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Road Hierarchy Associated Landscape, Urbanization, and Socio-Economic Transformation: Insights from Dhanbad District, India

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ABSTRACT



Road transport facilities stimulate regional development by influencing land-use change, accessibility, and socio-economic transformations. However, the extent to which road hierarchy alone drives regional transformation remains unclear, particularly in resource-dependent regions. The study examines the association between road hierarchy and development along the road corridors in the Dhanbad district. Dhanbad, despite being resource-rich, is counted among India's backward districts, so this study will provide an insightful look at how the roads incorporate various development aspects as they traverse the district. This study uses multi-temporal land-use/land-cover data, landscape metrics, and village-level census data to assess changes along national highways, state highways, and major district roads. To evaluate corridor-specific development outcomes, a Comparative Corridor Development Index (CCDI) has been developed. The outcome reveals considerable inter-corridor variations. Corridors stretching across the mining and urban-industrial areas of the district recorded the highest development scores (NH218: 5.88 and NH18: 4.99), while NH419 and the state highway exhibited comparatively limited transformation, with CCDI values of 0.81 and 0.98, respectively. Additionally, the study observed strong positive associations between urbanization, landscape consolidation, and socio-economic development. The study presents a corridor-based framework for analyzing transportation-led regional development, providing valuable insights for balanced infrastructure planning in resource-abundant regions.

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Highlights:

- Landscape, socio-economic transformation, and urbanization occurred differently along the corridors irrespective of the road hierarchy.
- Mining-industrial activity stimulates Road transportation leads development in the region.
- Urban expansion, or built-up growth, is positively associated with socio-economic indicators.
- Corridor development can't be explained only by road hierarchy; rather, it includes other local factors like mining activity, urban concentration, etc.

Contribution to the field statement:

The study presents a corridor-based integrated framework to examine how road hierarchy is associated with landscape transformation and socio-economic development in a resource-rich region. The findings reveal that road transport, mining activity, and urban expansion jointly shape the landscape-socio-economic transformation, providing significant insights into uneven regional development.

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1 Introduction

The Earth is now urbanizing at the fastest rate that it has ever experienced. Transport infrastructure, as the most vital driver of urbanization, is shaping growth patterns, the concentration of economic activity, and land transformation. A well-developed road network in any country can accelerate urbanization and resource-based industrialization by enhancing people's access to centers of activity, markets, and local resources (Dale et al., 1993; Ewing & Cervero, 2001; Forman et al., 2003). This eventually led to changes in land use and land cover, and in socio-economic status, in road-adjacent areas, which varied according to the hierarchy of the roads. The entire process aligns with Perroux's (1955) Growth Pole theory, which explains how urban centers, as growth poles, attract various forms of concentration and development. Similarly, the connecting roads act as an axis of corridor growth, and the corridor between the growth poles is recognized as the most accessible area of the region suitable for industrial concentration, intensifying urbanization, and mass movement.

However, numerous previous studies have revealed a deep nexus between transport infrastructure and land transformation (Bacior & Prus, 2018), landscape fragmentation (Mehdipour, 2019), ecological imbalance (Nematollahi, 2017), habitat disturbance, and other impacts. At the same time, studies have evaluated the socio-economic implications (Quium, 2019), mainly service accessibility, employment generation (Yuan et al., 2024), and improved accessibility. Even though they provide valuable insights, they are often discussed in isolation, leaving the knowledge incomplete and fragmented in understanding how landscape change interacts with social and economic aspects across different roadways. Additionally, most existing literature focuses on national, regional, or urban-scale studies, with little attention to district-level interactions. India, the World's fastest-growing economic power, has invested heavily in expanding road infrastructure, but lacks extensive studies on how different road categories shape development patterns. Specifically, a comparative evaluation that combines physical, social, and economic aspects in the resource-rich Indian context is rare.

Modern India has a variety of roads and multiple authorities responsible for their systematic maintenance and operation. Hierarchical categorization highlights a road's status, capacity, and importance from the perspectives of transport, planning, and development. Higher-order roads, such as National Highways, are meant to provide better connectivity, greater national integrity, and greater mobility than lower-order roads, and are therefore associated with a higher level of transformation and development. However, the extent to which the road hierarchy corresponds to such transformation, especially in regions with multiple economic drivers and uneven development, remains unanswered. Reduced travel time and cost from accessibility gains encourage land-use transformation and land-value appreciation, depending on the status and capacity of the roads. Ultimately, this relates to Alonso's (1967) Bid-Rent theory, which argues that higher-order roads lead to greater transformation.

Dhanbad, India's 148th-ranked district with a population of more than 2.68 million (2011), is recognized as the country's leading coal-producing district. The district has numerous coal mining and allied industries that drive localized development amid regional disparities. Development largely follows the urban centers and mining areas, leaving peripheral areas underdeveloped. In this context, it will be of great significance to determine how different categories of road corridors shape landscape configuration and socio-economic transformation in the resource-based district.

The present study examines the association between road hierarchy and changing landscape configuration, along with socio-economic transformation, in Dhanbad district, India. Integrating multi-temporal LULC data with village-level socio-economic indicators, the study adopts a road corridor-centric analytical framework. The objectives of the study are (a) to uphold the pattern of LULC change along different categories of vehicular roads; (b) to assess the change in socio-economic status of the villages located in the closer vicinity of the road corridors; and (c) to find out how spatial development corresponds with road hierarchy. The following flowchart shows the research progress (Figure 1).

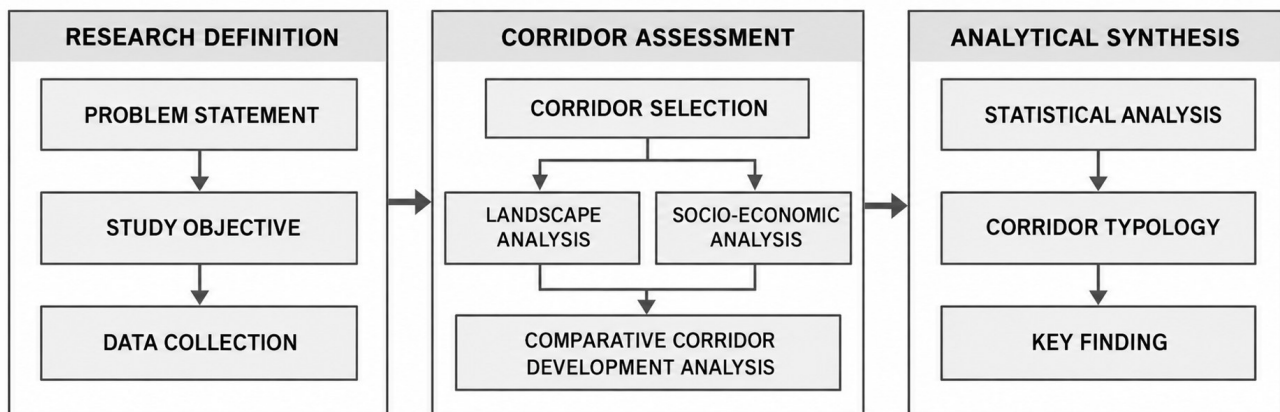


Figure 1. Structure of the Study.

2 Literature Review

2.1 Landscape transformation and Road infrastructure

Transport infrastructure is widely regarded as one of the foremost drivers of rapid urbanization and associated landscape transformation. Roads are the primary agents of landscape discontinuity, leading to fragmentation, land-use and land-cover alteration, habitat loss, etc. (Forman & Alexander, 1998; Saunders et al., 2002; Li et al., 2010). For example, Hawbaker et al. (2004), in a study across 19 counties in Wisconsin, USA, found positive relationships between road density and landscape patterns predominantly covered by forest. Li et al. (2010) found high to severe levels of landscape fragmentation, especially near the big cities in China, due to road development and urban expansion. Using a theoretical framework and techniques, Baciorek and Prus (2018) analyzed the impacts of highways on existing agricultural land and regional sustainability. Landscape metrics and other advanced analytical techniques enabled multidimensional, more precise, and better-suited approaches to assessing fragmentation and the dominance of land cover classes (McGarigal et al., 2012; Mehdipour et al., 2019).

Additionally, methodological advancements introduced approaches such as delineating road-effect zones and measuring disturbance intensity using composite indices. The cumulative effect of higher-order roads is assessed employing Roadless Volume Index (RVI), Spatial Road Disturbance Index (SPROAID), Zonal divisions, etc., and is mostly evident in areas dominated by multiple higher-order roads (Fu et al., 2010; Nematollahi et al., 2016; Lin et al., 2020). Patarasuk (2013) and Liang et al. (2014) statistically establish the relationship between transport improvement and landscape transformation, using Kendall's tau, the Wilcoxon matched-pairs test, and logistic regression, respectively. Altogether, the literature indicates that land use and land cover change, and Transport infrastructure are closely associated with varying spatial extents.

2.2 Socio-Economic development and Road infrastructure

Roads are the primary means of connecting to the various facilities that meet people's needs. Simultaneously, areas closer to the road offer opportunities to engage in multiple economic activities, such as fast-food sales, retail, wholesale, and service. Therefore, roads regulate people's lives by enhancing accessibility, minimizing transport cost and time, supporting the smooth movement of goods, services, and laborers, which eventually boosts the regional economy and strengthens the society (Banister & Berechman, 2001; Calderón & Servén, 2010; Asomani et al., 2015; Tucho, 2022). Empirical studies show that transport development, such as road improvements and expansions, is closely linked to employment generation, income growth, and other socio-economic indicators. Fan and Chan-Kang (2008) found that low-grade roads are far more profitable than high-grade roads in terms of national GDP, while Zhou et al. (2022) and Tian et al. (2024) found that transport development and investment play a significant role in poverty reduction. Pradhan and Bagchi (2013) examined the impact of transportation on economic development and the need for a suitable transportation policy to boost India's economic growth. Ayele (2017) and Quium (2019) examined transport corridors in

relation to wider socio-economic development. Moreover, increases in girls' school attendance and changes in employment patterns in the non-agricultural private sector are associated with higher-order road development (Limi et al., 2015; Chakrabarti, 2018).

Numerous studies using advanced methods also indicate a positive connection between transport facilities and economic status. Ng et al. (2019) established that the growth in road length per thousand people, along with other variables, has contributed positively to economic growth. Tian et al. (2023) and Yuan et al. (2024) find that proximity to an expressway is positively associated with increased farm productivity and labor allocation among enterprises. Komornicki & Goliszek (2023) and Hu et al. (2024) demonstrate that transport investment and highway construction are major factors in fostering regional economic growth.

2.3 Road Corridor and Development

The existing literature shows that extensive studies examine the association between road infrastructure and environmental and socio-economic development; however, fewer studies have adopted a corridor-based framework that integrates both perspectives. According to Rodrigue et al. (2017), transport or road corridors at different scales are consistently treated as units of integrated development, where added accessibility benefits spur LULC change, urban growth, and economic activity.

Road hierarchy helps the observer understand how accessibility to transport facilities at different levels influences development dynamics differently. For example, National Highways provides greater connectivity and movement capacity, consequently encouraging more extensive development than lower-order roads. Investigations done by Kasarda and Lindsay (2011) and Jain et al. (2021) have shown that the corridors are responsible for axis development, large scale urbanization, accumulating multi sector economic activities, You et al. (2022) has investigated the large scale socio-economic impact of six economic corridors under China's Belt and Road Initiative (BRI) region which itself is a global scale infrastructure development program. Amedzro et al. (2024) demonstrated the relationship between road corridor expansion and urban sprawl.

However, research explicitly comparing transformations across different road hierarchies has been found to be confounded. Existing literature has rarely combined physical, social, and economic indicators to comprehend corridor-related transformation. In India, studies are mostly conducted at large spatial scales or at the urban scale, with less emphasis on resource-based backward regions or districts.

Hence, the literature review has indicated the following basic gaps. Existing studies on road, landscape, and socio-economic improvements are generally conducted separately, creating a gap in apprehending their interactive behavior. Considerable district-level road corridor-based studies, particularly in resource-rich backward regions, are significantly lacking in India. Road hierarchy-based comparative analysis addressing physical, social, and economic development remains inadequate.

3 Study area

Dhanbad is a district in the state of Jharkhand, India, with an area between 23°37'3" N and 24°4' N latitude and 86°6'30" E and 86°50' E longitude. In terms of physiography, lies on the fringe of the Chotanagpur plateau, surrounded by two major rivers in the region, the Ajoy and the Damodar. According to the 2011 census, the district has a population density of 1,320 persons/km², with a total population of more than 2.6 million, of which 58.13% live in urban areas. Dhanbad is the main metropolitan city and district headquarters, also known as the coal city of India.

Economically, the district depends heavily on coal mining and allied industrial activities. Public and private service-operating enterprises are often concentrated in mining, industrial, and urbanized areas, intensifying localized growth and spatial inequality. The district has a long history of coal mining dating back to 1910, with large-scale industrial operations. Bharat Coking Coal (BCCL), Steel Authority of India (SAIL), Tata Steel, etc., have been operating mines for more than 50 years and

supplying coal across India. In addition, Hindustan Zinc Ltd, Om Besco Rail Products Ltd, Mithon Power Ltd, and Damodar Valley Corporation (DVC) operate in the district.

The district's road transport system is primarily served by National Highway-19, which forms the axis of the Amritsar-Kolkata industrial corridor, supported by other National Highways, State Highways, and Major district roads that connect mining and industrial areas, urban centers, and the hinterlands (Ankur et al., 2022). National and State highways mainly maintain the national- and regional-scale flow of raw materials, industrial products, and the labor force; in contrast, the others primarily support the local and regional movement of people. Hence, Dhanbad district, characterized by a resource-rich, mining-industry-based economy and spatially diverse infrastructure and development, is a potential location for evaluating how road hierarchy corresponds with LULC conversion and Socio-economic changes.

According to the 2011 census, the district comprises 9 community development blocks, 2 statutory towns, and 44 census towns, with 1,075 inhabited villages (Figure 2).

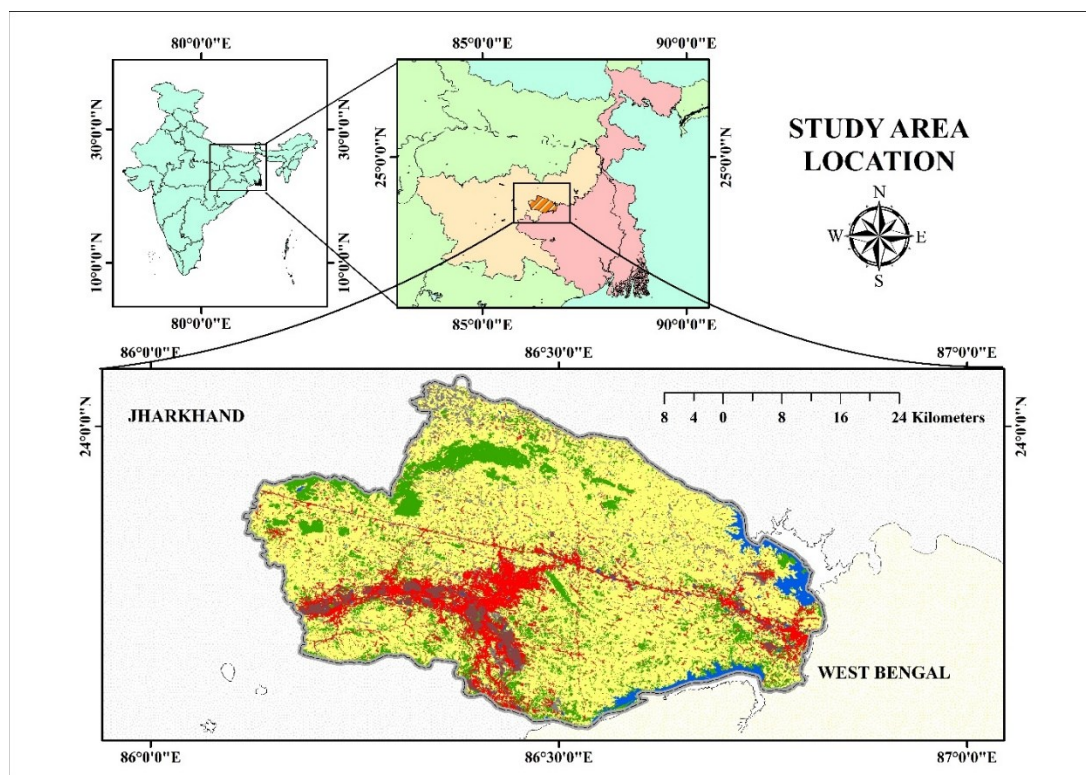


Figure 2. Study area location.

4 Database and Methodology

4.1 Data Sources

The present study comprises both remote sensing and census data, collected from the USGS Earth Explorer and the official Website of the Census of India, respectively.

- The Landsat 5 TM and Landsat 8 OLI data were obtained in 1990 and 2020 to generate LULC images, as per their availability during the research period. Both datasets are terrain-corrected and pre-georeferenced to the UTM Zone 45N projection.
- The village-level Female Literacy Rate (FLR) and Other Work Participation (OWP) data have been compiled using the district PCA (Primary Census Abstract) of the 1991 and 2011 censuses.
- Road data has been collected from OpenStreetMap, categorized, and rectified, with reference to the District planning map and Google Maps.

4.2 Road types and spatial extent

Road categories considered for the present analysis are National Highways (NH), State Highways (SH), and Major District Roads (MDR). As of 2020, the district had a maximum of four NHs (NH19, NH18, NH218, and NH419) and one State Highway (SH 5); all are included in the study. For Major district roads, two (MDR1 & 2) were selected: one located far from the coal mining belt and the other partially extending through it. To analyze the pattern of association, 2-kilometer buffer zones on both sides of the selected roads have been generated (Figure 3). Therefore, all subsequent analyses are conducted within these buffer zones, which represent the areas of potential road influence.

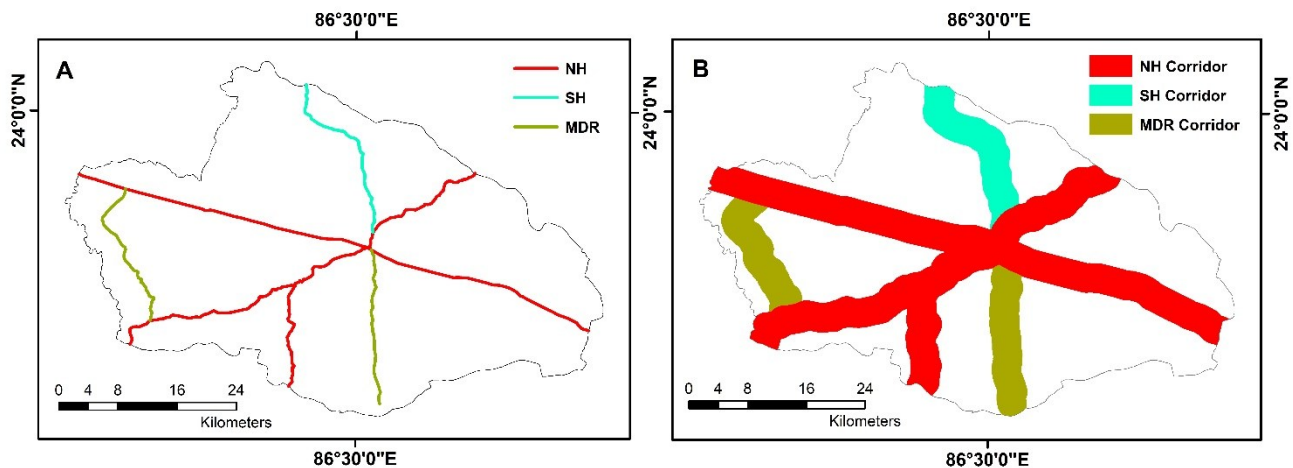


Figure 3: (A) Selected roads for the study, and (B) The road corridors.

4.3 Land Use Land Cover Classification Scheme

The land use and land cover of the study area have been categorized into six primary-level classes based on the LULC classification scheme provided by NRSC (2012). Minor adjustments have been made to reflect the prominence of LULC classes in the region. For example, the mining (secondary level) area has been separated from the built-up (primary level) category and treated as a primary-level class in the present study. Similarly, the sandy & bare soil category has also been separated from the secondary level (as mentioned in the NRSC classification) and treated as a primary-level class. The LULC scheme for the present study includes the following main land-use/land-cover classes: Built-up area (BA), Mining area (MA), Agricultural land (AL), Vegetation cover (VC), Waterbody (WB), and Sandy & bare soil (SBS).

4.4 Assessment of Landscape Transformation

4.4.1 Land Conversion Rate (LCR)

To obtain fine-grained information on how vehicular roads influence the rate of land transformation in the region, the land conversion rate has been calculated using the formula provided by Song and Deng (2017).

$$LCR = \frac{\sum_{i=1}^6 \Delta LUT_i}{\sum_{i=1}^6 LUT_i} \times \frac{1}{T} \times 100\% \dots \dots (1)$$

LCR can reveal both the conversion speed and degree of LULC, where ΔLUT_i represents the converted area of LULC type i , LUT_i is the area of LULC type i , and T indicates the research period.

4.4.2 Landscape metrics

Spatial and temporal change in landscape configuration during the period of study has been analyzed and elaborately discussed using the following two landscape metrics as described by McGarigal et al. (2012):

- Patch density (PD)** refers to the number of patches (of a particular patch type) per unit of area. This index expresses the fragmentation of the landscape; values nearer to 0 indicate less fragmentation, and values farther from 0, scilicet, more fragmentation.

$$PD = \frac{n_i}{A} \times 100 \dots \dots (2)$$

Here, n represents the number of patches in i^{th} category, and A is the total landscape area

- b) **Largest patch index (LPI)** describes the relative size of the largest cluster computed for a given land cover type and indicates the level of dominance. The LPI value approaches 0 as the largest patch decreases in size, while it reaches 100 when a single patch comprises 100 percent of the landscape.

$$LPI = \frac{\max_{j=1}^n (a_{ij})}{A} \times 100 \dots \dots (3)$$

Where a_{ij} represents the area of patch ij , and A is the total landscape area

4.5 Assessment of Socio-economic Status

Assessment of change in socio-economic status along the vehicular roads (VRs) was done using:

- a) Female literacy rate to total female population (FLR): Indicates access to education and potential for social development (Rahman & Alam, 2023).

$$FLR = \left(\frac{\text{Number of total literate Female person}}{\text{Number of total female person}} \right) \times 100 \dots \dots (4)$$

- b) Other work participation to the total worker (OWP): Indicate the occupational shift, the availability of higher-sector workers, and dependence on non-agricultural work (Oruç & Çağlar, 2022).

$$OWP = \left(\frac{\text{Number of total non agricultural workers}}{\text{Number of total workers}} \right) \times 100 \dots \dots (5)$$

- c) Main worker-Marginal worker ratio (MMWR): Used as a proxy for employment status and stability in the district. A ratio closer to 1 indicates stability in the availability of work, while an increase in value denotes a reduction in stability.

$$MMR = \frac{\text{Number of total main workers}}{\text{Number of total marginal workers}} \dots \dots (6)$$

4.6 Correlation Analysis

Lastly, to understand the relationships between landscape transformation and socio-economic development along the road corridors, Spearman's rank correlation analysis was employed. The method was selected because it is a non-parametric statistical technique that does not require normally distributed data and is suitable for small sample sizes.

$$\text{Spearman's rank correlation coefficient}(\rho) = 1 - \frac{6 \sum d^2}{n(n^2 - 1)} \dots \dots (7)$$

Where d represents the difference between the two ranks of each observation, and n denotes the total number of observations.

Spearman's rank correlation coefficients were calculated to assess the direction and strength of associations among land-use/land-cover, urbanization, and socio-economic development indicators across the seven road corridors. The analysis aimed to capture indicative relationships rather than to establish statistically generalizable causal effects, given the study's comparative corridor-level focus and the limited number of observations ($n = 7$).

5 Results

5.1 Transforming Land Use and Land Cover Scenario along the Road Corridors

Studying spatiotemporal changes in land use and land cover is essential for understanding the pace and pattern of human activity. From 1990 to 2020, the study area experienced significant LULC transformation along the major road corridors; Tables 1a and 1b and Figure 4 provide details. Agricultural land (AL) ranked highest in terms of areal coverage in both years and across all corridors, ranging from 86.40% to 27.74% in 1990, and decreasing to 80.65% to 19.43% in 2020. However, it

decreased along all road corridors, with the largest decrease on NH18 at 20.82%. Unlike agricultural lands, the built-up area is one such category that has increased over time and along all road corridors. It was confined to 18.31% - 0.62% in 1990 and increased to 45.10% - 4.98% in 2020. In absolute terms, NH19 recorded the highest total growth (3993.11 hectares), while SH had the lowest (459.43 hectares). Vegetation cover increased and decreased along the corridors; the largest increases and decreases were observed along NH19 (982 hectares) and NH218 (-1085.26 hectares), respectively. At a comparative scale, NH419, despite being categorized as a National Highway, has a built-up area that is six times smaller than that of NH218, four times smaller than that of NH18, and two times smaller than that of NH19, and it is even smaller than the major district roads. Since the SH is higher-order than MDRs, it should exhibit greater LULC dynamics, but it did not. SH has less built-up area than the MDRs, suggesting that other factors may be influencing the transformation. A significant difference is found between MDR1 and MDR2 across all LULC categories.

Table 1a: LULC pattern (in hectares) along various road corridors, 1990-2020.

Types of LULC	NH19		NH18		NH218		NH419	
	1990	2020	1990	2020	1990	2020	1990	2020
Built-up Area	1333.18	5326.30	1538.37	5083.24	1193.99	2944.84	135.86	677.51
Mining area	1036.91	489.54	853.75	710.88	1241.92	1219.17	11.51	20.10
Agricultural land	23908.31	18594.09	10734.62	7474.21	1809.02	1268.61	7362.32	6862.83
Vegetation cover	2210.32	3192.66	1798.59	1632.26	1659.49	574.24	224.52	314.75
Waterbody	277.21	612.46	143.96	121.67	87.13	77.61	45.41	137.01
Dry sandy & bare land	836.76	1400.59	563.68	598.46	528.80	445.75	742.08	496.71

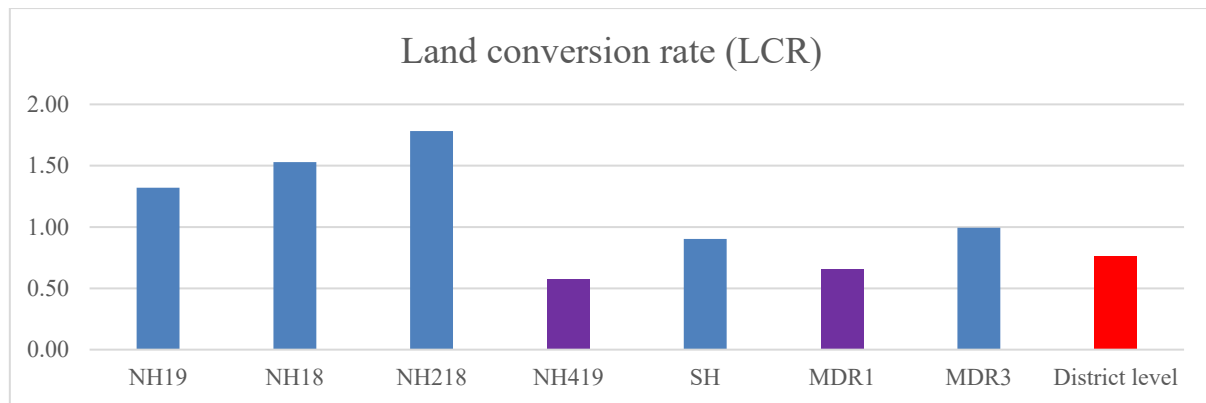
Table 1b: LULC pattern (in hectares) along various vehicular roads, 1990-2020.

Types of LULC	SH		MDR1		MDR2	
	1990	2020	1990	2020	1990	2020
Built-up Area	65.55	524.98	154.48	903.52	372.61	1485.65
Mining area	7.28	12.02	17.89	13.73	398.06	478.14
Agricultural land	9108.13	7774.42	7724.06	6770.41	7366.82	6115.24
Vegetation cover	548.58	1499.92	1542.06	1642.85	1230.95	1525.85
Waterbody	44.78	55.54	101.16	154.77	34.89	37.86
Dry sandy & bare land	779.93	679.57	114.19	158.90	571.96	336.74

The transformation of LULC along all road corridors is more comparable when expressed as the land conversion rate (LCR). The pattern of LCR distribution shows a clearer hierarchy of transformation: three out of four NHs recorded higher LCR among all road corridors (NH218-1.78, NH18-1.53, NH19-1.32), while the only SH possesses a score of 0.90 as per its yearly land conversion, and one out of two MDRs (MDR1) has an LCR of 0.66 (Table 2). The range between the highest and lowest LCR was 1.12, while the mean LCR was 1.11, indicating that the road corridors of NH 19, 18, and 218 were comparatively more dynamic and vibrant in terms of land use and land cover change than the other corridors in the district. However, according to the district-wide LCR, only two of the seven corridors recorded lower LCR values: NH419 (0.58) and MDR1 (0.66). More specifically, the hierarchy held with two exceptions: NH419 (0.58) and MDR2 (0.99). Therefore, the magnitude of transformation differs substantially across corridors, suggesting that road hierarchy alone may not fully explain observed patterns.

Table 2: LRC along various road corridors.

Area	Converted area	Total area	Land conversion rate (LCR)
NH19	11736.14	29615.63	1.32
NH18	7171.54	15632.98	1.53
NH218	3491.82	6530.22	1.78
NH419	1476.93	8521.70	0.58
SH	2860.34	10554.25	0.90
MDR1	1905.98	9653.83	0.66
MDR2	2977.80	9979.49	0.99
District level	46243.14	203132.78	0.76


Figure 4. LCR of the corridors and the district.

5.2 Landscape Configuration and Road Hierarchy

Landscape metrics reveal how different LULC types and the dynamic, interactive inner qualities of LULC components within the landscape configure the landscape. This section primarily focuses on built-up land and patch configurations to understand how urbanization shapes the study area's landscape. Built-up patch density along the road corridors shows that NH19, 18, and 218 recorded higher BPD values of 3.99, 3.93, and 6.86, respectively, while SH recorded the lowest BPD value (0.91) in 1990 (Table 3). In 2020, a significant change was seen in the BPD of NH218, which decreased to 3.32 at a rate of -1.72 percent/year, and NH18 remained mostly stagnant (3.98) with a growth rate of 0.04 percent/year. In 2020, NH19, MDR1, and SH were the three corridors with the highest BPDs of 6.07, 5.57, and 5.28, respectively, while SH had the highest growth rate of 16.02 percent/year. According to the largest built-up patch index (LPBI) for 1990 and 2020, both NH218 and NH18 were the two major corridors with higher values, although higher growth rates were recorded for NH19, MDR2, and MDR1 at 37.87, 36.73, and 25.33 percent/year. The range of LPBI increased to 45.10-4.98 in 2020 from just 18.31-0.62 in 1990. Additionally, higher PBL in 2020 was found along the corridors of NH218 (45.10), NH18 (32.54), and NH19 (17.98), but higher growth rates were observed in other road corridors, such as 23.38 (SH), 16.18 (MDR1), and 13.31 (NH419) percent/year. The overall landscape configuration indicates that the NH218 and NH18 corridors exhibit the highest agricultural land fragmentation and urban dominance. In contrast, NH419 and SH exhibit comparatively stable landscape structures, and both the MDRs with NH19 experienced a moderate type of transformation (Figure 5).

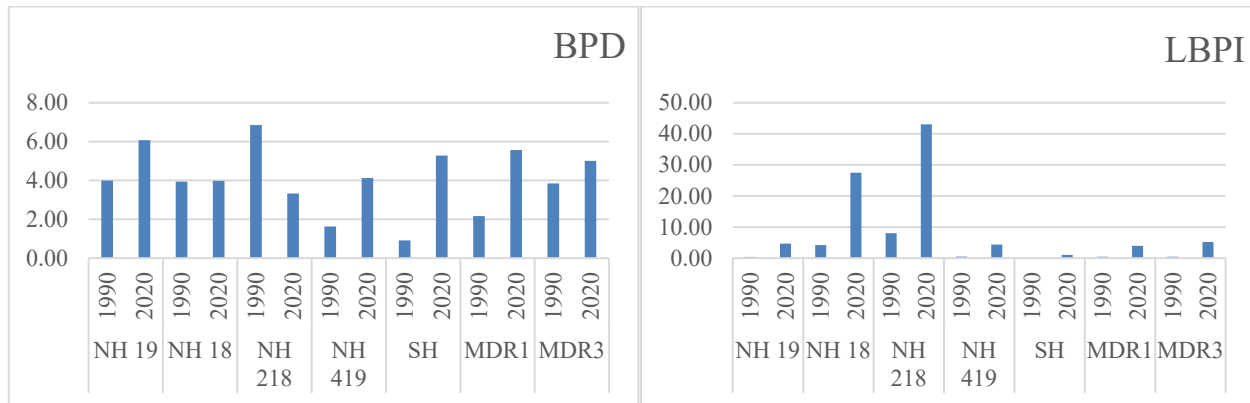


Figure 5: Status of BPD and LBPI along the corridors.

Table 3: Landscape metrics along the corridors.

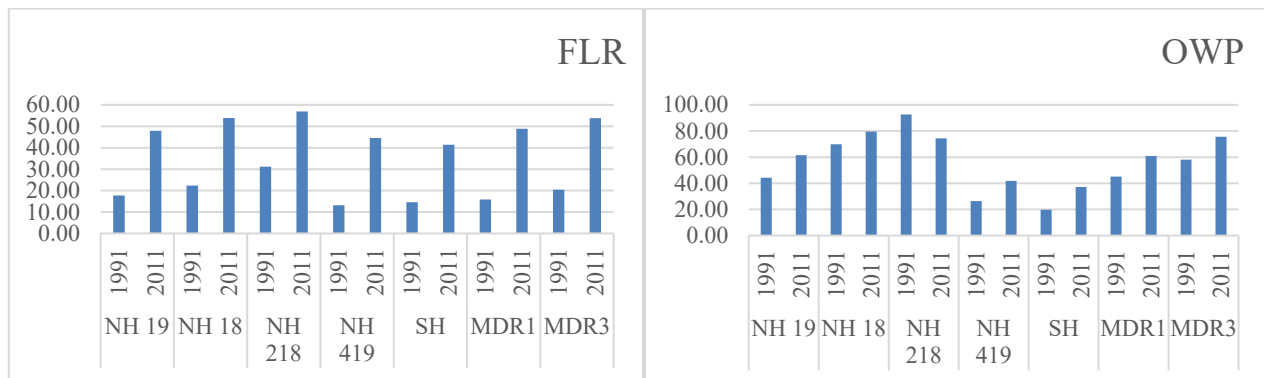
Road corridors	Period & Change	Percentage of Built-up land (PBL)	Built-up Patch Density (BPD)	Largest Built-up Patch Index (LBPI)
NH 19	1990	4.50	3.99	0.38
	2020	17.98	6.07	4.69
NH 18	1990	9.84	3.93	4.19
	2020	32.54	3.98	27.51
NH 218	1990	18.31	6.86	8.02
	2020	45.10	3.32	43.05
NH 419	1990	1.59	1.63	0.52
	2020	7.96	4.13	4.38
SH	1990	0.62	0.91	0.13
	2020	4.98	5.28	0.99
MDR1	1990	1.60	2.16	0.46
	2020	9.37	5.57	3.95
MDR2	1990	3.74	3.85	0.43
	2020	14.89	5.01	5.17

5.3 Pattern of Socio-Economic Transformation

The overall socio-economic transformation shows a clearer hierarchy of socio-economic development. National highways exceed State highways and Major district roads in terms of female literacy rate and other work participation rate. In 1991, the female literacy rate ranged from 31.14 to 13.15, and increased to 56.93 to 41.39 in 2011 (Table 4). The female literacy rate (FLR) along NH218 and NH18 was higher than all other road categories until 2011. Simultaneously, other work participation was higher, mostly along national highways rather than SHs and MDRs. For the main-to-marginal worker ratio, values decreased across all corridors. The range had decreased to 4.65-0.75 in 2011 from 115.42-6.00 in 1991 (Figure 6). However, notable inter- and intra-class anomalies were found in FLR among road corridors; for instance, despite being a major district road, MDR2 often surpasses NH19 and NH419 in socio-economic terms. In 2020, MDR2 had an FLR of 53.76, which was much higher than those of NH19, NH419, and SH. Similarly, in 2020, MDR2, at 75.61, exceeded all other road corridors (except NH18, 79.60) in the other work participation rate. For main and marginal work participation, a significant balance was observed across all corridors. So, there are likely factors behind these exceptions. Nonetheless, in both cases, the growth rate was higher along corridors with lower index values. In contrast, most highly indexed corridors remained more or less stagnant in growth rates, suggesting the study area's future.

Table 4: Indices of socio-economic status along the corridors.

Road corridors	Period & Change	Female literacy rate (FLR)	Other work participation (OWP)	Main-Marginal worker ratio (MMWR)
NH 19	1991	17.69	44.24	16.33
	2011	47.87	61.55	3.09
NH 18	1991	22.35	69.89	68.68
	2011	53.85	79.60	4.05
NH 218	1991	31.14	92.59	115.42
	2011	56.93	74.41	4.65
NH 419	1991	13.15	26.40	6.00
	2011	44.55	41.86	0.93
SH	1991	14.57	19.77	11.72
	2011	41.39	37.11	0.75
MDR1	1991	15.83	45.08	18.40
	2011	48.88	60.98	3.85
MDR2	1991	20.38	58.12	9.20
	2011	53.76	75.61	1.66


Figure 6. Status of FLR and OWP along the corridors.

5.4 Comparative Corridor Development Index (CCDI) and Corridor Typology

The indices discussed above were systematically aggregated to gain clearer insight into the transformation along the corridors. According to the Corridor Transformation Index (CCDI), NH218 ranked first with a score of 5.88; NH18 and NH19 ranked 2nd and 3rd, respectively, with scores of 4.99 and 3.62 (Table 5). NH419 received the lowest rank with a CCDI value of 0.81, altering the usual hierarchy of road influence. Considerable alterations were observed in SH (0.98), MDR1 (2.90), and MDR2 (3.24), with MDRs scoring higher than SH and MDR2 outperforming MDR1. Therefore, it is once again evident that collectively there is substantial variation both between and within road categories. The difference between the highest and lowest CCDI was 5.07; the mean CCDI was 3.20. Four of the seven corridors scored above the mean; hence, they are categorized as developed corridors, while the other three are categorized as underdeveloped corridors. Therefore, planning implementation should focus on these underdeveloped corridors to balance the uneven corridor development across the district.

**Table 5:** Comparative Corridor Development Index (CCDI).

Corridors	Land conversion rate (LCR)	Score	Percentage of Built-up land (PBL)	Score	Built-up Patch Density (BPD)	Score	Largest Built-up Patch Index (LBPI)	Score	Female literacy rate (FLR)	Score	Other work participation (OWP)	Score	Main-Marginal worker ratio	Score	Comparative Corridor Development Index
NH19	1.32	0.62	17.98	0.32	6.07	1.00	4.69	0.09	47.87	0.42	61.55	0.58	3.09	0.60	3.62
NH18	1.53	0.79	32.54	0.69	3.98	0.24	27.51	0.63	53.85	0.80	79.60	1.00	4.05	0.85	4.99
NH218	1.78	1.00	45.10	1.00	3.32	0.00	43.05	1.00	56.93	1.00	74.41	0.88	4.65	1.00	5.88
NH419	0.58	0.00	7.96	0.07	4.13	0.29	4.38	0.08	44.55	0.20	41.86	0.11	0.93	0.05	0.81
SH	0.90	0.27	4.98	0.00	5.28	0.71	0.99	0.00	41.39	0.00	37.11	0.00	0.75	0.00	0.98
MDR1	0.66	0.07	9.37	0.11	5.57	0.82	3.95	0.07	48.88	0.48	60.98	0.56	3.85	0.79	2.90
MDR2	0.99	0.35	14.89	0.25	5.01	0.61	5.17	0.10	53.77	0.80	75.61	0.91	1.66	0.23	3.24

5.5 Relationships: Landscape and Socio-Economic Indicators

Spearman's rank correlation has been performed using corridor-level indicators, including Land Conversion Rate (LCR), Percentage of Built-up Land (PBL), Built-up Patch Density (BPD), Largest Built-up Patch Index (LBPI), Female Literacy Rate (FLR), Other Work Participation (OWP), Main-Marginal Worker ratio (MMWR), and the Comparative Corridor Development Index (CCDI), to evaluate the relationship between landscape transformation and socio-economic development.

The outcomes show a strong positive association among land use, landscape, and socio-economic transformation indicators. The PBL shows a strong positive association with FLR ($\rho = 0.893$) and OWP ($\rho = 0.821$), indicating that corridors with greater urbanization exhibit higher female education and occupational diversity (Table 6). Similarly, strong positive relationships between LBPI and FLR ($\rho = 0.893$) and OWP ($\rho = 0.857$) indicate that compact urbanization will lead to socio-economic improvement. A relationship was found between LCR and the CCDI ($\rho = 0.964$), demonstrating that corridors undergoing greater land-use and land-cover change tend to exhibit higher overall development. PBL also exhibits a strong correlation with CCDI ($\rho = 0.964$), indicating the close association between urban expansion and corridor development. Nonetheless, the Main-Marginal Worker Ratio (MMWR) also exhibits strong positive associations with several indicators of landscape and socio-economic transformation. The relationships between MMWR and the Largest Built-up Patch Index ($\rho = 0.86$) and the Comparative Corridor Development Index ($\rho = 0.86$) indicate that corridors with more consolidated urban growth generally exhibit greater employment stability. MMWR also demonstrates strong positive correlations with Land Conversion Rate ($\rho = 0.79$), Percentage of Built-up Land ($\rho = 0.79$), and Female Literacy Rate ($\rho = 0.75$). In contrast, MMWR shows a strong negative association with Built-up Patch Density ($\rho = -0.71$), suggesting that fragmented urban growth is less likely to support stable employment structures. These findings indicate that employment stability tends to improve alongside urban consolidation and overall corridor development.

In contrast, Built-up Patch Density (BPD) shows negative correlations with most socio-economic indicators, including Female Literacy Rate ($\rho = -0.607$), Other Work Participation ($\rho = -0.429$), and CCDI ($\rho = -0.393$). This suggests that fragmented patterns of built-up growth are generally associated with lower levels of development than corridors characterized by larger, more continuous urban patches.

Overall, the correlation analysis provides quantitative evidence that landscape transformation and socio-economic advancement are closely interconnected processes along transportation corridors. Corridors exhibiting greater land conversion, urban expansion, and urban consolidation tend to demonstrate higher levels of socio-economic development, whereas fragmented growth patterns are associated with comparatively weaker development outcomes.

Table 6: Spearman's rank correlation matrix.

Variable	LCR	PBL	BPD	LBPI	FLR	OWP	MMWR	CCDI
LCR	1.00	0.89	-0.43	0.82	0.75	0.71	0.79	0.96
PBL	0.89	1.00	-0.46	0.93	0.89	0.82	0.79	0.96
BPD	-0.43	-0.46	1.00	-0.68	-0.61	-0.43	-0.71	-0.39
LBPI	0.82	0.93	-0.68	1.00	0.89	0.86	0.86	0.86
FLR	0.75	0.89	-0.61	0.89	1.00	0.86	0.75	0.86
OWP	0.71	0.82	-0.43	0.86	0.86	1.00	0.61	0.79
MMWR	0.79	0.79	-0.71	0.86	0.75	0.61	1.00	0.86
CCDI	0.96	0.96	-0.39	0.86	0.86	0.79	0.86	1.00

6. Discussion

6.1 Road Hierarchy and Spatial Transformation

The overall analysis clearly shows that road hierarchy and associated accessibility generally support greater transformation of land use and land cover, as well as urban growth and socio-economic change among inhabitants in closer proximity. Being national highways (NH19, NH18, and NH218), they attract economic activity, population concentration, service provision, and employment generation. NH218 extends entirely over the historical core of the urbanized city of Dhanbad and the main mining-industrial belt of the region, covering Dhansar, Bhagatdih, Katras, Jharia, Jharia Khas, Jamadoba, Jorapokhar, and Bhowra, resulting in greater land transformation, urbanization, and socio-economic shifts (Figure 7). Simultaneously, NH18 has recorded a slightly less similar pattern of transformation and ranked 2nd as per corridor transformation. Unlike NH218, it is partially extended across the newer urban concentration of Dhanbad city, such as Gosaidi, Saraidhella, Haripur, and the core mining areas of Godhar, Dharia joba, Ganshadih, Kusunda, etc. NH19, on the other hand, stretched across the district's east-west direction, dividing it into two halves and mostly covering the secondary urban centers (beyond Dhanbad city), such as Chirkunda, Mugma, Nirsra, Gobindpur, and Topchanchi, as well as regions outside the district's main mining core. These all provide insight into how accessibility interacts with local catalysts, such as mining and urban growth. This will be more transparent in the discussion of the following sections.

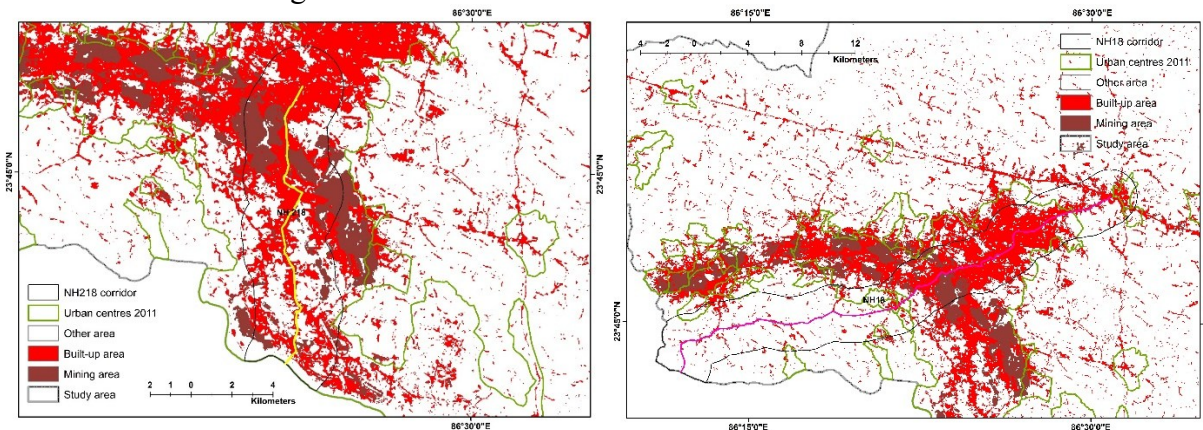


Figure 7. Showing the locational advantages of Corridor NH218 and NH18.

6.2 Development Beyond Road Hierarchy

Previous sections discussed the road hierarchy in higher-grade corridors; however, significant inter- and intra-class transformations remain visible and will be the main focus of this section. Despite belonging to the same road category, NH218 and NH19 show a notable difference, with values of about (5.88-3.62). This indicates the influence of a localized mining industry and associated urban expansion, which lead to greater landscape transformation and development in the surrounding area; in the absence of such catalysts, the NH19 corridor remains less developed and transformed (Figure 8). A difference has also been recorded between MDR1 and MDR2, with the latter exceeding the former according to the CCDI. MDR2 is partially extended at the southern end over the western stretch (Baghmara, Dumra, Mahuda, etc.) of the Jharia coal mining area, and the entire middle-northern part runs across the rural areas of the Baghmara and Topchanchi blocks. By contrast, MDR1 runs through the rural areas of Gortopa, Jagdis, Sindurpur, Hariaria, Sitalpur, etc., located farther away but within 5 km of both Dhanbad city and the mining industrial regions, resulting in differences in land transformation and socio-economic development. Therefore, similar road classes show markedly different development outcomes, supporting the argument that the observed transformation cannot be explained solely by accessibility.

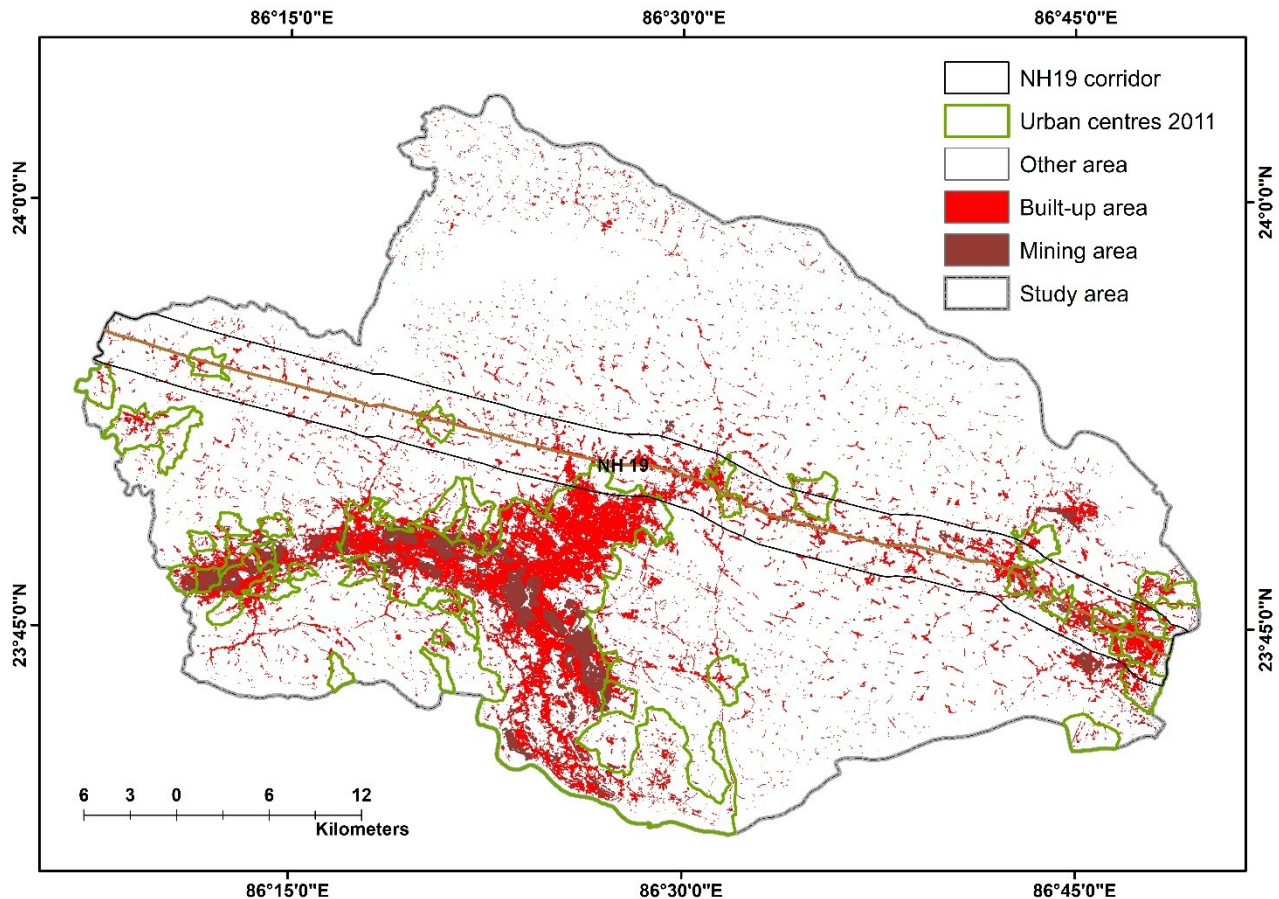


Figure 8. Shows the path through which the NH19 corridor traverses the region.

6.3 Catalyst of Corridor Development

From the above discussion, it follows that mining-industry-based urban concentration accelerates and shapes the pace and pattern of transformation along road corridors. The Dhanbad-Jharia coal field is a leading coal mining area in eastern India; therefore, the regional transport facilities are mainly developed to connect the major Iron & Steel industries of India with this region. Infrastructural development, such as road connectivity, is also guided by the spatial distribution of mining industrial activities. Naturally, with the regional economy dependent on this mining industry, urbanization and other industrial development are concentrated mostly around the coalfield regions. NH218, NH18, and MDR2 therefore exhibit a different transformation scenario from other corridors in the same category; all three have significant mining-industrial effects that stimulate transformation along their corridors (Figure 9). The score for other work participation in the CCDI table also indicates the labor force's engagement in non-agricultural urban industrial activities along the corridors. Additionally, the infrastructure development carried out by ECL for residents encouraged population concentration. Clearly, the discussion shows that roads facilitate movement, while mining generates the economic demand that translates accessibility into development.

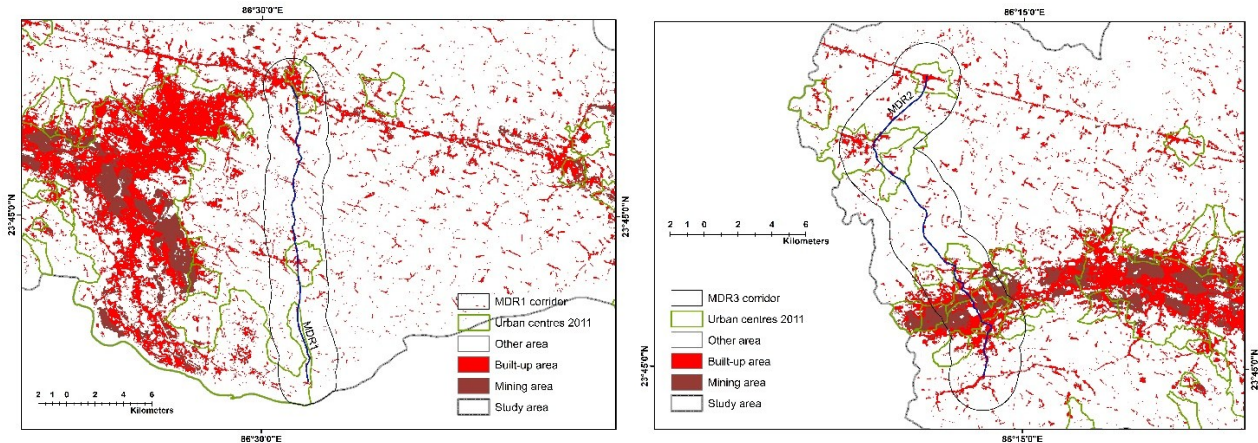


Figure 9. Extension of MDR1 and MDR2 road corridor.

6.4 Uneven Development and Corridor Effects

The CCDI scores recorded along the NH419 and SH generated scope for more discussion. While most of the transformation and development concentrated along the NHs, NH419 has a totally different scenario; it has scored the lowest CCDI among all the corridors, not only state highways, but even below the CCDI value of major district road corridors. From past events in the district, it is found that the northern part of the district, mainly the forest areas of Pareshnath hill, was the region of Red terror. So those areas faced various acts of terror over a long period, most of which involved the demolition of infrastructure. Consequently, those regions remained underdeveloped. In addition, the absence of mining and other industrial activities led to the backwardness of the corridor regions. However, recent improvements in the road network have enabled the corridor to undergo the necessary transformation, as evidenced by the growth rates of the indicators, which are sometimes recorded as higher in corridors with lower CCDI values. However, the pull factor generated by the coal mining industry and associated urbanization has confined all development to the areas surrounding the historical city core and coal fields (Figure 10).

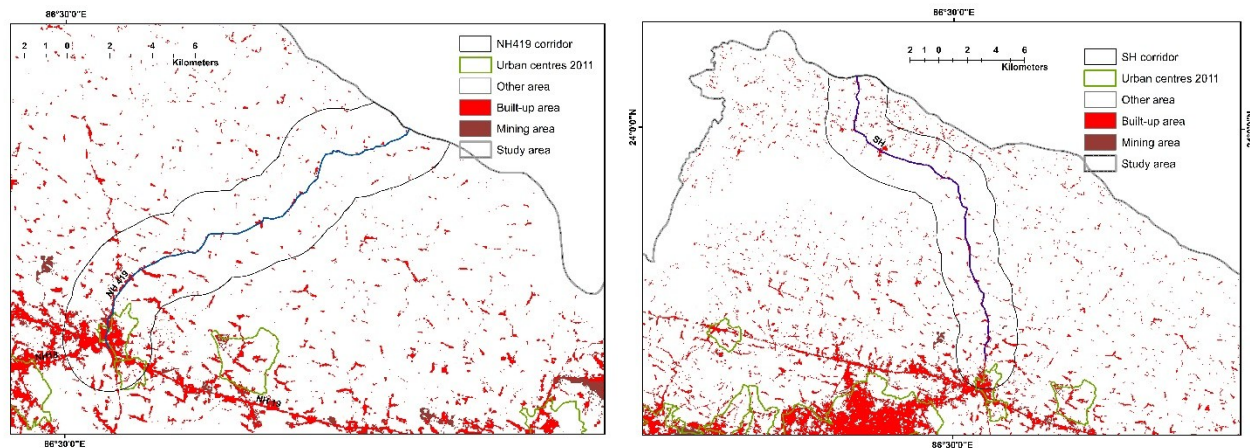


Figure 10. Location of corridor NH419 and SH.

6.5 Accessibility, Mining Activity, Urbanization, and Development Outcomes

Corridor-level observations have been consolidated through correlation analysis, demonstrating a strong association between landscape transformation and socio-economic development. However, these relationships spatially vary across the district and along the corridors. NH218 and NH18 have undergone the greatest transformations while traversing intensive mining and highly urbanized areas. In contrast, NH419 and the State Highway show comparatively weak transformation despite their transport infrastructure, while major district roads score higher than some higher-order corridors. This suggests that development outcomes are not determined by accessibility alone; rather, accessibility enables development, with mining activity, industrial concentration, and urban proximity stimulating

developmental effects. At the same time, the study's outcome supports an accessibility–resource development perspective in which road hierarchy influences development, with local economic geography operating in the background (Figure 11).

Finally, a corridor typology table was generated based on the road hierarchy, mining influence, urban proximity, and CCDI, revealing notable spatial variation in the overall transformation category irrespective of road hierarchy. These findings indicate that corridor transformation is shaped by the interaction among transportation accessibility, mining activity, and urban proximity, rather than by road hierarchy alone (Table 7).

Table 7: Comparative Assessment of Corridor Types.

Corridor	Road Hierarchy	Mining Influence	Urban Proximity	CCDI	Transformation Category
NH218	National Highway	High	High	5.88	Very High
NH18	National Highway	High	High	4.99	High
NH19	National Highway	Low	Moderate	3.62	Moderate
MDR3	Major District Road	Moderate	Moderate	3.24	Moderate
MDR1	Major District Road	Low	Moderate	2.9	Moderate
SH	State Highway	Low	Low	0.98	Low
NH419	National Highway	Low	Low	0.81	Low

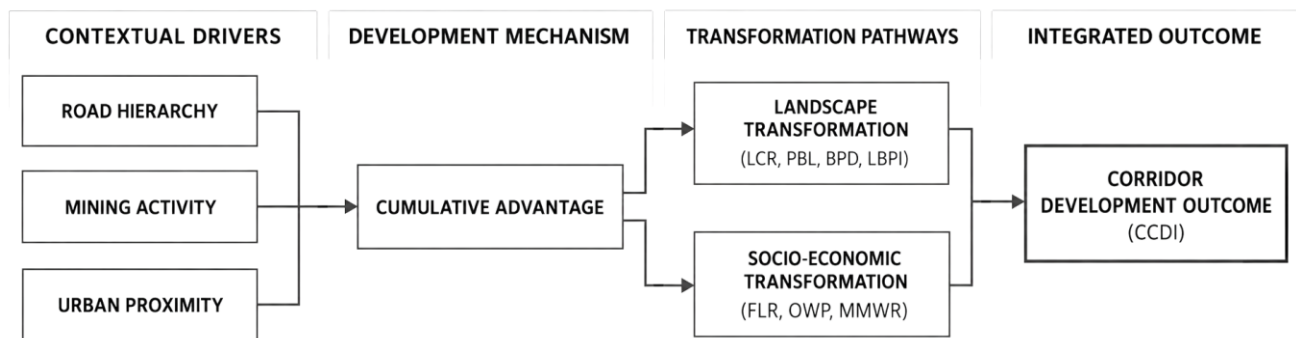


Figure 11. Corridor development outcome.

6.6 Planning Implications

The study offers significant insight into planning transport development and the associated socio-economic and physical transformation in the region, suggesting the integration of transport investments with broader economic development strategies. In resource-dependent regions like Dhanbad, road development and accessibility alone may not be sufficient to stimulate development in peripheral areas unless accompanied by employment-generating activities and institutional support. This is also generating a cumulative effect of transformation in the Dhanbad city and Jharia coal field regions. The government should encourage allied industries by providing loan subsidies, enhanced road connectivity, etc., to decentralize their units to distant areas of the district. Corridor-based planning approaches that address accessibility, industrial development, and environmental management simultaneously may therefore contribute more effectively to balanced regional development. Moreover, the study aligns with United Nations Sustainable Development Goal 9 (Industry, Innovation and Infrastructure), examining the association between landscape and socio-economic changes and different road categories. The study outcomes encourage more advanced, information-based planning and investment to support inclusive and sustainable regional development.

7 Conclusion

The present study evaluates the road-hierarchy-associated patterns of landscape and socio-economic transformation in Dhanbad district, India, using an integrated analytical framework that combines

land-use and land-cover dynamics, landscape metrics, and socio-economic indicators. Notable variation and alteration in transformation across transportation corridors have been observed, with National Highways generally exhibiting higher levels of built-up expansion, landscape reconfiguration, and socio-economic improvement compared to State Highways and Major District Roads. The alteration of results also indicates that observed development patterns cannot be interpreted solely by road hierarchy. Prominent differences were noted among corridors belonging to the same road category. Despite being National Highways, NH218 and NH18 exhibited higher levels of transformation than NH19 while traversing Dhanbad city and the Jharia coalfields. Similarly, MDR3 experienced development outcomes to a greater extent than MDR1, due to its partial association with mining activities. These findings imply that road accessibility alone may not be able to induce such transformation unless it interacts with local stimuli to shape development trajectories.

The study demonstrated that road infrastructure may primarily act as an enabling factor and cannot be considered an independent driver of regional transformation. Mining activity and allied industries drove development at different scales along the road accessibility zones, concentrating landscape and socio-economic changes in Dhanbad district. Therefore, the changes observed in the landscape, socio-economic status, etc., are the aggregate outcome of the road hierarchy, local mining and industrial activity, and urban proximity. The study also gives insight into the coexistence of development and environmental distortion. Along with aggregate development, the road corridors also experienced increasing landscape fragmentation and land-cover modification. This signifies the need for a balanced planning approach that supports development while ensuring environmental sustainability. Additionally, the findings from a policy perspective suggest that regional disparity of development may not be reduced merely by transport investment; rather, it should be combined with broader governmental initiatives like setting up new industries, decentralizing economic activities, employment generation, etc., which will lead to balanced regional development in the near future.

Although the study provides valuable insights into road corridor-associated land use and socio-economic transformation, it has certain limitations as usual: (i) it assesses spatial associations. It does not establish causal relationships among the variables. Future research may (ii) employ spatial econometric models and accessibility measures to quantify the relative influence of transportation infrastructure, mining activity, and urban proximity on development outcomes. (iii) Systematic comparative studies, including other mining districts, would also help to bring out the broader applicability of the findings.

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Conflicts of Interest

The author declares no conflicts of interest.

Data availability statement

The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

Institutional Review Board Statement

Not applicable.



CRedit author statement

P. A.: Conceptualized the study, prepared the maps and illustrations, wrote the original draft, and revised the manuscript. **A. C.:** Supervised and guided the work; provided valuable suggestions for the overall scientific presentation and revised the manuscript. All authors have read and approved the final version of the manuscript.

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