Mapping the Transition: Evaluating the Land Use and Land Cover Changes in Ib Valley Coalfields, Odisha

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Abstract

The Ib Valley Coalfield in Odisha, one of India's major coal-producing regions, has the third-highest coal reserves in the country. The study assesses how mining expansion and associated developments have reshaped the landscape over nearly five decades. Guided by the research goal of quantifying the impacts of coal mining activity on land use and land cover (LULC) changes, the study leverages multi-spectral/multi-temporal satellite imagery from multiple Landsat missions (2, 5, 7, 8, and 9) acquired between 1976 and 2024. The images were processed and divided into six primary LULC classes—Vegetation, Waterbodies, Mining Regions, Settlements, Industries, and Others—which were identified by employing visual interpretation techniques alongside using advanced band indices, namely, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) to validate the actual features on the ground, along with Google Earth Engine for ground truth. Comparative analysis reveals significant shifts in LULC composition over the study period, during which the expansion of coal mining activities emerged as a dominant driver of change. Results show a pronounced expansion in Mining Regions, from 0.12 km^2 in 1976 to 49.49 km^2 in 2024, reflecting the increasing dominance of open-cast mining. Concurrently, Settlements grew from 10.67 km^2 to 97.06 km^2, underscoring rapid urbanization. By contrast, Vegetation declined from 1304.08 km^2 to 1142.14 km^2, underscoring pressures on natural ecosystems. Waterbodies exhibited modest fluctuations, influenced by reservoir management and rainfall patterns. Moreover, the open land available for agriculture was severely affected as 111.84 km^2 of open land was converted into mines, settlements and industries. The transition matrix of the findings highlights the substantial environmental transformations, emphasizing on how vegetation experienced significant loss, primarily due to urbanization and mining, indicating ecological stress from human activities. Similarly, the conversion of water bodies into agricultural land highlights the growing human demand for cultivable areas, often resulting in the degradation of natural ecosystems. The expansion of extractive industries and urban settlements, collectively reflect the mounting pressures of industrialization and urbanization on the region's ecological balance. This also highlights severe air and water pollution from open-cast mining operations with implications for habitat integrity, water resource management, and regional socio-economic dynamics—environmental assessments. Overall, this study underscores the far-reaching ecological and socio-economic consequences of coal extraction in Ib Valley.

Keywords: Coal Mining, Land Use/Land Cover (LULC), Environment

1. Introduction

Coal Mining is a cornerstone of numerous countries' industrial and economic development, especially in the last 100 years. However, the extensive mineral extraction operations often serve as “The Great Disruptor”, which significantly impacts the socio-economic and ecological landscapes of the societies. However, alongside these changes, there has also been a discernible increase in environmental degradation and natural topography change (Manna and Maiti, 2014) caused by mining activities. Mining leads to changes in land-use patterns, the creation of wastelands, and people's physical and occupational displacement (Lahiri-Dutt, 2014).

This disruption manifests through social displacement, where local communities are forced to relocate due to mining activities, leading to the fragmentation of traditional social structures and the erosion of cultural heritage. Moreover, the incremental land grab due to mining operations affecting forest cover, including dense and open forests, experienced a gradual decline due to deforestation and infrastructure development, which raises environmental concerns in the region driven by the fugitive dust emissions from coal mining operations. These include land degradation resulting from deforestation and habitat destruction, water pollution due to the release of toxic substances and heavy metals into water bodies, and air pollution stemming from dust emissions and the combustion of fossil fuels (K.C, 2015).

The Ib Valley Coalfield, situated primarily in Odisha’s Sundargarh and Jharsuguda districts, lies within the valley of the Ib River—a tributary of the Mahanadi—and to the north of the Hirakud reservoir. The Ib Valley’s terrain—characterized by undulating plains, low hills, and the presence of the Ib River and its tributaries—plays a vital role in shaping the area's drainage systems and ecological equilibrium. Coal was first discovered in the region in 1900 during the construction of a railway bridge, which led to the establishment of the Himgir Rampur Coal Company’s first mine in 1909. The region saw the operation of several private underground collieries until the nationalization of the coal industry in 1973. Initially brought under Western Coalfields Limited, management of the mines transitioned to South Eastern Coalfields Limited in 1986 and Mahanadi Coalfields Limited in 1992. Following nationalization, open-cast mining became the dominant extraction method, with significant operations at Lajkura, Samleswari, and Lilari mines. Coal production experienced exponential growth, increasing from 0.55 million tonnes in 1972–73 to 15.51 million tonnes by 2002–03. Today, the coalfield spans 1,375 square kilometres and holds an estimated 22.3 billion tonnes of coal reserves, ranking it the third-largest in India. It forms a part of the larger Gondwana coal basin, which extends into neighbouring Chhattisgarh.

Mining operations carried out by Mahanadi Coalfields Limited (MCL) in the Ib Valley Coalfield have had a considerable impact on the local environment. Since the nationalization of India’s coal industry in 1973, the region has experienced a marked increase in coal production, primarily driven by open-cast mining. This escalation in extractive activity has triggered significant Land Use and Land Cover (LULC) changes, such as widespread deforestation, expansion of mining zones, and rapid urbanization. This led to severe environmental concerns such as air and water quality degradation, soil fertility loss, and local biodiversity disruptions. These ecological impacts are accompanied by profound socio-economic consequences: local communities have faced displacement, shifts in traditional livelihoods, and increased health risks from mining-related pollution.

Given the region’s rapidly evolving landscape, a detailed assessment of LULC changes provides a critical perspective for understanding the environmental implications of mining, particularly in terms of its influence on landscape dynamics (El Gammal et al., 2010). This study employs remote sensing and Geographic Information System (GIS) tools to analyse the spatial and temporal evolution of LULC patterns in the Ib Valley Coalfield from 1976 to 2024. By combining geospatial data with on-ground realities, the research aims to offer a holistic view of the environmental and socio-economic impacts of mining and to unravel the complex changes reshaping the Ib Valley’s landscape.

2. Methods and Methodology

2.1 Study Area

The Ib Valley Coalfield, primarily located in the districts of Sundargarh and Jharsuguda in Odisha, is one of India's most significant coal-producing regions, with the northern half of the coalfield in Sundargarh district and the southern half in Jharsuguda district. Named after the Ib River, a tributary of the Mahanadi River—the coalfield spans between latitudes 21°31′N to 22°14′N and longitudes 83°32′E to 84°10′E (CMPDI, 2020), and the region boasts the third-largest coal reserves in India, estimated at approximately 22.3 billion tonnes.

The topography of the Ib Valley Coalfield is characterised by undulating plains and low hills, with elevation gradients shaping the drainage patterns of the aforementioned river systems. This varied landscape affects the mining processes and the environmental management strategies employed in the region. The region is well-connected through an extensive network of railways and roads, facilitating efficient coal transportation. Major railway stations such as Brajrajnagar, Belpahar, and Himgir enhance accessibility and support the coalfield's logistical operations. Road networks link the coalfield to industrial hubs like Rourkela (45 km northeast) and Bhubaneswar (300 km southeast). This connectivity has accelerated urbanisation, particularly around Jharsuguda, which serves as a commercial node for mining operations.

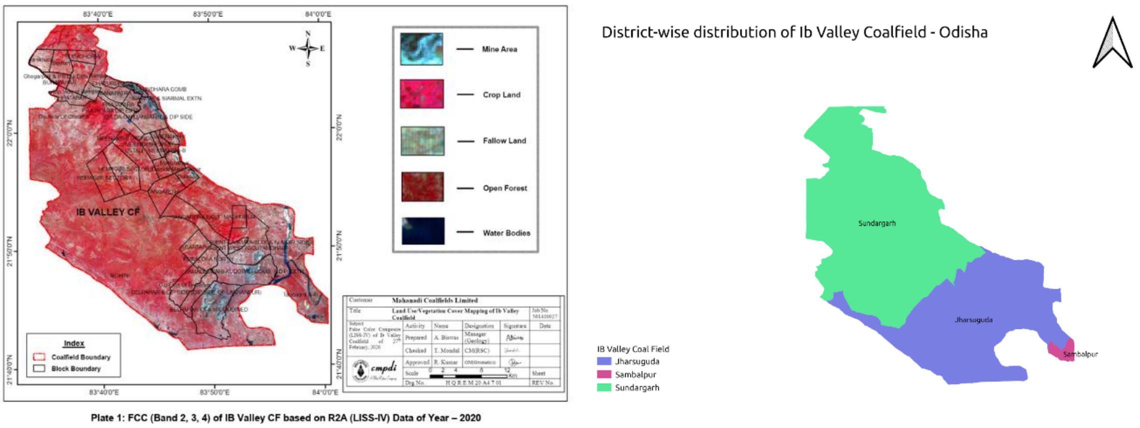

Figure 1: Ib Valley Coalfield (Mahanadi Coalfields Limited et al., 2014)

Coal was accidentally discovered in 1900 during the construction of a railway bridge, leading to the establishment of the first coal mine by Himgir Rampur Coal Company in 1909. Several private underground collieries operated until the industry was nationalised in 1973 by the Indira Gandhi government, bringing the mines under Western Coalfields Limited, later shifting to South Eastern Coalfields Limited in 1986 and Mahanadi Coalfields Limited (MCL), a subsidiary of Coal India Limited (CIL) in 1992. Today, MCL manages two primary coalfields: the Ib Valley Coalfield and the Talcher Coalfield in the Talcher-Angul belt. Within the Ib Valley Coalfield, mining operations are concentrated in several key areas, including Orient, Lakhanpur, Basundhara, and Garjanbahal. The first three areas are primarily in the Jharsuguda district, while Garjanbahal falls within the Sundargarh district. (Mahanadi Coalfields Limited et al., 2014).

Hydrologically, the coalfield is significant due to the Ib River and other critical river systems, including the Ghoghar Nadi, Sapai Nadi, and Bhedan River. These water bodies are crucial in draining the coalfield area, influencing its ecological balance and mining activities. The Ib River traverses the eastern fringe of the coalfield before merging into the Hirakud Reservoir, highlighting the area's hydrological importance. In recent years, the Jharsuguda section of the coalfield has experienced a rapid increase in coal production, mainly through open-cast mining operations. While these methods are efficient for coal extraction, they have led to significant environmental and socio-economic consequences, including land degradation, deforestation, and displacement of local communities. (P. P. Mishra, 2005)

Administratively, the coalfield encompasses several key tehsils, including Jharsuguda, Laikera, Orient, Badmal, Lakhanpur, Rengali, Belpahar, Banaharapali, and Brajrajnagar in Jharsuguda District, as well as Hemgir and Lephripara in Sundargarh District. Additionally, mining operations have recently commenced in Thelkoloi tehsil of Sambalpur District. These tehsils host a mix of active open-cast mines, settlements, and forested tracts, reflecting the coalfield's heterogeneous LULC profile. By concentrating on the tehsils encompassing the Ib Valley Coalfield, this study aims to provide a detailed analysis of LULC changes, assessing the environmental and socio-economic impacts of mining activities within these administrative units.

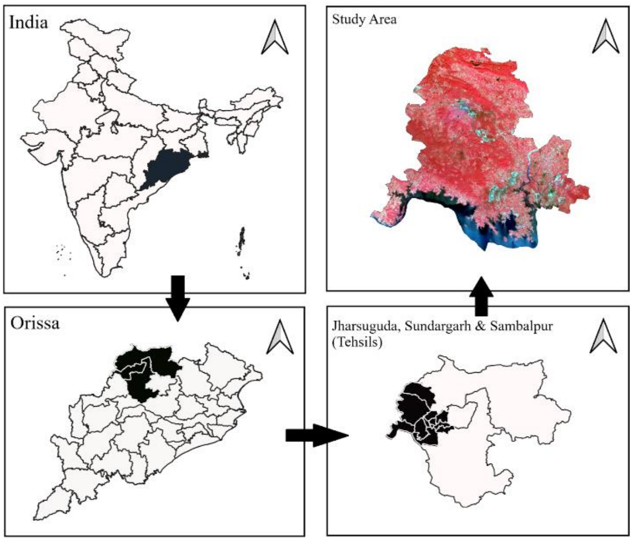

Figure 2: Process of selection of study area

2.2 Data and Pre-Processing

District	Satellite	Date of Acquisition	Path/Row
Sundargarh	Landsat 2 MSS	18-02-1976/19-02-1976	151/045 & 152/045
	Landsat 5 TM	25-01-1992	141/045
	Landsat 7 ETM+	13-02-2002	141/045
	Landsat 8OLI	20-12-2013	141/045

	Landsat 9OLI	10-02-2024	141/045
Jharsuguda	Landsat 2 MSS	18-02-1976/19-02-1976	151/045 & 152/045
	Landsat 5 TM	25-01-1992	141/045
	Landsat 7 ETM+	13-02-2002	141/045
	Landsat 8OLI	20-12-2013	141/045
	Landsat 9OLI	10-02-2024	141/045
Sambalpur	Landsat 2 MSS	19-02-1976	152/045
	Landsat 5 TM	25-01-1992	141/045
	Landsat 7 ETM+	13-02-2002	141/045
	Landsat 8OLI	20-12-2013	141/045
	Landsat 9OLI	10-02-2024	141/045

Table 1: Satellite Images used in the study

In this study, satellite imagery was obtained from several Landsat missions—specifically, Landsat 2 Multispectral Scanner (MSS), Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), Landsat 8 Operational Land Imager (OLI), and Landsat 9 Operational Land Imager 2 (OLI-2) to generate thematic LULC maps and assess temporal shifts. These sensors capture 4, 7, 8, 9, and 9 spectral bands every fortnight. Notably, Landsat 2 provides a spatial resolution of 60 m, whereas the remaining missions each offer a spatial resolution of 30 m.

Landsat satellite imagery (dates provided in Table 1) was sourced from the United States Geological Survey (USGS) EarthExplorer platform (https://earthexplorer.usgs.gov/) and selected based on minimal cloud cover during the subcontinent's winter season. This approach ensured consistent vegetation conditions and minimised surface features being obscured by clouds. Before proceeding with LULC classifications, each dataset was thoroughly evaluated for spatial resolution, consistency, and radiometric and geometric quality to maintain reliability and precision in the analysis. All images were then projected using a common coordinate reference system in ArcGIS 10.8, and the area of interest defined in Section 2.1 was clipped for further examination.

2.3 LULC Classification

Based on the objectives, the study area was divided into six different LULC classes: Vegetation, Waterbodies, Mining Regions, Settlements, Industries, and others, as mentioned in Table 2.

LULC Class	Description
Waterbodies	Encompasses all open water features such as lakes, rivers, streams, ponds, and reservoirs.
Vegetation	Covers forests (moist and deciduous), grasslands, and biologically reclaimed overburden hills located within mining areas.
Mining Regions	Includes coal mine pits, ash dykes, and overburden hills that have not yet been reclaimed.

Settlements	Represents manmade residential zones and associated infrastructure, which may include urban, suburban, and rural communities.
Industries	Designates areas primarily engaged in manufacturing, production, or processing activities, typically characterised by factories, warehouses, and other industrial complexes.
Others	It encompasses all land parcels not classified under the above categories, including temporary crops, plantations, shrubs, barren land, and vacant lots.

Table 2: LULC Classes and their description

These classes were selected to assess how expanding mining activities influence landscape features. The Mining Regions category encompasses all coal mine pits, ash dykes, and unclaimed overburden hills, offering a direct indicator of increased mining operations. In parallel, the Vegetation class includes forests, grasslands, and reclaimed overburden hills, allowing for evaluation of areas being restored to more natural conditions. The **Settlements** and **Industries** categories highlight areas experiencing urban expansion and industrial development, respectively. **Waterbodies** were incorporated to account for the effects of mining and urban growth on local water systems, such as lakes, rivers, and ponds. Finally, the **Others** category captures any remaining land types—such as temporary crops, plantations, or barren land—ensuring a comprehensive understanding of land use and land cover changes.

In this study, a false-colour composite (FCC) of pre-processed images was employed for visual interpretation of various land use and land cover classes. Observations were guided by tone, shape, size, pattern, texture, and the associations among surface features. To accurately distinguish vegetation, the Normalized Difference Vegetation Index (NDVI) was applied, while the differentiation between settlements and industries was informed by their geographic context and spatial associations. Mining regions and waterbodies were readily recognised due to their distinctive colour signatures. The remaining land parcels were classified under "Others," as in Table 2. Additionally, each mapped feature was manually verified against high-resolution Google Earth imagery to minimise classification errors.

3. Results

This study conducted a detailed investigation to explore LULC changes from 1976 to 2024. Temporal maps were created to visually depict shifts in the area of interest, enabling spatial and quantitative assessments of these changes. A comparison of LULC classes over this period indicates a dynamic transition of surface features among different categories. Moreover, the temporal analysis reveals a positive correlation between infrastructure growth and regional mining activity. The following table presents the LULC statistics for each time period:

LULC Class	1976	1992	2002	2013	2024
Waterbodies	368.11	358.18	301.67	385.24	380.78
Vegetation	1304.08	1274.54	1259.89	1186.61	1142.14
Others	1292.81	1312.61	1364.12	1293.16	1287.7
Settlements	10.668	26.21	41.86	72.69	97.06
Mining Regions	0.12	3.02	6.97	20.49	49.49

Industries	0.31	0.59	0.78	17.95	20.59
Total	2976.318	2975.15	2975.29	2976.14	2977.76

Table 3: LULC Area Statistics (values in km^2)

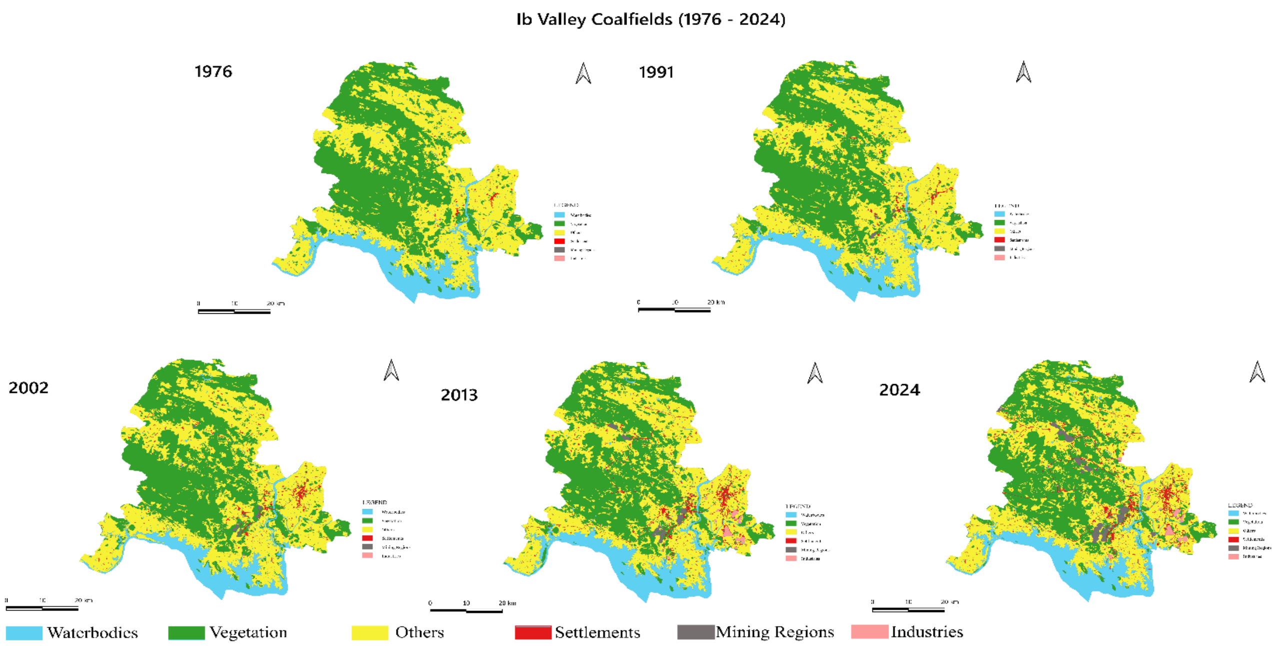

Figure 1: Temporal LULC Maps of the Ib Valley Coalfields

The corresponding transition matrix of LULC Classes between 1976 and 2024 is given in Table 4.

	To Waterbodies	To Vegetation	To Others	To Settlements	To Mining Regions	To Industries	Total 1976
From Waterbodies	348.82	3.6	14.71	0.67	0.29	0.02	368.11
From Vegetation	6.1	1060.1	192.83	19.29	23.02	2.94	1304.28
From Others	25.9	78.57	1076.93	68.59	26.05	17.2	1293.24
From Settlements	0	0.28	1.9	8.37	0	0.12	10.67
From Mining Regions	0	0	0	0	0.12	0	0.12
From Industries	0	0	0	0	0	0.3	0.3
Total 2024	380.82	1142.55	1286.37	96.92	49.48	20.58	2976.72

Table 4: Transition Matrix of Land Use and Land Cover between 1976 and 2024 (values in km^2)

4. Discussion

The snapshot of the land use and land cover (LULC) data from 1976 to 2024 reveals a landscape in flux, influenced by both natural processes and human interventions. The distribution among different classes has changed substantially, reflecting shifts in priorities such as urban expansion, industrial development, and resource extraction.

Waterbodies remain a key component of the regional landscape, providing essential ecological services and resources for urban and industrial activities. Over the study period, these areas experienced modest fluctuations: they spanned 368.11 km² in 1976, dropped to 301.67 km² by 2002, and rose again to nearly 380 km² in 2024. The transition matrix shows that 348.82 km² (about 95%) of the original 368.11 km² classified as waterbodies in 1976 remained in that category, while the remainder mostly transitioned to “Others” (14.71 km²) or Vegetation (3.60 km²). These variations are primarily driven by the Hirakud Reservoir—one of the region’s most significant waterbodies—and influenced by rainfall patterns, water-level management, and vegetation's gradual reclamation of shallow aquatic zones. Notably, the marked dip in 2002 likely reflects drier conditions or reservoir drawdown, coinciding with an arid period around 2000–01 when the reservoir failed to fill to capacity (Wetlands International South Asia et al., 2015). Subsequent recovery of waterbodies suggests the return of wetter conditions or more effective management practices. Meanwhile, heightened mining activity and rising temperatures have intensified land surface heating, contributing to the drying of smaller lakes in the region.

In contrast, **Vegetation** exhibits a marked decrease from 1304.08 km² in 1976 to 1142.14 km² in 2024. According to the transition matrix, much of this vegetation (approximately 192.83 km²) transitions into the “Others” category, particularly for agricultural land and about 45 km² in total shifts into settlements, mining, or industrial areas. This reduction is linked to expanding settlements, industrialisation, and mining, mirroring broader national trends in land conversion (Kumar et al., 2020). The transition matrix data confirms that built-up areas primarily replace vegetation loss, reflecting the increasing pressure on natural landscapes due to economic activities.

Perhaps the most striking trend is the substantial rise in **Mining Regions** from a negligible 0.12 km² in 1976 to 49.49 km² in 2024. Open-cast mining in Ib Valley Coalfields is as new as 1973; only 0.12 km² was under open-cast mining in 1976. However, the aggressive mining can be seen as the “digging in” effect—like excavating a small hole that eventually becomes an extensive cavern. As mining ventures grow, they reshape the land, creating deep pits, large ash dykes, and overburden areas. Consistent with these data, the transition matrix shows that mining areas predominantly emerge from vegetation (23.02 km²) and “Others” (26.05 km²). This growth has broad implications for environmental conservation (loss of vegetation and changes to water systems) and socioeconomic factors (job creation and settlement patterns around mines).

Urban growth is evident in the **Settlements** category, which has expanded markedly from 10.668 km² in 1976 to 97.06 km² by 2024. The transition matrix indicates that much of this growth originates from vegetation (19.29 km²) and “Others” (68.59 km²), highlighting the encroachment of residential zones into formerly natural or mixed land uses. This resembles a growing neighborhood where small towns evolve into larger cities. Population influx, economic opportunities, and improved infrastructure contribute to this ninefold increase. Moreover, the decadal percentage increase in the population of Jharsuguda, Sundargarh, and Sambalpur was 25.74%, 29.79%, and 24.32%, respectively, according to the 1981 census, where the state average was 20.17% (Census of India, 1981). Moreover, this trend continued till 2011 and positively correlated with increased settlement regions. **Industries** also show a considerable rise, from 0.31 km² in

1976 to 20.59 km² in 2024. Although the absolute value remains relatively small compared to other categories, this upward trend in industrial footprint reveals the increasing role of manufacturing and processing activities in the region's economy. This change is mainly driven by the setting up the Hindalco plant in Derba, JSW Bhushan Power and Steel Limited in Thelkoloi, and Vedanta's Aluminum Captive Plant in Jharsuguda. The transition matrix confirms that industries are chiefly developed on land previously classified as vegetation (2.94 km²), "Others" (17.2 km²), and, to a lesser extent, settlements (0.12 km²)—underscoring the competition between industrial expansion and other land uses.

The **Others** category, which encompasses uses such as temporary crops, fallow land, barren land, and miscellaneous spaces, remains significant, varying between 1292.81 km² and 1364.12 km² over the study period. The transition data show that "Others" acts as a transitional pool: some "Others" land is reclaimed by vegetation (78.57 km² from 1976 to 2024), but large portions also convert into settlements (68.59 km²) or industries (17.2 km²). This flexibility suggests that these areas are neither entirely natural nor permanently developed, making them susceptible to rapid conversion based on socio-economic demands.

5. Conclusion

Significant changes brought about by coal extraction, industrialization, and urbanization have been shown by examining Land Use Land Cover (LULC) variations in the Ib Valley Coalfields between 1976 and 2024. The landscape's dynamic character emphasizes how human activity and natural processes interact, highlighting the necessity of sustainable land management techniques. The most notable finding is that mining areas have grown exponentially, from 0.12 km² in 1976 to 49.49 km² in 2024. The area's ecological balance has been drastically altered by this increase, which has mostly come at the price of vegetation and other land cover types. Deforestation, disturbance of hydrological cycles, and soil degradation have all resulted from the fast growth of open-cast mining. These results are consistent with earlier studies on the effects of coal mining on the environment (Ghose, 2007; Mishra et al., 2012), indicating that uncontrolled mining may have long-term effects on local communities and biodiversity. With settlements increasing by approximately nine times in the last 5 decades, urban growth has been a distinguishing characteristic of LULC evolution. The coal belt region's infrastructure development, economic prospects, and population movement are all responsible for this quick expansion. Large-scale industrial development has stimulated economic expansion while escalating pressures for land conversion. The open lands functioning as a flexible buffer emphasizes how vulnerable they are to changes in socioeconomic priorities. It has been used as a source for industrialization and settlement growth, demonstrating how land use can adapt to changing economic conditions, which underlines the requirement of a balanced approach to regional planning is required because of the increased rivalry for land between forestry, urban growth, and agriculture brought about by the expansion of industry.

These results provide crucial new information on how LULC changes affect environmental preservation and regional planning. Rapid industrialization and urbanization highlight the pressing need for integrated land-use plans that balance ecological protection and growth. To reduce environmental degradation, policymakers must consider the combined effects of mining, deforestation, and infrastructure expansion. They may implement policies like afforestation initiatives, sustainable mining methods, and urban green spaces. Ultimately, this study is an essential resource for legislators, environmentalists, and urban planners as they navigate the complexity of land use changes. The trends seen in the Ib Valley Coalfields represent more general developmental issues that mining regions worldwide confront, highlighting the need for sustainable land management to guarantee long-term ecological and financial stability.

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