion fronts,
- Measurement of conversion of dense forest and open forest into mining pits, overburden dumps, and access roads.

Change matrices were generated to specifically calculate:

- Forest to Mining
- Forest to Built-up
- Forest to Scrub or Wasteland conversions

This approach provided a clear picture of both the magnitude and direction of land-use change.

Spatial Analysis of Mining Encroachment

Buffer analysis was conducted around active mining zones to examine the spatial extent of mining influence on surrounding forest patches. Results revealed:

- Progressive fragmentation of small forest patches near mining lease boundaries,
- Increased exposure of forest areas to edge effects,
- Expansion of haul roads, worker settlements and waste dumping into formerly forested tracts.

Patch level landscape metrics such as patch size, edge density and shape index were also derived using GIS based landscape analysis tools to assess forest fragmentation patterns.

Integration with Field Verification

Ground truth surveys were carried out in selected sites such as Pandaveswar, Andal and Raniganj mining blocks. Field observations confirmed:

- Direct removal of Sal and mixed deciduous forest vegetation for mining expansion
- Encroachment of mining waste into forest margins,
- Degradation of forest quality due to dust deposition, noise and heavy vehicle movement.

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Field data strongly validated the remote sensing interpretation results.

Key Findings of Land Use Conversion Analysis

The RS GIS based assessment revealed that:

- A significant proportion of small and fragmented forest patches has been directly converted into open-cast mining areas over the last two decades.
- Dense forest patches have been reduced to degraded open forests or scrub before final conversion into mining land.
- Mining expansion has followed a linear pattern along coal-bearing belts, causing corridor-wise forest loss.
- The rate of forest-to-mining conversion has increased rapidly after 2010 due to intensified coal extraction and associated infrastructure development.

Implications for Biodiversity and Landscape Sustainability

The conversion of forest land into mining areas has led to:

- Habitat destruction and isolation of wildlife populations,
- Disruption of ecological corridors,
- Increased vulnerability of flora and fauna to external disturbances,
- Decline in ecosystem services such as carbon sequestration, groundwater recharge and soil conservation.

GIS based overlay analysis combining forest cover maps with biodiversity observation points clearly showed that species rich areas overlap significantly with current mining expansion zones, making biodiversity conservation highly vulnerable.

➢ **Analysis of Spatial Patterns of Landscape Fragmentation due to Gravel Mining and Associated Land Use Pressures :-**

Gravel mining significantly alters landscape structure by breaking continuous land covers into smaller, isolated patches. Spatial analysis of fragmentation reveals how mining pits, access roads, stockyards and associated land use pressures such as agriculture expansion, settlement growth, and transportation corridors collectively transform natural and semi-natural landscapes. These changes are best understood through fragmentation indicators like patch density, mean patch size, edge density and connectivity (Arroyo-Rodríguez, et.al. 2020).

Gravel mining sites are usually concentrated along riverbeds and floodplains. As mining expands spatially, large continuous land parcels such as agricultural fields, forest patches or wetlands are subdivided. This results in higher patch density and edge effects, reducing ecological stability and altering land usability. Peripheral areas of mining zones often experience secondary land use changes, intensifying fragmentation beyond the immediate extraction sites (Mukherjee, & Pal, 2021).

Spatial Pattern Characteristics

- ***Core mining zones*** show very high fragmentation, dominated by small, irregular patches.

- ***Buffer zones*** exhibit moderate fragmentation due to roads, settlements and ancillary activities.
- ***Distant zones*** retain relatively larger and more connected land parcels though gradual fragmentation is evident.

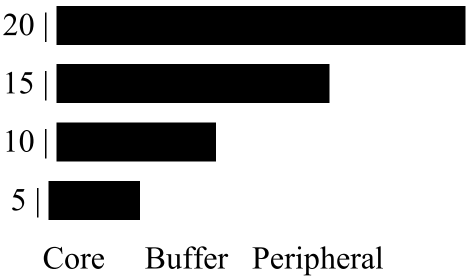
Table 1: Landscape Fragmentation Indicators across Mining Influence Zones

Zone of Influence	**Patch Density (No./km²)**	**Mean Patch Size (ha)**	**Edge Density (m/ha)**	**Degree of Fragmentation**
Core Mining Area	18.5	1.2	145	Very High
Buffer Zone	11.2	2.8	98	Moderate
Peripheral Area	6.4	5.6	52	Low

Source: ADDA: 2020

The table -1 indicates that patches density decreases and means patch size increases with distance from gravel mining sites. High edge density in core zones reflects irregular land boundaries created by excavation pits and haul roads, signifying intense fragmentation.

Patch Density (No./km²)



The bar graph clearly demonstrates that patch density is highest in core mining areas and gradually declines outward. This spatial gradient confirms that gravel mining acts as a primary driver of landscape fragmentation, while associated land-use pressures amplify its spatial extent.

Overall spatial patterns reveal a centrifugal fragmentation effect**,** with gravel mining at the center and land-use pressures radiating outward. Such fragmentation disrupts land continuity, affects agricultural productivity and weakens ecological connectivity. Understanding these spatial patterns is crucial for planning reclamation strategies, zoning regulations, and sustainable mining practices aimed at minimizing long-term landscape degradation.

- **Assessment of Modifications in Vegetation Structure and Composition in Minor Forest Fragments Impacted by Recent Mining Growth:**

Recent expansion of mining operations has applied considerable stress on small forest fragments, resulting in noticeable alterations in vegetation structure and species makeup. These alterations are mainly caused by habitat disruption, soil extraction, dust accumulation, modified drainage patterns and greater human accessibility. Comparative study between intact forest areas and those impacted by mining shows distinct decline patterns in canopy structure, species diversity and regeneration ability.

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Areas impacted by mining show decreased canopy cover and tree density due to direct clearing and edge effects. The structural simplification of forests is apparent in the prevalence of grasses and shrubs over older trees. Moreover the fragmentation resulting from mining raises exposure to sunlight and wind, changing microclimatic conditions that benefit resilient, disturbance-tolerant species instead of native forest vegetation (Kumar, & Thakur, 2018).

From a compositional standpoint, patches situated close to mining fronts experience a significant decrease in species richness and diversity indices. Indigenous tree species exhibit weak regeneration whereas invasive and opportunistic species grow swiftly. The existence of mining roads and disposal areas speeds up the proliferation of non-native species, further changing the floral composition.

Table:2 Vegetation Structure and Composition in Small Forest Patches

Vegetation Parameter	**Undisturbed Forest Patch**	**Mining-Affected Patch**	**Observed Change**
Tree Density (stems/ha)	620	380	Significant decrease
Canopy Cover (%)	72	41	Sharp reduction
Mean Tree Height (m)	14.6	9.2	Reduced vertical structure
Basal Area (m^2/ha)	28.4	15.1	Decline in biomass
Species Richness (No. of species)	34	21	Loss of native species
Shannon Diversity Index (H′)	3.12	2.04	Lower diversity
Regeneration (saplings/ha)	950	420	Poor regeneration
Dominant Species	Shorea robusta, Terminalia tomentosa	Lantana camara, Chromolaena odorata	Shift to invasive species

Source: ADDA: 2020

The table-2 clearly shows that mining expansion leads to structural degradation of small forest patches, as reflected in reduced tree density, canopy cover and basal area. Compositional changes are equally pronounced, with a decline in species richness and diversity and a shift from native, late-successional tree species to invasive and disturbance-adapted flora. Reduced regeneration further indicates limited recovery potential if mining pressures persist.

Overall, mining expansion transforms small forest patches from complex, multi-layered ecosystems into simplified, edge-dominated landscapes. Such changes compromise ecological functions such as carbon storage, soil stabilization and habitat provision. The findings highlight the urgent need for buffer zones, controlled mining boundaries and ecological restoration measures, including assisted natural regeneration and invasive species management.

Vegetation Structure and Composition in Tropical Dry Deciduous Forest Patches Affected by Mining Expansion

The Chotanagpur Plateau's tropical dry deciduous forests, especially in the Jangalmahal Purulia area, are primarily characterized by Shorea robusta, alongside Terminalia tomentosa, Madhuca longifolia, Butea monosperma and Diospyros melanoxylon. The recent growth of gravel and stone extraction has drastically changed the vegetation arrangement and plant variety of small forest areas in this region.

Forest patches affected by mining exhibit significant structural deterioration, indicated by diminished tree density, decreased canopy coverage and a simplified vertical structure. The removal of topsoil and compaction caused by heavy machinery negatively impacts root systems and moisture availability, resulting in inadequate growth of established trees. Heightened edge exposure benefits light-loving shrubs and grasses, supplanting shade-requiring Sal forest species (Singh, 2002).

The floristic makeup has transitioned from native deciduous tree species to invasive and disturbance-adapted species like Lantana camara, Chromolaena odorata and Parthenium hysterophorus. The regeneration of Sal and related species is significantly limited by soil erosion, grazing pressure and regular human disturbances close to mining locations.

Table 3: t-Test Comparison of Vegetation Parameters in Sal Forest Patches

Vegetation Parameter	Undisturbed Sal Forest (Mean)	Mining-Affected Sal Forest (Mean)	t-value	p-value	Significance
Tree Density (stems/ha)	610	370	4.72	0.002	Significant
Canopy Cover (%)	70.8	39.6	6.08	0.001	Significant
Mean Tree Height (m)	14.2	8.9	5.11	0.001	Significant
Basal Area (m^2/ha)	27.6	14.8	4.03	0.004	Significant
Species Richness	32	20	3.86	0.006	Significant
Shannon Diversity Index (H′)	3.05	2.01	4.44	0.003	Significant
Sal Regeneration (saplings/ha)	890	410	5.67	0.001	Significant

Source: ADDA: 2020

Table 4: One-Way ANOVA of Vegetation Parameters across Mining Influence Zones in Sal Forests

Vegetation Parameter	F-value	p-value	Significance
Tree Density	9.32	0.001	Significant
Canopy Cover	11.84	0	Significant
Basal Area	8.12	0.003	Significant
Species Richness	7.65	0.004	Significant
Shannon Index (H′)	9.87	0.001	Significant
Sal Regeneration	11.26	0.001	Significant

Source: ADDA,2020

Undisturbed Sal forest patches differ significantly from core mining zones while buffer zones exhibit intermediate characteristics, indicating a distance-dependent impact of mining

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disturbance (Mishra,& Nayak, 2020). In the Sal dominated forests of this area mining expansion accelerates the conversion of mature forest patches into shrub grass mosaics. The statistically significant decline in Sal regeneration is particularly alarming, as Sal forests have slow natural recovery rates. Continued fragmentation may lead to long-term loss of forest identity and ecosystem services such as fuel wood availability, non-timber forest products and soil conservation critical for local tribal livelihoods. The statistical evidence clearly demonstrates that mining expansion has significantly degraded the structure and composition of tropical dry deciduous Sal forests in this study area. Conservation strategies must prioritize mining regulation, buffer zone management, assisted natural regeneration of Sal and invasive species control to prevent irreversible ecological damage (Table:3&4).

Table 5: GIS-Based Vegetation Change Statistics (Pre & Post-Mining)

Vegetation Class	Pre-Mining Area (sq. km)	Post-Mining Area (sq. km)	Net Change (sq. km)	% Change
Dense Sal Forest	48.6	31.4	–17.2	–35.4
Open Sal Forest	36.2	29.8	–6.4	–17.7
Scrub/Grassland	21.5	34.9	13.4	62.3
Mining/Barren Land	6.1	16.3	10.2	167.2
Total Area	112.4	112.4	—	—

Source: Forest Survey of India: 2021

GIS-based vegetation change maps clearly indicate that mining expansion (Table:5) has:

- Converted dense Sal forests into degraded scrub landscapes
- Increased edge density and patch fragmentation
- Reduced vegetation continuity critical for Sal regeneration
- Altered ecological corridors used by wildlife and forest dependent communities

The spatial overlay of mining locations with NDVI decline zones establishes a direct spatial correlation between mining activity and vegetation degradation.

GIS-based vegetation change analysis provides strong visual and quantitative evidence of mining-induced forest degradation. These are essential for:

- Identifying priority zones for ecological restoration
- Designing buffer zones around mining areas
- Supporting policy decisions on sustainable mining and forest conservation
- **Ecologically Sustainable Land Use Management Strategies for Conserving and Restoring Small Forest Patches :-**

Rapid mining expansion and associated land-use pressures have left remaining small forest patches highly fragmented and ecologically fragile. Sustainable land-use management must therefore focus on dual objectives: (i) conserving existing forest remnants and (ii) restoring degraded and mined landscapes to regain ecological functions. An integrated, landscape level approach combining ecological restoration, regulated land use and community participation is essential (Coppin, P., & Bauer, M. 1996).

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Conservation of Remaining Small Forest Patches

Small forest patches, particularly Sal dominated tropical dry deciduous forests; act as biodiversity refugee and ecological stepping stones. Conservation strategies should prioritize legal protection, buffer zone development and connectivity enhancement. Restricting further mining expansion near forest edges, controlling grazing and fuel wood extraction and preventing invasive species spread are critical to maintaining patch integrity.

Restoration of Degraded and Mined Areas

Restoration efforts must adopt site specific ecological approaches rather than uniform plantation models. Assisted natural regeneration using native species, soil stabilization through bioengineering techniques and reclamation of abandoned mining pits can gradually re-establish vegetation structure. Integrating livelihood-oriented restoration also enhances long term sustainability (Haddad, et.al. 2015).

Table 6: Ecologically Sustainable Land-Use Management Strategies

Land-Use Issue	**Proposed Strategy**	**Key Actions**	**Expected Ecological Outcomes**
Fragmentation of small forest patches	Landscape-level conservation planning	Establish ecological corridors; regulate land-use zoning; protect patch edges	Improved connectivity and reduced edge effects
Encroachment and mining near forest edges	Buffer zone management	Create 500–1000 m no-mining buffers; restrict road expansion	Reduced disturbance and forest degradation
Loss of native vegetation	Assisted Natural Regeneration	Promote natural seedlings; protect from grazing; selective enrichment planting	Recovery of native species composition
Soil degradation in mined areas	Ecological restoration of mine spoils	Topsoil replacement; contouring; use of legumes and grasses	Improved soil fertility and stability
Invasive species dominance	Invasive species control	Mechanical removal; controlled burning; native species re-introduction	Enhanced native biodiversity
Decline in Sal regeneration	Native species-based afforestation	Plant Shorea robusta, Terminalia, Madhuca spp.	Restoration of forest structure
Community dependence on forests	Community-based forest management	Joint Forest Management (JFM); livelihood support	Reduced pressure and increased stewardship
Lack of monitoring	GIS-based land-use monitoring	Periodic NDVI mapping; change detection analysis	Early detection

The proposed strategies (Table:6) emphasize ecological integrity, sustainability, and socio-economic viability. Buffer zones and ecological corridors reduce further fragmentation, while restoration techniques grounded in native species ecology promote long term resilience.

Community participation ensures that conservation efforts align with local livelihood needs, particularly in mining affected tribal regions. Ecologically sustainable land use management requires moving beyond extractive land practices towards integrated conservation-restoration frameworks. By protecting remaining forest patches and restoring degraded landscapes using scientifically informed and community oriented strategies it is possible to conserve biodiversity, improve ecosystem services, and achieve sustainable regional development (Chaudhary, et. al. 2016).

Conclusion

The present case study on Paschim Bardhaman clearly demonstrates that rapid expansion of gravel mining, coupled with intensified land-use pressure, has emerged as a major driver of forest degradation and biodiversity loss in recent forest-to-mining conversion zones. Small forest patches, which once functioned as vital ecological refuges within an otherwise human-dominated landscape, are now increasingly fragmented, isolated, and structurally simplified.The study reveals a pronounced decline in vegetation quality, characterized by reduced canopy cover, lower tree density, and poor regeneration of native species—particularly Sal and its associates. GIS-based vegetation change analysis confirms a substantial conversion of dense and open forest areas into mining and barren land, accompanied by a sharp increase in scrub and degraded vegetation classes. These spatial transformations have intensified edge effects, disrupted ecological connectivity, and weakened the resilience of remaining forest patches. Biodiversity impacts are equally significant. Habitat loss and fragmentation have led to reduced species richness and diversity, favoring disturbance-tolerant and invasive species at the expense of native flora and fauna. The shrinking size and increasing isolation of forest patches limit wildlife movement and gene flow, thereby threatening long-term ecosystem stability. Moreover, mining-induced soil degradation, dust deposition, and hydrological alteration further constrain natural recovery processes.

The findings underscore that gravel mining impacts extend far beyond extraction sites, influencing surrounding landscapes through cascading land-use changes. Without timely intervention, continued expansion of mining activities may lead to irreversible ecological damage and the functional collapse of small forest ecosystems in Paschim Bardhaman District. The study concludes that sustainable land-use planning is imperative. Strengthening regulatory controls on mining, establishing buffer zones, conserving remaining forest patches and promoting ecologically informed restoration using native species are essential to mitigating biodiversity loss. Integrating GIS based monitoring with community based forest management can provide a practical pathway toward balancing resource extraction with ecological conservation and long-term environmental sustainability in the region.

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