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Monitoring Ecorestoration Success using Spatial and Temporal Change Detection Techniques in Nandini Limestone Mines of Chhattisgarh, India

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ABSTRACT

Limestone mining plays a vital role in India's industrial development, particularly in cement and construction sectors. However, large-scale extraction significantly alters land use/land cover (LULC) patterns and degrades ecological balance, especially in mineral-rich regions like Chhattisgarh. This study aims to monitor and evaluate the success of ecorestoration initiatives in the Nandini Limestone Mine, located in Dhamdha block of Durg district, using spatial and temporal remote sensing techniques over a 30-year period (1994–2024). Multi-date satellite imageries from LANDSAT 5 (TM) and LANDSAT 9 (OLI/TIRS) were analyzed using supervised classification and maximum likelihood algorithms in a GIS environment to map five key LULC classes: plantation, scrubland, mining area, wasteland, and water body. The results reveal a significant increase in plantation cover (+26.10%) and water bodies (+2.81%), indicating successful restoration and hydrological recovery. Conversely, scrubland declined sharply (-26.91%), suggesting vegetation transition toward more stable land use types. Mining areas showed a marginal reduction (-1.85%), while wasteland remained relatively unchanged. The study demonstrates that integrating satellite-based LULC analysis with ground truthing provides a powerful and scalable framework for assessing long-term restoration outcomes in degraded mining landscapes. The findings offer crucial insights for sustainable mine closure planning, policy formulation, ecological resilience building and restoration planning in extractive industry zones.

Keywords LULC change detection, Ecorestoration, Mining reclamation, LANDSAT, Post-mining recovery.

INTRODUCTION

India is endowed with substantial limestone reserves, making it one of the key players in the global limestone market. Limestone is a crucial raw material for various industries, especially in cement production, metallurgy, and as a building material. The total reserves/resources of limestone of all categories and grades as per NMI database based on UNFC system as on 1.4.2020 has been estimated at 2,27,589 million tonnes. Chhattisgarh, located in central India, is one of the richest states in terms of mineral wealth, with limestone being a significant component. Despite the

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tremendous support of limestone mining activities on the economic growth of Chhattisgarh and India, its negative impact on ecosystem is of great environmental concern (Sahu and Goel 2004). Mining also severely effects the land use land cover (LULC) and vegetation distribution of the area. These changes are driven by human actions but cause changes that influence humans also (Gbedzi *et al.* 2022). These patterns are one of the important parameters, which depict the changes (Jayakumar and Arockiasamy 2003) and these changes in land use and land cover caused due to anthropogenic activities like mining can be detected on a temporal scale such as a decade (Rawat and Kumar 2015).

Mapping of LULC change is an important activity of land management and monitoring. The changes can be mapped using remotely-sensed multi-date satellite in a Geographic Information System (GIS). Remotely sensed data were used to detect the ongoing change in landscape structure (Pirnazar *et al*. 2018, Rana *et al.* 2024). Now a day remote sensing is a popular tool used for environmental monitoring in various aspects of ecosystems at local, regional, and global scales (Latifovic *et al.* 2004, Jiao 2024). Spatial and temporal changes in the land use/land cover can be quantified using landscape metrics (Sarma *et al.* 2008). Additionally, tracking the re-establishment of native flora and fauna through these methodologies can serve as an indicator of the overall health and resilience of the restored ecosystem (de Sousa *et al.* 2020, Neto *et al.* 2021, Pratiwi *et al.* 2021) paving a way forward to the concept of ecorestoration (Maitry *et al*. 2024, Maitry *et al*. 2025a). Hence, the main objective of the study is to understand the ecorestoration success through geospatial temporal change detection over a 30-year period of time from 1994 to 2024.

MATERIALS AND METHODS

Study site

The study was carried out in Nandini Limestone Mine located in Dhamdha, District- Durg of Chhattisgarh State. The total area of mine is distributed in 1528 hectares located between Latitude N 21° 22’ 25.56” to N 21° 25’ 04.1” and Longitude E 81° 22’ 01.2” to E 81° 23’ 01.88” in which about 549 hectares are covered by core mining lease area and about 978 hectares are covered by outer buffer zone (Fig. 1). The maximum elevation of the site is about 284 meters from mean sea level. The general ground slope is towards N, with gradient about 5°. The district receives an annual rainfall of 1130 mm in which 80% of rainfall was during the month of June-September. The study site exhibited mean annual temperature and humidity around 28.67°C and 56% respectively.

Spatial-temporal change analysis

The study primarily focused on assessing land use/

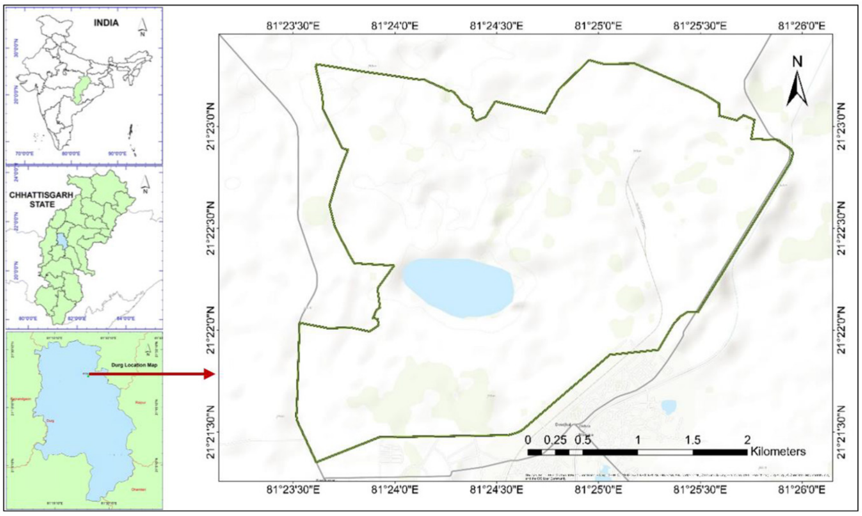

Fig. 1. Geographical location of Nandini Limestone Mines (distributed over a total area of 970 hectares) in Durg, Chhattisgarh.

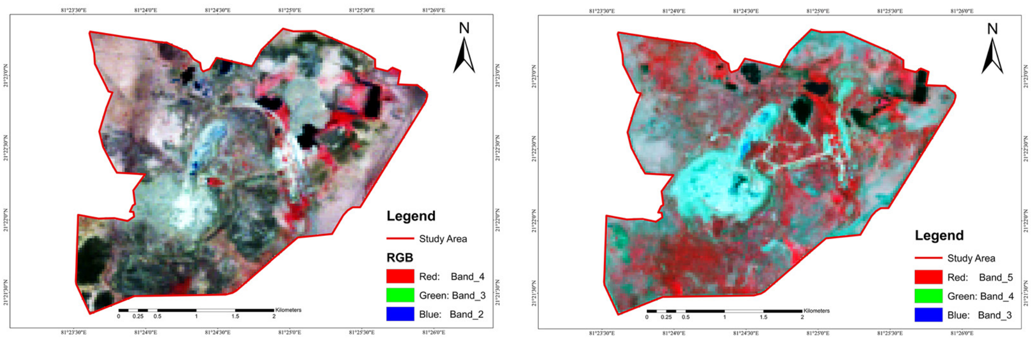

Fig. 2. False Color Composite (FCC) Map of Nandini Limestone Mines for year 1994 (left) and 2024 (right) showing different bands representing various LULC classes.

land cover (LULC) patterns and detecting changes in the Nandini Limestone Mines by analysing open-source data from different time periods. To prepare LULC maps specifically for the years 1994 and 2024 multi-temporal LANDSAT data sets were used, along with various digital image processing techniques. The satellite imageries used for the FCC and LULC classification was acquired from the LANDSAT 5 Thematic Mapper (TM) data set for the year 1994 while the LANDSAT 9 Operational Land Imager (OLI) / Thermal Infrared Sensor (TIRS) data set was used for 2024 (Figs. 2–3). The specifics of the satellite imageries used in the study are provided in Table 1.

All satellite data were obtained from the open data source, Earth Explorer, USGS (United States Geological Survey), with a cloud cover of less than 10%. The downloaded data covers the pre monsoon season in May to reduce seasonal variation and to get uniform spectral and radiometric attributes. A base map of the research area was created using Survey of India (SOI) toposheets at a scale of 1:250,000. All

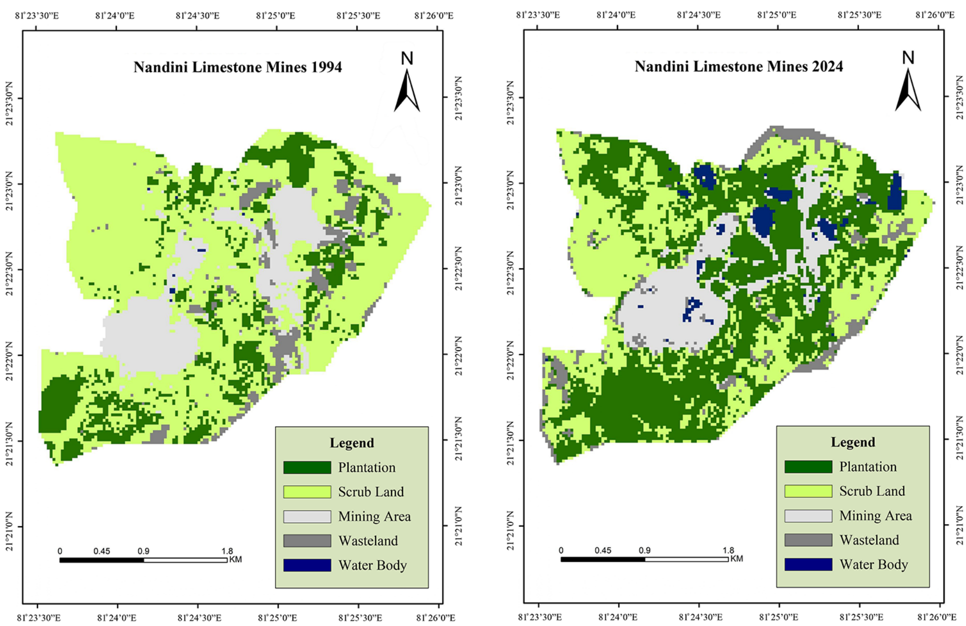

Fig. 3. Land use/land cover (LULC) map of Nandini Limestone Mines for year 1994 (left) and 2024 (right) showing the net changes in five different LULC classes.

Table 1. Satellite image description.

Year	Acquisition date	Satellite	Sensor	Path/Row	Spatial resolution	Spectral resolution
1994	29/05/1994	LANDSAT 5	TM	143/ 45	30 m	7 Bands
2024	23/05/2024	LANDSAT 9	OLI/TIRS	143/ 45	30 m	11 Bands

Table 2. Land use/land cover classes.

Sl. No.	Level I	Level II	Description
1	Plantation	Plantation	It covers all the plantations carried out on wasteland along the roadside, over-burden dumps/backfill areas
2	Scrub land	Scrub land	It covers a vegetative area with less than 10% canopy density
3	Mining area	Active mining	It includes the area of existing quarry sites
		Barren dump	It indicates an overburden dump area which is fallow
4	Wasteland	Dump area	It covers an area in which spoils are dumped
		Waste land	It covers degraded and unutilized lands under mining area
5	Water body	Water body	It comprises all bodies of surface water, such as ponds and streams

satellite imageries were subsequently geometrically corrected. Field surveys and ground truthing were conducted in April-May 2024 using the Geographic Positioning System (GPS), which also aided in image classification and overall accuracy assessment (Garai and Narayana 2018). After downloading the satellite imagery from Earth Explorer, all band layers of the same resolution were imported into ArcMap (version 10.4) and used for digital processing and supervised maximum likelihood classification of satellite images into primary LULC classes (Table 2).

Change detection

The change analysis of various LULC classes were accomplished by using relevant formula and cross tabulation method. Area distribution of various LULC classes were use to detect the trend, net change, percentage change in area and rate of change between the year 1994 and 2024. Change between the years was calculated by subtracting the years' areas for each class whereas percentage change over the given time span was calculated by using following formula:

$$\text{Percentage change} = \frac{\alpha_{t2} - \alpha_{t1}}{A} \times 100$$

RESULTS AND DISCUSSION

The spatial and temporal analysis of Land Use Land Cover (LULC) changes in the Nandini Limestone Mine area over a 30-year period (1994–2024) reveals significant transitions across various land classes (Table 3), highlighting both anthropogenic pressures and restoration efforts (Fig. 3).

Plantation

A notable and encouraging trend is observed in the plantation category, which increased significantly from 1.6892 km² (17.13%) in 1994 to 4.2624 km²

Table 3. Summary of change trends (1994–2024).

LULC classes	1994		2024		Change	
	Area (km²)	Percentage	Area (km²)	Percentage	Area (km²)	Percentage
Mining Area	1.5400	15.619	1.3571	13.764	-0.1829	-1.854
Plantation	1.6892	17.132	4.2624	43.233	2.5732	26.100
Scrub land	6.0255	61.111	3.3722	34.203	-2.6533	-26.908
Wasteland	0.5959	6.044	0.5817	5.900	-0.0143	-0.144
Water Body	0.0093	0.095	0.2859	2.900	0.2766	2.806

(43.23%) in 2024, reflecting a net gain of 2.5732 km² (a +26.1% change). This indicates successful implementation of afforestation and ecological restoration strategies. Such transformations are often linked with regulatory mandates under mine closure plans and compensatory afforestation programs (Ghose 2001, Bandyopadhyay and Maiti 2019). Moreover, this increase reflects a shift toward sustainable post-mining land use practices aimed at stabilizing overburden dumps and improving ecosystem functions (Juwarkar and Jambhulkar 2008). Similar trends were reported in studies monitoring reclamation in coal and limestone mining areas in central India (Akala and Lal 2005, Mehta *et al.* 2024).

Scrub land

The scrub land, which initially covered 6.0255 km² (61.11%) of the landscape in 1994, reduced to 3.3722 km² (34.20%) by 2024, a net loss of 2.6533 km² (-26.91%). This substantial decline may be attributed to natural succession converting scrub into plantation, or to anthropogenic encroachment from mining expansion and infrastructure development (Sudhakar and Reddy 2019). In many post-mining regions, scrubland often serves as transitional vegetation, which when unmanaged, may degrade further or improve under assisted regeneration (Sengupta 2021). In this case, the decline coinciding with plantation increase likely indicates restoration success, aligning with findings by Tang *et al.* (2025) in similar landscapes.

Mining area

The mining area decreased from 1.5400 km² (15.62%) in 1994 to 1.3571 km² (13.76%) in 2024, showing a slight decline of 0.1829 km² (-1.85%). This reduction may signify exhaustion of active mining pits, conversion into reclaimed land uses, or enhanced spatial planning that confines mining within designated boundaries (Sinha *et al.* 2022). Similar observations were reported in Karan *et al.* (2016), where post-operational mines underwent phased land restoration as per statutory guidelines. However, it is also possible that mapping variations or classification shifts between bare dumps and active mining influenced this apparent decrease (Foody 2002).

Wasteland

The wasteland category changed only marginally, from 0.5959 km² (6.04%) in 1994 to 0.5817 km² (5.90%) in 2024, a negligible net change of -0.0143 km² (-0.14%). This stagnant trend suggests that certain degraded patches continue to pose ecological restoration challenges, possibly due to poor soil quality, lack of organic matter, or heavy metal contamination from overburden (Sheoran *et al.* 2010, Bandyopadhyay and Maiti 2019). Such areas often require intensive reclamation inputs such as bio-remediation, soil amelioration, and adaptive plantation techniques (Tordoff *et al.* 2000, Ghose 2004).

Water body

The water body class, though minimal in extent, increased significantly from 0.0093 km² (0.10%) in 1994 to 0.2859 km² (2.90%) in 2024, indicating a gain of 0.2766 km² (+2.81%). This increase likely stems from the formation of pit lakes, rainwater harvesting ponds, and improvement in drainage systems, common in rehabilitated mine sites (Maiti 2007). Such developments not only serve hydrological functions but also promote biodiversity and local climatic amelioration (Wali 1999, de Sousa *et al.* 2020). The positive trajectory of surface water bodies is aligned with the concept of sustainable landscape reclamation as highlighted by Rana *et al.* (2024).

The results demonstrate clear signs of ecorestoration success in the Nandini Limestone Mine area, particularly through increased plantation and surface water presence. The conversion of scrub and mined-out lands into vegetated cover signifies successful land management interventions, possibly supported by policy frameworks such as the Mine Closure Guidelines mandated to submit a 'Progressive Mine Closure Plan' (PMCP) as a part of the Mining Plan (Indian Bureau of Mines 2011) and CAMPA funds. The rise in water bodies adds ecological and hydrological value to the landscape, creating microhabitats and supporting rewilding (Neto *et al*. 2021, Pratiwi *et al.* 2021, Maitry *et al.* 2025b). However, the persisting wasteland areas and scrubland loss warrant continued attention. They underscore the complexity of full ecosystem recovery in post-mining landscapes and call for site-specific restoration strategies that integrate biophysical and socio-economic considerations (Bradshaw 1997, Parrotta and Knowles 2001). The use of remote sensing and GIS-based monitoring has proven to be an effective approach in tracking restoration progress, offering a scalable tool for adaptive land management (Latifovic *et al.* 2004, Sarma *et al.* 2008, Rawat and Kumar 2015, Shah *et al.* 2022). Overall, the findings provide robust evidence of a positive trajectory in land transformation toward more ecologically balanced and resilient post-mining landscapes, contributing to both environmental sustainability and policy objectives.

CONCLUSION

The present study highlights the utility of remote sensing and GIS-based change detection techniques in assessing the spatial-temporal transformation of land use and land cover over a 30-year period (1994–2024) in the Nandini Limestone Mine area of Chhattisgarh. The analysis reveals a significant increase in plantation cover and water bodies, alongside a notable reduction in scrubland and marginal decline in mining areas. These transitions collectively indicate a positive trajectory toward ecological restoration, driven by afforestation, reclamation, and land management initiatives implemented within the mining lease and buffer zones. The considerable rise in plantation area (over 26%) reflects the success of targeted rehabilitation interventions on overburden dumps and degraded lands. The emergence and expansion of water bodies further suggest improvements in microclimatic and hydrological conditions, which are vital for ecosystem recovery. However, the persistence of certain wasteland patches and the substantial decline in scrubland highlight areas where ecological functionality is yet to be fully restored, warranting continued efforts through site-specific and science-based restoration strategies. Overall, the study demonstrates that temporal LULC analysis is an effective tool to monitor and evaluate the outcomes of ecorestoration in post-mining landscapes. The findings support the integration of geospatial technologies into mine closure planning, restoration monitoring, and adaptive landscape management. Moving forward, incorporating biodiversity indicators, soil health parameters, and community participation into restoration frameworks will further enhance the sustainability and resilience of reclaimed mining ecosystems.

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