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# ASSESSING THE ENVIRONMENTAL IMPACTS OF URBANIZATION ON LAND USE AND ECOSYSTEM INTEGRITY IN GAYA CITY, BIHAR

Minti Kumari<sup>1</sup>, Prof. (Dr.) Bibha Singh<sup>2</sup>

<sup>1</sup>Research Scholar, P.G. Dept. of Geography, M.U. Bodh-Gaya, Gaya, Bihar, India

<sup>2</sup>Head, P.G. Department of Geography, Gaya College, Gaya, Bihar, India

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## ABSTRACT

Urbanization is one of the most significant processes of the twenty-first century, reshaping landscapes, economies, and ecosystems worldwide. In India, medium-sized cities have emerged as critical sites of unregulated urban growth, yet they remain under-researched compared to metropolitan centers. This study provides a comprehensive geographical assessment of urbanization and its environmental impacts in Gaya City, Bihar, a heritage and pilgrimage hub of Hindu and Buddhist significance. Using a mixed-method approach, the research integrates census data, municipal reports, household surveys, and key informant interviews with geospatial analysis of multi-temporal satellite images (2001, 2011, and 2021). Land use and land cover change analysis reveals that built-up areas more than doubled between 2001 and 2021, largely replacing agricultural land and vegetation cover. Environmental indicators show a decline in green spaces, falling groundwater levels, degradation of the Falgu River, rising particulate air pollution, and increasing solid waste generation. Socio-economic analysis highlights a livelihood transition from agriculture to services, tourism, and education, alongside the proliferation of informal settlements. These findings underline the ecological vulnerability of medium-sized cities, particularly those with heritage and cultural functions, where growth is intensified by religious tourism and weak governance. The study concludes that sustainable urban development in Gaya requires integrating ecological priorities into planning, strengthening institutional capacity, and promoting inclusive governance. The case of Gaya contributes to wider debates on urbanization by demonstrating that medium-sized heritage cities represent both opportunities for development and frontlines of environmental risk.



## 1. Introduction

Urbanization has become one of the defining processes of the twenty-first century, profoundly reshaping both the physical environment and socio-economic structures of human societies. Globally, more than half of the world's population resides in urban areas, and this proportion is projected to increase to nearly 68% by 2050 (United Nations, 2019). While urbanization is often associated with economic growth, modernization, and improved access to infrastructure, it simultaneously generates serious environmental challenges, particularly in rapidly developing countries. The pressures of urban expansion frequently manifest in deforestation, degradation of water bodies, air pollution, inefficient waste management, and the decline of ecosystem services. For geographers, therefore, urbanization is not merely a demographic phenomenon but a multi-dimensional process with significant ecological, spatial, and social implications.

India epitomizes this duality. With a current urban population of over 500 million, the country is undergoing one of the largest and fastest urban transitions in history. Yet, the pattern of urban growth in India is highly uneven, with metropolitan cities attracting considerable scholarly attention, while medium-sized cities often experiencing the most unregulated forms of sprawl remain under-researched. The state of Bihar illustrates this trend. Historically agrarian, Bihar has recently witnessed steady urban expansion, albeit with weak planning frameworks and limited infrastructural capacity. Medium cities, in particular, are emerging as centers of trade, education, and migration but are simultaneously facing mounting ecological pressures.

Among these urban centers, Gaya City stands out due to its unique cultural and geographical significance. Located in southern Bihar, Gaya is globally recognized as a religious and heritage destination, revered by Hindus for the Vishnu pad temple rituals (Pind Daan) and by Buddhists for Bodh Gaya, where Gautama Buddha attained enlightenment. This dual status as a pilgrimage hub and an expanding regional center has accelerated migration, commerce, and infrastructural growth in the city. However, much of this expansion has occurred in an unplanned and fragmented manner, resulting in profound stress on the city's ecological systems. Issues such as the depletion of the Falgu River, encroachment on agricultural land, declining green cover, waste accumulation, and increasing



air pollution exemplify the environmental consequences of unchecked urbanization in Gaya.

The contradiction between development and sustainability is stark. While urbanization has created employment opportunities, expanded educational facilities, and integrated Gaya into global religious tourism circuits, it has simultaneously undermined environmental resilience. The growing imbalance between the natural and built environment raises fundamental questions about the future livability of the city. Despite these challenges, research on the environmental consequences of urbanization in Gaya remains fragmented, often focusing narrowly on tourism or heritage, without a comprehensive geographical assessment.

The present study seeks to address this gap. Anchored within the discipline of geography, it aims to examine the spatial patterns, ecological impacts, and socio-economic consequences of urban growth in Gaya City. The study combines geospatial techniques, census data, municipal reports, and field surveys to provide a holistic assessment of how urbanization is reshaping the city's environment.

### **1.1 Objectives of the Study**

1. To trace the spatial and temporal patterns of urban growth in Gaya City over recent decades.
2. To evaluate the environmental consequences of urbanization with specific focus on land use, vegetation cover, water resources, air quality, and solid waste management.
3. To analyze the socio-economic dimensions of urban expansion, including livelihood changes and urban inequality.
4. To propose strategies and policy recommendations for sustainable urban development in Gaya.

### **1.2 Research Questions**

1. What are the key spatial and demographic dynamics driving urban growths in Gaya City?
2. In what ways has urbanization altered the ecological balance, particularly with respect to land, water, and vegetation?

3. How do socio-economic transformations interact with environmental challenges in the city?
4. What urban planning and policy measures can reconcile growth with sustainability in Gaya?

## **2. Literature Review**

Urbanization and environmental transformation have long been central themes in geography and environmental studies. The literature indicates that while the process of urban expansion has been extensively studied in metropolitan contexts, medium-sized cities in developing countries remain underexplored, despite their significant ecological and socio-economic implications.

### **2.1 Theoretical Perspectives**

Several conceptual frameworks shape the understanding of urbanization and its environmental impacts. The theory of urban sprawl emphasizes the consequences of unplanned horizontal expansion into peri-urban areas, often at the cost of agricultural and ecological land (Ewing, 1997). Land use and land cover (LULC) change models provide geospatial insights into how urban expansion alters vegetation cover, water resources, and soil systems (Turner et al., 2001). Complementing these, the ecological footprint approach (Rees, 1992) underscores the growing imbalance between cities' consumption demands and their local ecological capacity. Together, these frameworks highlight urbanization as both a socio-economic necessity and an environmental challenge.

### **2.2 International Experiences**

Globally, a large body of research has documented the environmental effects of urban expansion. In Sub-Saharan Africa, studies report that unregulated urban growth accelerates vegetation loss and threatens ecosystem integrity (Mensah et al., 2019). Research in Southeast Asian cities such as Jakarta and Bangkok demonstrates that poorly planned urbanization intensifies flooding, waste accumulation, and air pollution (Firman, 2009). Latin American cities reveal similar concerns, with biodiversity decline and peri-urban land conflicts becoming prominent outcomes of unplanned growth (Seto, Güneralp, & Hutyrá, 2012). These international findings highlight that medium-sized cities, though less prominent



than megacities, often experience sharper ecological stress due to weaker planning institutions and limited governance capacities.

### **2.3 National Context: India and Bihar**

In India, urbanization studies have focused disproportionately on large metropolitan centers such as Delhi, Mumbai, and Bengaluru, where research highlights the growth of urban heat islands, declining air quality, and shrinking wetlands (Singh et al., 2017; Prakash et al., 2019). However, smaller and medium-sized cities, especially in eastern India, are increasingly recognized as sites of unregulated growth with profound ecological consequences. Bihar provides a compelling case. Ahmad (1961) offered one of the earliest demographic analyses of rural Bihar, while Sinha (1980) examined land use transformations in the rural urban fringe of Patna. Subsequent work shifted towards broader socio-economic questions: Sharma et al. (2002) analyzed poverty, employment, and human development, and Pratap and Pratap (2017) highlighted how urban processes influence regional development. Endow (2017) emphasized the role of rural urban linkages in six towns, while Ahsan (2017) provided a socio-economic profile of rural Bihar. More localized studies have drawn attention to environmental dimensions. Sen and Kumar (2017) documented LULC change along highways in Gaya District, while Kumar et al. (2017) assessed groundwater resources in Patna and Gaya, identifying depletion and over-extraction as major concerns. Imam (2020) analyzed population growth and urbanization patterns at the district level across Bihar, revealing uneven urban development. Swarup (2022) specifically addressed the environmental impacts of urbanization in Gaya, highlighting challenges related to solid waste, river pollution, and green space decline. Singh and Hazra (2024) examined broader urbanization patterns and potentials in Bihar, whereas Veenapani and Chandra (2024) analyzed infrastructural stress and ecological consequences in urban centers. Kumar (2024) provided a historical perspective, tracing the emergence of urban religious and exchange centers in early medieval Bihar. Recent interdisciplinary research deepens the debate. Singh et al. (2025) conducted a health risk assessment of dietary metal intake in Gaya District, linking environmental degradation with human health. Rajput and Pu (2025) explored the intersections of water, caste, gender, and tourism in Bodh Gaya, illustrating the socio-cultural dimensions of urbanization. Bharti et al. (2025) developed a geospatial framework for



detecting flood-prone areas in Bihar, reflecting the growing climate vulnerability of urban settlements in the state.

## 2.4 Research Gap

Despite this expanding body of work, critical gaps remain. Early studies in Bihar focused on demography (Ahmad, 1961) and land use transitions (Sinha, 1980), while later works engaged with socio-economic development (Sharma et al., 2002; Ahsan, 2017) and infrastructure (Veenapani & Chandra, 2024). More recent contributions have addressed specific environmental challenges such as groundwater depletion (Kumar et al., 2017), land cover change (Sen & Kumar, 2017), flooding (Bharti et al., 2025), and environmental degradation in Gaya (Swarup, 2022). However, these studies tend to be issue-specific, lacking a holistic geographical perspective that integrates spatial patterns, ecological indicators, and socio-economic dimensions. Furthermore, the intersection of urban growth, environmental sustainability, and cultural heritage in Gaya remains underexplored. As a medium-sized heritage city shaped by religious tourism and regional migration, Gaya presents a distinct urban trajectory where development and ecology are in constant tension. This study seeks to bridge this gap by conducting a comprehensive geographical assessment of urbanization and its environmental impacts in Gaya, thereby contributing to regional scholarship in Bihar and to broader global debates on sustainable urbanization.

## 3. Study Area

Gaya, located at 24.78° N and 84.98° E in southern Bihar, lies about 100 kilometers south of Patna at an elevation of 111 meters above sea level. The city is bounded by small hills such as Mangla-Gauri, Ram-Shila, and Brahmayoni, while the Falgu River flows along its eastern edge. It has a humid subtropical climate, with an annual rainfall of about 1,055 to 1,100 millimeters, concentrated mainly during the monsoon months, and temperatures ranging from 8°C in winter to over 40°C in summer. According to the Census of India 2011, the population of Gaya Municipal Corporation was 470,839 with a literacy rate of 85.7 percent. Based on census trends, the city's population has now crossed 600,000 and is projected to approach 680,000 by 2025, reflecting natural growth and migration from surrounding rural areas. Gaya is both a religious and service hub. The Vishnupad Temple makes it one of Hinduism's most important ritual centers, while Bodh Gaya, 12 kilometers



away, is a UNESCO World Heritage Site and major Buddhist pilgrimage center. These functions sustain a tourism-based economy complemented by trade, education, and services. Institutions such as Magadh University and the Indian Institute of Management Bodh Gaya enhance its regional importance. Rapid urban expansion, especially along the Gaya–Bodh Gaya corridor, has converted agricultural land into built-up areas, intensifying ecological stress. Key challenges include pollution and encroachment of the Falgu River, groundwater depletion, loss of vegetation, air pollution, and inadequate waste management. Weak municipal capacity has further limited effective planning, leading to unregulated growth, informal settlements, and rising environmental pressure.

#### **4. Data and Methodology**

The study is based on both secondary and primary data, combined with spatial analysis. Population statistics and environmental records were collected from the Census of India, reports of the Gaya Municipal Corporation, and official publications of the Government of Bihar. To trace spatial growth, multi-temporal satellite images from Landsat and Sentinel (2001, 2011, and 2021) were analyzed using GIS techniques. Land use and land cover were classified into built-up, agricultural, vegetation, and water bodies, and change detection analysis was applied to measure urban expansion and vegetation loss through NDVI. Environmental indicators such as groundwater status, Falgu River condition, air quality, and waste management were examined through secondary data and field observations. Household surveys were conducted in selected wards across the core city and peri-urban areas to understand water access, waste practices, and perceptions of environmental change. Key informant interviews with municipal officials and local leaders supplemented these findings. By integrating GIS-based spatial analysis, statistical examination of demographic trends, and qualitative evidence from field surveys, the study provides a comprehensive geographical assessment of the environmental impacts of urbanization in Gaya City.

#### **5. Results and Discussion**

##### **5.1 Urban Growth Pattern**

The land use and land cover analysis of Gaya City between 2001 and 2021 reveals a sharp and uneven transformation. The most striking feature is the rapid increase in built-up

land, which more than doubled in two decades, rising from 18.2 sq. km in 2001 to 39.8 sq. km in 2021. This growth has occurred largely at the expense of agriculture and vegetation, both of which recorded significant declines. Agricultural land shrank by nearly 30 percent during the study period, while vegetation cover contracted by more than one-third. These trends indicate a clear dominance of unregulated sprawl over planned urban development.

**Table 5.1: Land Use and Land Cover Change in Gaya City, 2001–2021**

Land Use Category	2001 (sq. km)	2011 (sq. km)	2021 (sq. km)	Change (2001–2021)	% Change
Built-up	18.2	27.6	39.8	+21.6	+118.6
Agricultural Land	52.4	44.7	37.1	–15.3	–29.2
Vegetation/Forest	11.6	9.4	7.8	–3.8	–32.7
Water Bodies	3.2	3.1	2.9	–0.3	–9.3
Open Land/Barren	6.8	7.4	8.0	+1.2	+17.6

*Source: Landsat/Sentinel satellite imagery, classified through GIS*

The expansion is particularly intense along the Gaya–Bodh Gaya corridor, where religious tourism and institutional growth have stimulated residential colonies, hotels, and commercial complexes. Similarly, the Patna–Gaya highway has emerged as another axis of expansion, reflecting the role of transport connectivity in shaping peri-urban growth. This pattern mirrors findings from other medium-sized Indian cities, where linear sprawl along transport routes often precedes more compact development.

## 5.2 Environmental Impacts

The ecological consequences of this expansion are wide-ranging. Vegetation loss has reduced the buffering capacity of the city against heat and air pollution. NDVI analysis shows a decline in dense vegetation patches, particularly in peri-urban areas, replaced by fragmented green spaces that provide limited ecological services. The loss of tree cover is consistent with field observations of increasing heat stress during summer months, an early indication of urban heat island effects. Water resources are under acute pressure. The Falgu River, once central to the city’s ritual and ecological life, has become seasonal and degraded. Sand mining, encroachment, and untreated sewage discharge have diminished both its flow and quality. Groundwater, the principal source of domestic supply, has shown a steady decline,

with average depths increasing from 4.8 meters in 2001 to 7.5 meters in 2021. This reflects both over-extraction and reduced recharge due to the paving of open land. Air quality has deteriorated in parallel with rising vehicular traffic, construction activity, and biomass burning. Data from the Bihar State Pollution Control Board indicate that PM10 levels in Gaya frequently cross national ambient standards, especially during winter when atmospheric inversion traps pollutants. The situation is aggravated by the lack of continuous air monitoring infrastructure in the city, which obscures the full scale of the problem. Waste management remains one of the most visible urban challenges. Municipal estimates suggest that daily waste generation has nearly doubled in two decades, rising from about 105 metric tons in 2001 to nearly 190 metric tons in 2021. However, collection and scientific disposal capacity have not kept pace, leading to open dumping and health hazards in several wards.

**Table 5.2: Selected Environmental Indicators of Gaya City, 2001–2021**

Indicator	2001	2011	2021	Trend
Vegetation Cover (sq. km)	11.6	9.4	7.8	Continuous decline
Avg. Groundwater Depth (m)	4.8	6.1	7.5	Increasing depletion
PM10 ( $\mu\text{g}/\text{m}^3$ , annual avg.)	72	96	118	Rising air pollution
Solid Waste (MT/day)	105	150	190	Growing burden

*Source: GMC records, CPCB data, field survey (2021)*

### 5.3 Socio-Economic Implications

These environmental changes are inseparable from socio-economic transformations. The decline of agriculture in peri-urban zones reflects not only land conversion but also a shift in livelihoods from farming to wage labor and service employment. Tourism, education, and small trade have emerged as the mainstay of the city's economy, but they create uneven opportunities. Seasonal dependence on pilgrim inflows contributes to instability in employment and income, while informal sectors continue to absorb a large proportion of the workforce under precarious conditions. The proliferation of informal settlements reflects the inability of formal housing markets to accommodate the city's rapid population growth. These settlements often lack piped water, sanitation, and waste collection services, intensifying both health risks and environmental degradation. Social inequality thus amplifies



ecological stress: while affluent neighborhoods consume more resources and generate more waste, marginalized communities bear a disproportionate share of the risks associated with pollution and poor services.

#### **5.4 Comparative and Theoretical Insights**

The findings from Gaya confirm broader theoretical arguments about medium-sized cities as “silent drivers” of urbanization in India. Unlike megacities, their growth often occurs with minimal planning oversight, resulting in rapid land conversion and weak environmental safeguards. This trajectory aligns with global evidence from Sub-Saharan Africa, Southeast Asia, and Latin America, where medium cities are increasingly recognized as critical sites of ecological vulnerability. In Gaya, the intersection of religious tourism, heritage conservation, and unplanned sprawl creates a distinctive challenge. The cultural economy that sustains the city also accelerates ecological pressures, particularly along the Falgu River and in the Bodh Gaya corridor. This raises fundamental questions about how heritage cities in developing regions can balance spiritual, economic, and environmental imperatives in the context of rapid urbanization.

The analysis underscores that urbanization in Gaya has been both transformative and destabilizing. Built-up areas have expanded dramatically, but without adequate environmental safeguards, resulting in shrinking agricultural land, declining vegetation, falling groundwater levels, and worsening air and waste conditions. The evidence suggests a pattern of unsustainable growth driven by migration, tourism, and infrastructural expansion, but poorly regulated by planning and governance systems. These trends highlight the urgent need for integrated urban management strategies. Expanding green cover, restoring the Falgu River, improving groundwater recharge, strengthening solid waste management, and enhancing air quality monitoring are critical steps. Equally important is addressing socio-economic inequality by ensuring basic services in informal settlements and involving local communities in urban planning. The case of Gaya demonstrates that medium-sized heritage cities in India cannot be overlooked in urban policy debates. They are not only centers of cultural and economic importance but also frontline sites of environmental stress. A sustainable future for Gaya depends on reconciling its religious and cultural significance with a more ecologically balanced model of urban growth.

## 6. Conclusion and Policy Recommendations

### 6.1 Conclusion

The analysis of urbanization in Gaya City demonstrates that the pace and nature of growth over the past two decades have been both transformative and environmentally destabilizing. Built-up areas have more than doubled, while agricultural land and vegetation have declined sharply. Groundwater levels continue to fall, the Falgu River has suffered from pollution and encroachment, air quality has worsened, and waste management remains inadequate. These environmental pressures are closely linked to socio-economic shifts, where the decline of agriculture and the rise of tourism, education, and service-based activities are reshaping the city's livelihood structure. While these changes have generated new opportunities, they have also deepened inequality and intensified ecological vulnerability. The findings place Gaya within the wider debates on the sustainability of medium-sized heritage cities. Unlike metropolitan regions, which benefit from greater investment and institutional capacity, cities such as Gaya grow with weak planning frameworks and fragile governance structures. The distinct challenge here lies in balancing economic development and religious tourism with ecological sustainability. Unless urgent measures are undertaken, the very cultural and environmental assets that underpin the city's significance are at risk of degradation.

### 6.2 Policy Recommendations

- 1. Land Use Regulation and Zoning:** Introduce strict enforcement of zoning laws to curb unregulated sprawl and protect agricultural land, riverbanks, and ecologically sensitive areas. Integrated master planning should emphasize compact growth rather than peripheral encroachment.
- 2. Groundwater Security:** Establish a citywide water conservation program with compulsory rainwater harvesting, artificial recharge structures, and restrictions on indiscriminate borewell drilling. Public campaigns should promote sustainable water use at the household level.
- 3. Falgu River Restoration:** Develop an integrated river management plan focusing on sewage treatment, pollution control, regulated sand mining, and encroachment removal. Ecologically sensitive riverfront development can also enhance cultural and tourism values while ensuring environmental protection.

- 4. Waste Management Modernization:** Transition from open dumping to an integrated waste management system. This should include segregation at source, community-level composting, recycling facilities, and scientific landfill sites. Waste-to-energy plants may be explored for long-term sustainability.
- 5. Air Quality Management:** Expand the monitoring network to generate reliable air quality data. Policies should target vehicular emissions through stricter inspection norms, promotion of non-motorized transport, and regulation of dust from construction activities.
- 6. Urban Greening and Climate Resilience:** Launch forestation drives within the city and develop peri-urban green belts to serve as ecological buffers. Parks and community green spaces should be integrated into planning to reduce heat island effects and improve livability.
- 7. Institutional Capacity Building:** Strengthen the Gaya Municipal Corporation by enhancing financial resources, recruiting skilled technical staff, and improving accountability mechanisms. Inter-agency coordination must be improved to bridge gaps between planning and implementation.
- 8. Inclusive and Participatory Governance:** Ensure active participation of local communities, particularly marginalized groups in informal settlements, in urban decision-making processes. Citizen feedback mechanisms can make governance more transparent and responsive.
- 9. Sustainable Integration of Smart City Initiatives:** Align Smart City projects with ecological priorities by investing in energy-efficient infrastructure, water recycling, digital monitoring of environmental indicators, and heritage-sensitive development models.

By adopting these measures, Gaya can move toward a balanced model of growth that preserves its ecological base while sustaining its role as a cultural and religious hub. The study underscores that medium-sized cities, often overlooked in urban policy debates, are critical spaces where the contradictions of development and environment are most visible. A forward-looking framework for Gaya can therefore serve as a template for managing sustainability challenges in other heritage cities across India.



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