

Changing Land Use and Land Cover: A Case Study of Bettiah City, Bihar

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Abstract:

This study uses Landsat satellite imagery for 1991, 2001, 2011, and 2022, processed through supervised classification, to quantify changes across five broad LULC classes – waterbody, agriculture, built-up, vegetation, and open area – within the Bettiah Nagar Parishad area and its immediate surroundings. The results show that built-up area increased from 6.58 sq. km in 1991 to 10.33 sq. km in 2022, with the sharpest expansion occurring after 2011, largely at the cost of agricultural land, which fell from 27.31 sq. km in 2011 to 20.52 sq. km in 2022. Waterbody area also increased over the period, reflecting the emergence of new water-holding depressions and possibly classification effects linked to seasonal flooding, while open/vacant land declined overall as it was progressively absorbed into either cultivation or construction. The findings are discussed in relation to Bettiah's administrative upgradation, ribbon development along National Highway-28B and State Highway-54, the outer ring road, and growth of the Mithanpura industrial belt. The paper concludes with planning implications for the management of Bettiah's future urban expansion.

Keywords: Land Use/Land Cover, Remote Sensing, GIS, Urban Expansion, Bettiah, Bihar

ABSTRACT

Bettiah, the headquarters of West Champaran district in north-western Bihar, has undergone a visible transformation of its land use and land cover (LULC) over the last three decades. This study uses Landsat satellite imagery for 1991, 2001, 2011, and 2022, processed through supervised classification, to quantify changes across five broad LULC classes – waterbody, agriculture, built-up, vegetation, and open area – within the Bettiah Nagar Parishad area and its immediate surroundings. The results show that built-up area increased from 6.58 sq. km in 1991 to 10.33 sq. km in 2022, with the sharpest expansion occurring after 2011, largely at the cost of agricultural land, which fell from 27.31 sq. km in 2011 to 20.52 sq. km in 2022. Waterbody area also increased over the period, reflecting the emergence of new water-holding depressions and possibly classification effects linked to seasonal flooding, while open/vacant land declined overall as it was progressively absorbed into either cultivation or construction. The findings are discussed in relation to Bettiah's administrative upgradation, ribbon development along National Highway-28B and State Highway-54, the outer ring road, and growth of the Mithanpura industrial belt. The paper concludes with planning implications for the management of Bettiah's future urban expansion.

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1. INTRODUCTION

Land Use/Land Cover (LULC) refers to the classification of the earth's surface into categories that describe both the physical cover of the land (land cover) and the purpose for which people use it (land use). Because LULC integrates human activity with the physical landscape, it is one of the most sensitive indicators of how a settlement is developing. A town that is growing outward, densifying its core, converting cropland into housing colonies, or losing its water bodies to encroachment will register these changes directly in its LULC record.

The systematic mapping of LULC through satellite remote sensing and Geographic Information Systems (GIS) has therefore become a standard tool in urban and regional planning. Multi-date satellite imagery allows changes that would otherwise be difficult to perceive year to year – the slow conversion of a field into a colony, the silting of a pond, the thickening of built-up clusters along a highway – to be measured over a decadal time-scale and mapped with precision. Such information is essential not only for understanding what has already happened but also for anticipating the direction in which a town is likely to grow, and for designing planning interventions before haphazard growth becomes difficult to reverse.

Small and medium towns of Bihar, including district headquarters such as Bettiah, have generally received far less LULC research attention than the state capital, Patna, even though their rate of physical expansion in the last two decades has often been just as significant relative to their size. Bettiah is a useful case in this respect: it is an old administrative and market town

with a defined historical core, but it has been reclassified from a Nagar Parishad to a Nagar Nigam in recent years, and its peripheral growth along highways and the outer ring road is visibly reshaping the town's built form. A systematic, image-based account of how its land use has actually changed – rather than an impressionistic one – is therefore of direct value to the municipal authorities responsible for its future planning.

2. BACKGROUND OF THE STUDY

Bettiah Nagar Parishad was constituted as a municipality in 1869 and has long functioned as the administrative and commercial headquarters of West Champaran district, located about 225 km north-west of Patna. The town carries considerable historical importance: it was the seat of the seventeenth-century Bettiah Raj estate, one of the principal British administrative centres in the region during colonial rule, and the place from which Mahatma Gandhi launched the Champaran Satyagraha in 1917.

As per the 2011 Census, the Municipal Council area of about 8.01 sq. km recorded a population of 132,896 persons, up from 116,670 in 2001 – a density increase from 145 to 165 persons per hectare in just one decade. This population pressure, combined with the town's administrative upgradation to Nagar Nigam status, has been accompanied by unplanned and largely unregulated physical growth. Three factors in particular have shaped the direction of this expansion: ribbon development along National Highway-28B and State Highway-54; the construction of an Outer Ring Road that both improves connectivity and functions as a bypass; and the emergence of the Mithanpura Industrial Area, which is pulling development towards the north, north-east, and east of the historic core. Commercial activity remains concentrated in the town centre, producing congestion in the innermost wards even as new development spreads outward along the transport corridors.

This administrative change is itself part of the story. Under the Nagar Parishad, Bettiah was governed as 39 electoral wards over the compact 8.01 sq. km municipal area recorded at the 2011 Census. Following its upgradation to a Municipal Corporation (Nagar Nigam), the local body's jurisdiction was enlarged and reorganised into 46 wards (as per the current, 2023 ward-boundary map), bringing a considerably larger peripheral area – including revenue villages that were previously outside municipal limits – under the corporation's administration. This enlargement of the urban local body is not incidental to an LULC study: it is the formal, institutional counterpart of the physical peripheral growth that the classified imagery is intended to measure. In effect, the municipal boundary has been redrawn to catch up with settlement that had already begun to spread beyond the old Nagar Parishad limits along the highway and ring-road corridors described above.

It is against this background of administrative change, demographic growth, and infrastructure-led expansion that the present LULC assessment becomes relevant – not as a description of a static town, but as a record of a settlement actively in transition.

3. NEED OF THE STUDY

Several considerations make a dedicated LULC study of Bettiah necessary at this time.

First, planning documents for Bettiah have so far relied largely on descriptive and anecdotal accounts of urban growth rather than a quantified, image-based LULC time series. Without measured figures for how much agricultural or open land has actually been converted to built-up use, and where, municipal authorities have little basis for evidence-based zoning or infrastructure planning.

Second, Bettiah's recent upgradation to Nagar Nigam status is likely to accelerate development pressure, as municipal boundaries expand and infrastructure investment increases. A baseline LULC record covering the period leading up to this transition is valuable precisely because it can later be used as a benchmark against which post-upgradation change can be measured.

Third, unplanned conversion of agricultural land and open space into built-up area has known environmental costs – reduced infiltration, increased surface runoff, pressure on drainage, and loss of productive farmland in the urban fringe. Given that Bettiah lies in the fertile alluvial plains of the Gandak basin, monitoring the pace at which this productive land is being urbanised is relevant both to local food security and to flood and drainage management in a town that already experiences monsoon waterlogging in several wards.

Finally, small and medium towns such as Bettiah are frequently overlooked in the wider literature on Indian urbanisation, which tends to focus on metropolitan cities. Yet these towns collectively house a large and growing share of India's urban population, and the drivers and patterns of their growth – ribbon development along highways, industrial-belt-led expansion, and slow densification of an old core – are not always identical to those of larger cities. A case study of Bettiah therefore also contributes to the broader understanding of small-town urbanisation in the Bihar plains.

4. LITERATURE REVIEW

Research on LULC change in Bihar has grown steadily over the last decade, mostly using multi-temporal Landsat imagery classified through supervised methods such as Maximum Likelihood, Random Forest, or Artificial Neural Networks, followed by post-classification change detection.

Mishra, Rai, and Mohan (2014) used the Land Change Modeler with remote sensing data to analyse and predict LULC change in Muzaffarpur district, Bihar, demonstrating the utility of change-modelling techniques for tracking the conversion of agricultural land under urban pressure in the state. Building on this line of work, Sajan, Kanga, Singh, Mishra, and Durin (2023) examined the relationship between LULC change and land surface temperature (LST) and NDVI in Muzaffarpur district between 1990 and 2020 using Google Earth Engine, and found a strong negative correlation between vegetation cover and surface temperature – a

reminder that LULC change in Bihar's towns has measurable micro-climatic consequences and not merely a change in the appearance of the land.

Outside Bihar, Khan, Ullah, and Chen (2021) analysed the relationship between LULC indices and land surface temperature in Beijing using Landsat-8 and GF-2 imagery and a random forest classifier, showing how built-up expansion at the cost of green cover measurably raises local temperatures – a relationship of direct relevance to the interpretation of built-up expansion trends of the kind observed in the present study of Bettiah. Rimal, Zhang, Keshtkar, Wang, and Lin (2017) demonstrated the value of an integrated Markov Chain – Cellular Automata framework for monitoring and modelling spatiotemporal urban expansion and LULC change, an approach increasingly used in Indian small-town studies to project future growth once a baseline change record has been established.

Taken together, this body of work establishes two points that inform the present study. First, supervised classification of multi-date Landsat imagery is a reliable and widely validated method for quantifying LULC change even for data-scarce small and medium towns. Second, the conversion of agricultural and vegetated land into built-up area in Bihar's urban centres is not merely a change of surface category but carries measurable environmental consequences – rising local temperatures, altered drainage, and reduced agricultural productivity in the urban fringe – that make LULC monitoring a planning necessity rather than an academic exercise alone. The present study extends this literature, which has so far concentrated on Patna and Muzaffarpur, to Bettiah, a smaller but rapidly reorganising district headquarters town that has not previously been assessed in this way.

5. STUDY AREA

Bettiah is situated in the fertile alluvial plains of the Gandak river system in West Champaran district, north-western Bihar, approximately 225 km from Patna. The Bettiah Nagar Parishad area covers approximately 8.01 sq. km, though the LULC classification presented here also captures a surrounding buffer, giving a total classified area of roughly 45–46 sq. km across the four study years.

The town's population grew from 116,670 in 2001 to 132,896 in 2011 (Census of India), a density rise from about 145 to 165 persons per hectare. Bettiah functions as the administrative, educational, and commercial centre of West Champaran and has recently been upgraded from Nagar Parishad to Nagar Nigam status. Physically, the town's growth is being channelled along three axes: ribbon development along National Highway-28B and State Highway-54; the Outer Ring Road, which both improves connectivity and functions as a bypass; and expansion towards the Mithanpura Industrial Area, pulling development towards the north, north-east, and east. The commercial core remains concentrated in the town centre, producing congestion in the innermost wards, while the urban fringe shows the classic transitional land-use sequence

of agricultural land giving way first to vacant or under-construction plots and then to permanent built-up use.

5.1 Location of the Study Area

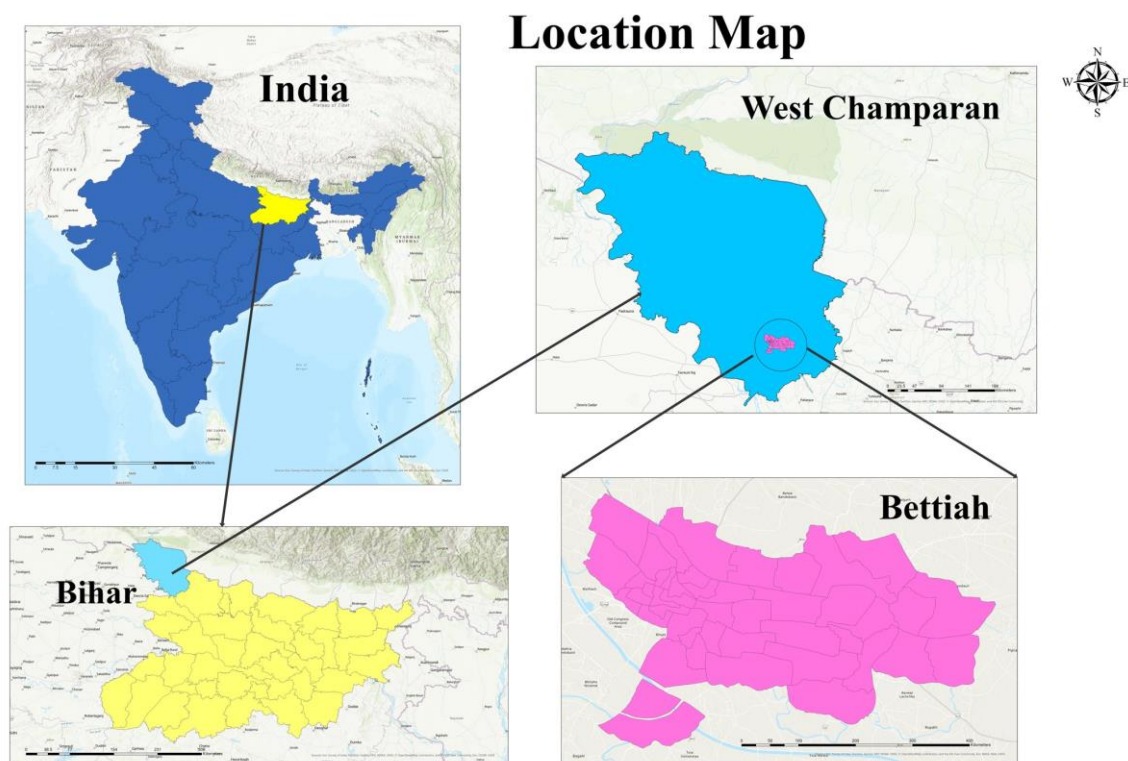


Figure 1: Location Map of the Study Area – India, Bihar, West Champaran and Bettiah

Figure 1 places the study area at four successive scales. The first panel shows Bihar within India, and the second shows Bihar itself, with West Champaran tucked into its north-western corner along the border with Nepal. The third panel isolates West Champaran, where Bettiah lies in the southern part of the district, and the last panel enlarges the city and its ward boundary. The base map in this last panel also shows river channels running along the western and south-western side of the city, which agrees with the narrow linear water feature that appears in the south-western lobe of the LULC maps presented later.

5.2 Administrative Boundary and Ward Structure

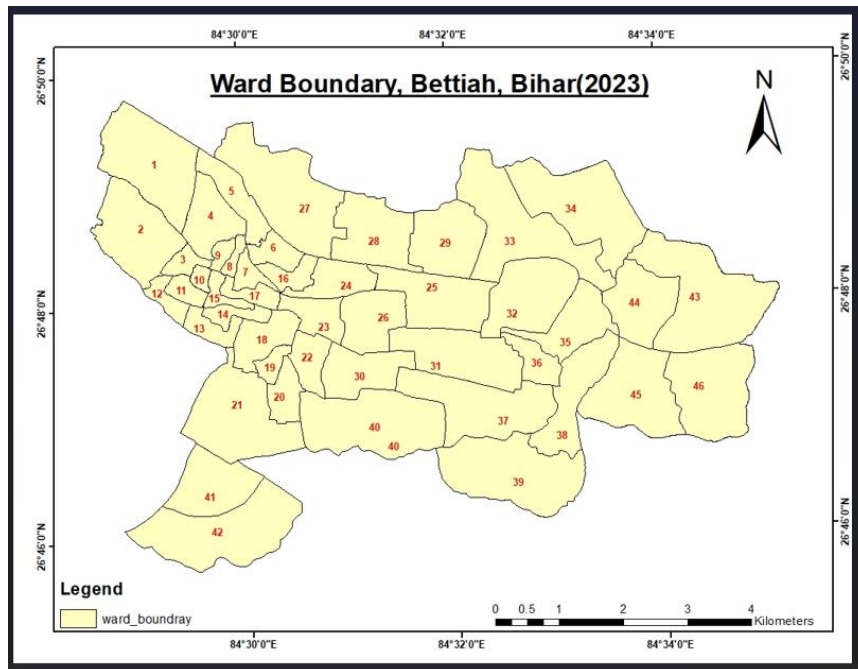


Figure 2: Ward Boundary of Bettiah Nagar Nigam, Bihar (2023)

Figure 2 shows the current administrative boundary of Bettiah Nagar Nigam, divided into 46 numbered wards as per the 2023 ward-boundary map. This supersedes the earlier 39-ward configuration of the Bettiah Nagar Parishad recorded at the 2011 Census, and the enlarged, irregular outline visible in the figure – elongated along a broadly north-west to south-east axis

rather than compact and circular – is itself a spatial record of the corridor- and periphery-led growth discussed in Section 2. Two features of the ward pattern are worth noting for the interpretation of the LULC results that follow. First, wards in the north-western and central parts of the city (approximately wards 1–23) are small and closely packed, corresponding to the older, denser urban core around the historic town centre and commercial area. Second, wards towards the south and east (approximately wards 37–46) are considerably larger in area, reflecting the recent incorporation of peripheral, still-transitional land – much of it agricultural or open land at the time of incorporation – into the municipal limits. This administrative boundary, rather than the smaller 2011 Nagar Parishad limit, defines the outer reference frame against which the buffer used for the satellite classification in this study should be understood; the LULC change reported in Sections 7 and 8 is, in effect, a quantitative record of the same peripheral transformation that required the ward map itself to be redrawn.

6. METHODOLOGY

6.1 Methodological Framework

The methodology of this study follows two parallel workflows that converge in the final analysis, as summarised in Figure 3. The first workflow builds the administrative base layer of Bettiah from the local Nagar Nigam ward map. The second workflow derives the land use/land cover (LULC) maps of the four reference years from Landsat satellite imagery.

Workflow A – Base shapefile from the local map. The printed/scanned ward map of Bettiah Nagar Nigam was first georeferenced in ArcGIS by assigning real-world coordinates to well-defined control points (road junctions and ward corners) and projecting it to WGS 84 / UTM Zone 44N. The georeferenced map was then digitized on screen as a polygon shapefile, tracing the outer municipal boundary and each ward boundary. Each polygon was given a ward-number attribute, so that the 46 wards could be classified and later used to clip the satellite images and to compare the older, denser core wards with the newer peripheral wards.

Workflow B – LULC mapping from satellite data. Landsat scenes for 1991, 2001, 2011, and 2022 were downloaded from the USGS EarthExplorer portal by defining the area of interest around Bettiah, selecting the Landsat Collection 2 Level-1/Level-2 datasets, filtering for low cloud cover, and downloading the best available scene covering the study area for each year. Each scene was layer-stacked, corrected, and clipped with the ward-based shapefile from Workflow A. Land-cover training samples for the five classes (waterbody, agriculture, built-up, vegetation, and open area) were then digitized, the images were classified using a supervised classifier, and the resulting LULC maps for 1991, 2001, 2011, and 2022 were checked for accuracy and used to calculate class-wise areas.

The four LULC maps and the ward layer were finally brought together to analyse the transformation of Bettiah's land use and land cover, both for the city as a whole and, where required, ward-wise.

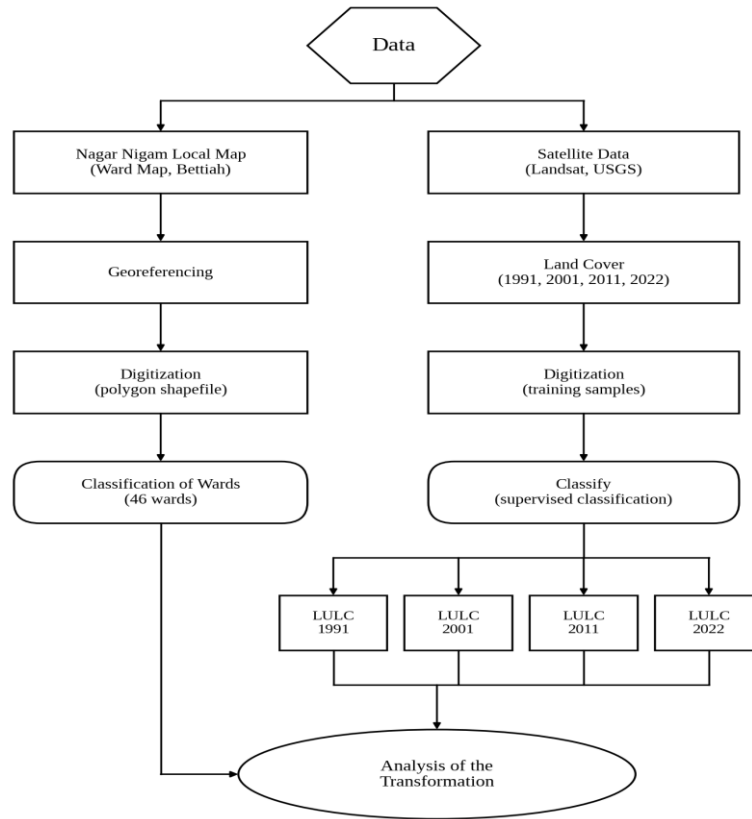


Figure 3: Methodological Framework of the Study

6.2 Data Source

Landsat satellite imagery for 1991, 2001, 2011, and 2022 was obtained from the United States Geological Survey (USGS) archive. Landsat 4-5 Thematic Mapper (TM) imagery (used for the earlier dates) provides seven spectral bands at 30 m spatial resolution (bands 1–5 and 7), with band 6 (thermal) resampled from 120 m to 30 m. Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) imagery (used for the later date) provides nine spectral bands at 30 m resolution for bands 1–7 and 9, a 15 m panchromatic band 8, and 100 m thermal bands 10 and 11. For each reference year the least cloudy usable scene was chosen. Because cloud-free scenes are not available for the same month every year, the acquisition months of the four images are not identical. This is a known constraint of the data, and its possible effect on the results is discussed under the limitations of the study in Section 9.

6.3 Classification Procedure

A supervised classification approach was adopted, following the standard sequence used in ArcGIS-based LULC studies:

- (i) Data collection – acquisition of cloud-free scenes for each of the four reference years; (ii) Training sample selection – identification of representative pixels for each of the five LULC classes used in this study (waterbody, agriculture, built-up, vegetation, and open area); (iii)

Pre-processing – radiometric and atmospheric correction and removal of noise; (iv) Training-sample creation in the Image Classification toolbar; (v) Classifier training, using a maximum-likelihood/random-forest type supervised algorithm; (vi) Classification of the full scene for each date; (vii) Accuracy assessment against reference points; and (viii) Map presentation, including tabulation of the area under each class for every reference year.

6.4 Change Analysis

For each LULC class, the net area change (ΔA) between two dates was computed as $\Delta A = A_2 - A_1$, and the percentage change as $[(A_2 - A_1) / A_1] \times 100$, where A_1 and A_2 are the areas in the initial and final years respectively. This was calculated both for the full 1991–2022 period and decade-wise (1991–2001, 2001–2011, 2011–2022) to identify when each class changed most rapidly.

7. BETTIAH LULC: CLASSIFICATION RESULTS

7.1 Area Statistics of the LULC Classes

Five LULC classes were mapped for Bettiah city and its surroundings for 1991, 2001, 2011, and 2022: Waterbody, Agriculture, Built-up, Vegetation, and Open Area. Table 1 presents the classified area (sq. km) for each class in each reference year.

Table 1: Area under LULC Classes in Bettiah City and Its Surroundings, 1991–2022 (sq. km)

S. No.	LULC Class	Area 1991 (sq. km)	Area 2001 (sq. km)	Area 2011 (sq. km)	Area 2022 (sq. km)
1	Waterbody	0.72	0.62	1.65	2.21
2	Agriculture	25.47	26.57	27.31	20.52
3	Built-up	6.58	7.54	6.29	10.33
4	Vegetation	10.66	9.88	9.79	11.70
5	Open Area	2.20	1.44	1.02	1.33

Agriculture was the dominant class throughout the study period, though its share fell in the final decade. Built-up area followed a non-linear path – rising through 1991–2001, contracting in the 2001–2011 classification, and then rising sharply by 2022. Waterbody area more than tripled over the full period, while open/vacant land generally declined, consistent with its progressive absorption into either cultivation or construction.

7.2 The LULC Classes Used in This Study

The classified maps in Figures 4 to 7 use the same five-class legend, so that any two years can be compared directly. The classes were kept broad on purpose. With 30 m Landsat pixels, a finer scheme would have asked the imagery to separate things it cannot reliably tell apart, such as a fallow field from a vacant plot, or a tiled roof from bare compacted soil. The five classes, and what each one means on the maps, are as follows.

Waterbody (blue). This class holds the river or canal channel, ponds, tanks, and other standing water. The most conspicuous feature is the narrow, straight-edged channel that cuts diagonally across the south-western lobe of the study area in every year. Most other waterbodies are small and scattered, and since the four scenes were acquired in different months, shallow ponds that fill or dry with the season may be over- or under-represented from one year to the next.

Agriculture (yellow). Cultivated land, including standing crops and fields that are fallow or freshly harvested at the time of the scene. It forms the background matrix of the whole map and is the single largest class in every year. Its outline is the easiest way to see where the city stops and the countryside begins.

Built-up (red). Houses, roads, markets, offices, schools, hospitals, and other sealed or roofed surfaces. On the maps it appears as a dense red core in the north-west and centre, thinning into scattered red pixels along roads and around village clusters. Because a 30 m pixel often mixes rooftops with courtyards and trees, the edge of the built-up class should be read as approximate.

Vegetation (green). Tree groves, orchards, homestead plantations, roadside trees, and other woody or dense green cover. Large continuous patches lie on the western edge and in the south-east, while the rest occurs as small fragments among the fields.

Open Area (grey). Vacant plots, bare ground, exposed soil, playgrounds, and cleared land awaiting use. It is a transitional class. Land often enters it after crops or buildings are removed and leaves it when a plot is cultivated again or built over, so its area is expected to swing from one date to the next.

7.3 LULC of Bettiah, 1991

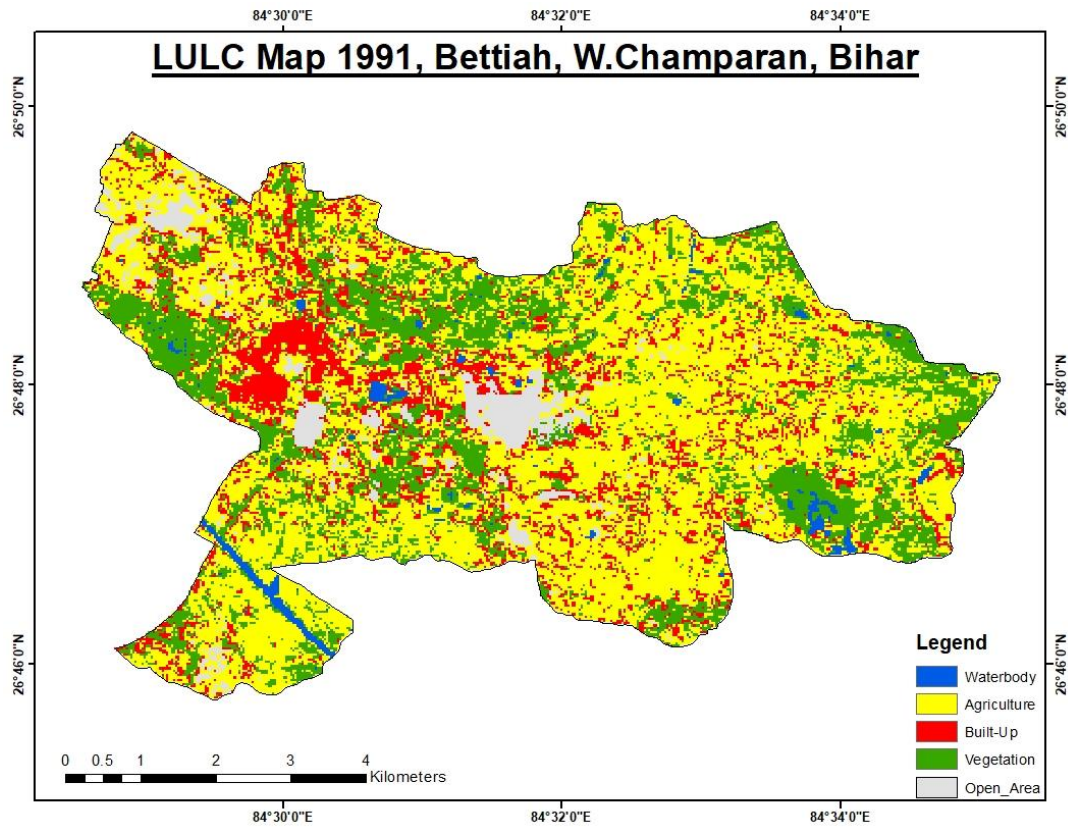


Figure 4: LULC Map of Bettiah City and Its Surroundings, 1991

In 1991 (Figure 4) the built-up area covered 6.58 sq. km, or roughly 14 per cent of the mapped area. It formed a single compact red mass in the north-western and central part of the map, corresponding to the old town, with only faint extensions along the roads leading away from it. Beyond that core, built-up land appears mainly as isolated specks, most of which represent village settlements and roadside clusters set inside the farmland.

Agriculture dominated the landscape at 25.47 sq. km (about 56 per cent), running almost unbroken across the east, the south, and the fringe of the town. Vegetation was the second largest class at 10.66 sq. km, with a broad green block on the western margin and another in the south-east. Open area was at its highest of the whole record, 2.20 sq. km, and included a large continuous grey patch in the centre of the map. Waterbodies were few and small (0.72 sq. km), apart from the diagonal channel in the south-west and a handful of ponds near the town centre.

7.4 LULC of Bettiah, 2001

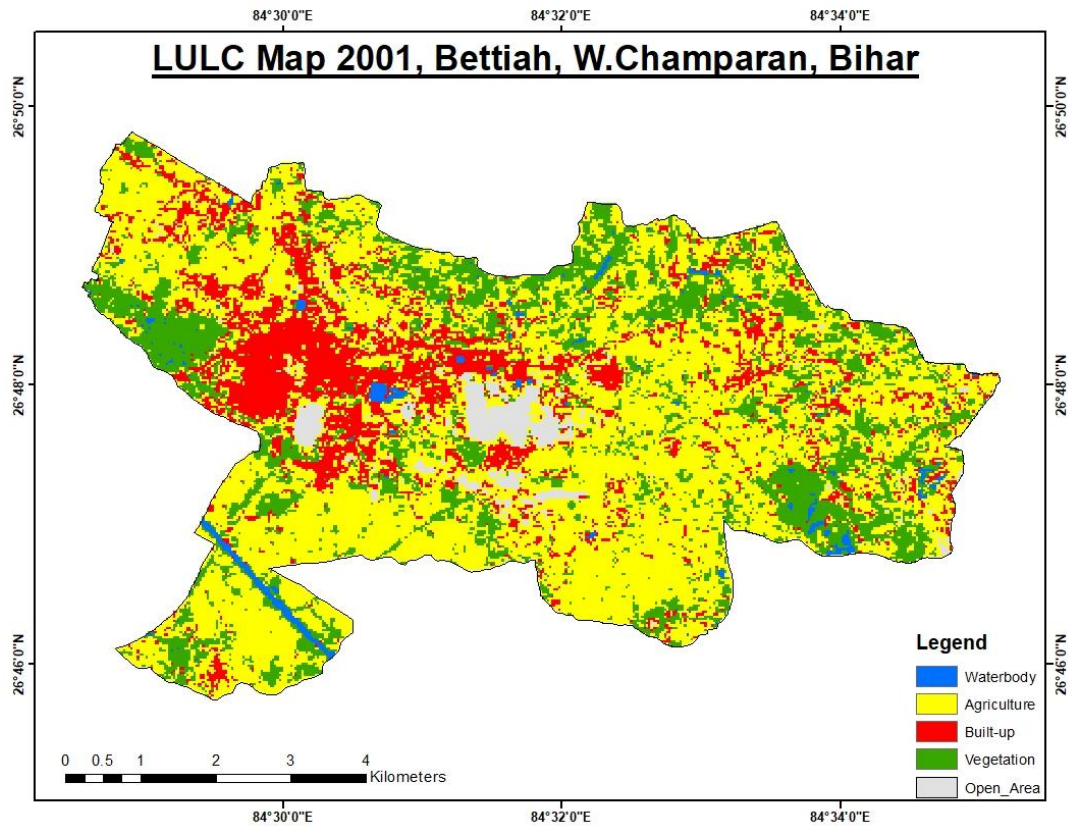


Figure 5: LULC Map of Bettiah City and Its Surroundings, 2001

By 2001 (Figure 5) the built-up class had grown to 7.54 sq. km, about 16 per cent of the area. The change is one of consolidation rather than dispersal. The red core is visibly thicker and more solid than in 1991, and it has stretched eastward along the central axis of the map, which is the direction of the main road corridor. Several small built-up clusters have also appeared in the northern half of the study area.

Agriculture held its position and even gained slightly, reaching 26.57 sq. km. Part of this gain comes from land that was open in 1991 and had been brought back under cultivation. Vegetation slipped to 9.88 sq. km, while open area shrank to 1.44 sq. km and broke into smaller patches. Waterbody area stayed low at 0.62 sq. km. Overall, the decade reads as one of steady, moderate growth around an already established town.

7.5 LULC of Bettiah, 2011

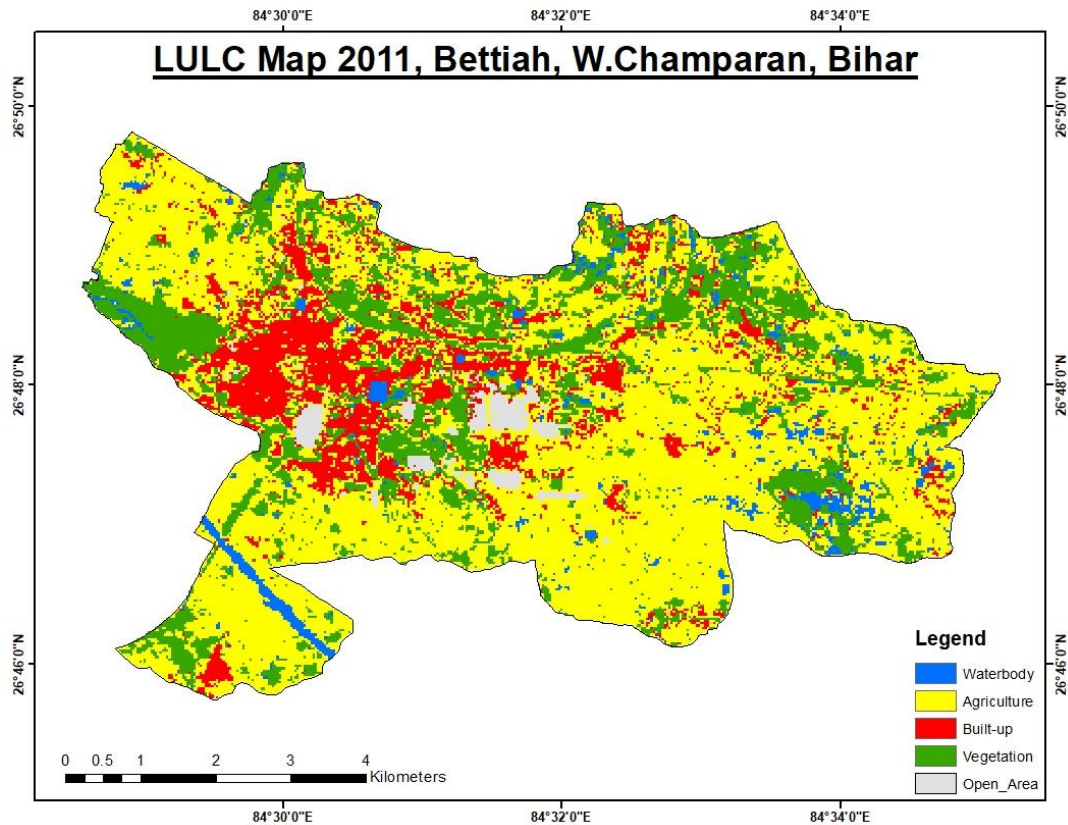


Figure 6: LULC Map of Bettiah City and Its Surroundings, 2011

The 2011 map (Figure 6) shows a dense built-up core that is, if anything, more heavily concentrated than before, with grey open plots now sitting inside it and along its eastern side. The classified built-up area, however, is 6.29 sq. km, lower than in 2001. Comparing Figures 5 and 6 suggests why. Most of the difference lies in the scattered red pixels of the northern and eastern fringe, many of which do not reappear in 2011, whereas the core itself has not shrunk. This is more likely to reflect mixed pixels and small differences in image condition than a real loss of buildings, and the figure should be treated with caution.

Agriculture reached its maximum of 27.31 sq. km, covering close to 59 per cent of the area. Waterbody area rose sharply to 1.65 sq. km, with a clearer south-western channel and more small ponds in the north and east, while vegetation (9.79 sq. km) and open area (1.02 sq. km) both continued to decline. In 2011 the surroundings of Bettiah were at their most agricultural, which makes the change in the following decade all the more striking.

7.6 LULC of Bettiah, 2022

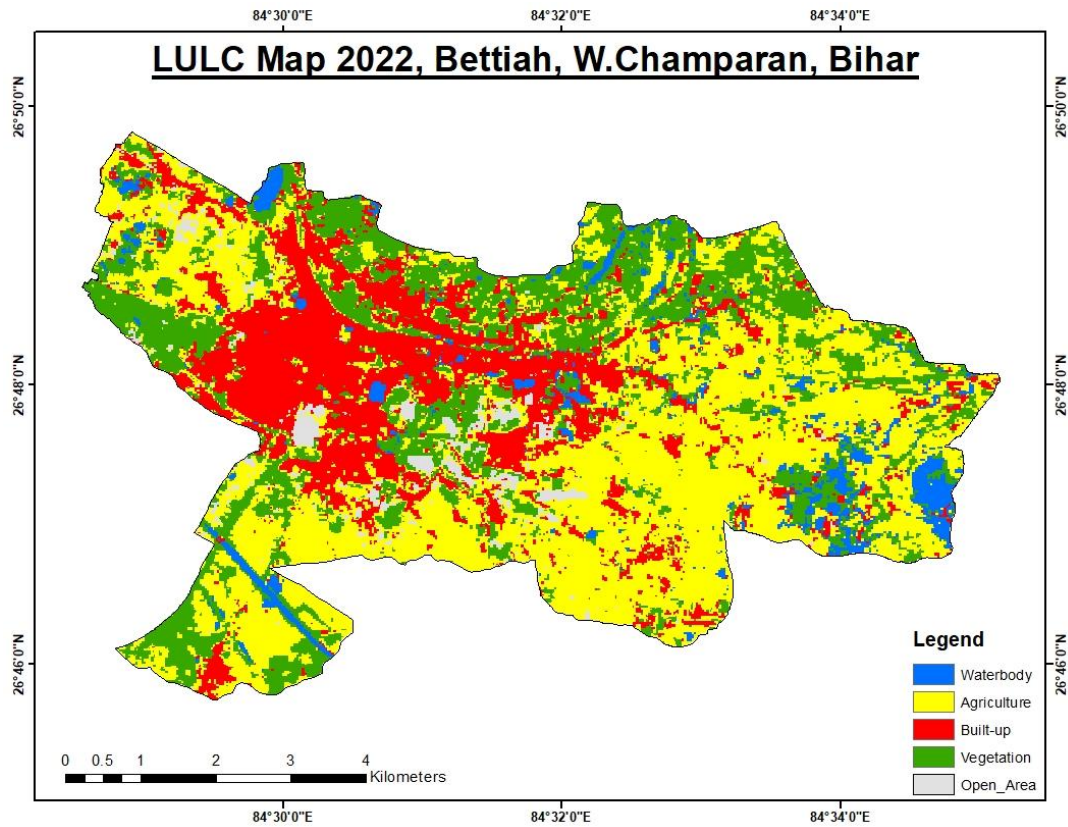


Figure 7: LULC Map of Bettiah City and Its Surroundings, 2022

Figure 7 shows the clearest transformation in the series. Built-up area jumped to 10.33 sq. km, or about 22 per cent of the mapped area. The red mass now spreads well beyond the old core. It runs north-west and north-east from the centre, reaches far along the eastern axis, and has thickened into a continuous belt, while a separate new patch has appeared in the south-west lobe. Compared with 1991, the town does not simply look larger; it looks connected to its own outskirts.

The price was paid by farmland. Agriculture fell to 20.52 sq. km, a drop of nearly seven square kilometres in eleven years, and the yellow now survives mainly in the outer eastern and southern parts. Vegetation recovered to 11.70 sq. km, and waterbodies expanded to 2.21 sq. km, with new larger water surfaces visible in the north and in the east, near the vegetation cluster. Open area stood at 1.33 sq. km, mostly as small patches within or beside the built-up zone. The maps therefore point to an outward, corridor-led expansion of Bettiah after 2011.

8. RESULT AND DISCUSSION

8.1 Overall Change, 1991–2022

Table 2: Net Change in LULC Area between 1991 and 2022

LULC Class	1991 (sq. km)	2022 (sq. km)	Net Change (sq. km)	Change (%)
Waterbody	0.72	2.21	+1.48	+204.6

Agriculture	25.47	20.52	−4.95	−19.4
Built-up	6.58	10.33	+3.75	+56.9
Vegetation	10.66	11.70	+1.05	+9.8
Open Area	2.20	1.33	−0.87	−39.4

Over the full three-decade period, built-up area in and around Bettiah expanded by nearly 57 per cent, while agricultural land contracted by close to 20 per cent. This is the clearest and most planning-relevant signal in the dataset: Bettiah's urban footprint has grown substantially, and it has grown chiefly at the expense of cropland rather than of vegetation or open land, both of which registered smaller net changes over the same period.

The shares of the five classes in the first and last years are compared in Figure 8, and the areas for all four dates are set side by side in Figure 9. Between them, the two charts show the same story as the maps: a shrinking share of agriculture, a growing share of built-up land, and a much larger waterbody share.

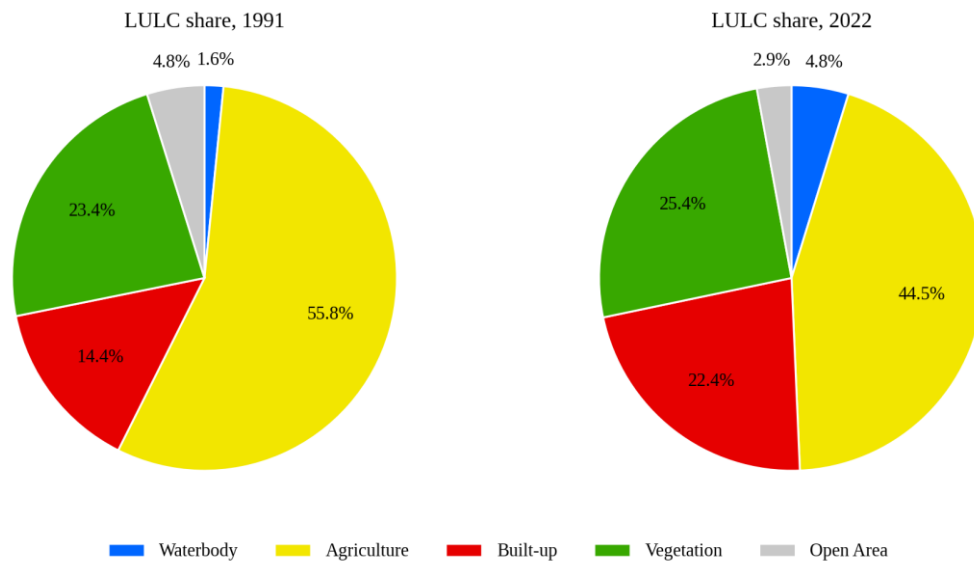


Figure 8: Percentage Share of LULC Classes in 1991 and 2022

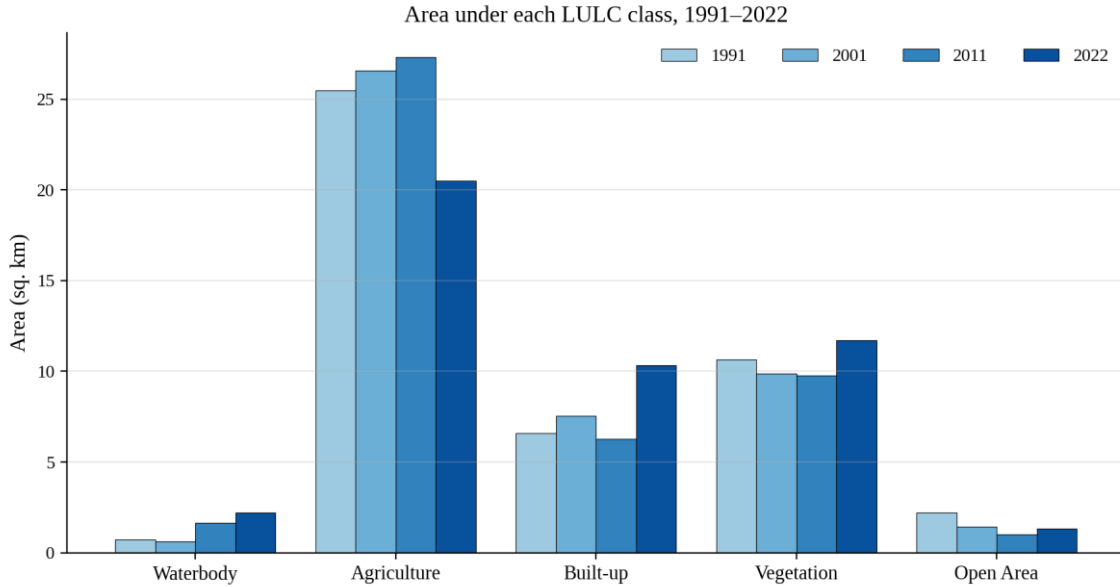


Figure 9: Area under Each LULC Class, 1991, 2001, 2011 and 2022

In 1991, agriculture made up 55.8 per cent of the mapped area and built-up land only 14.4 per cent. By 2022, agriculture had fallen to 44.5 per cent while built-up land had risen to 22.4 per cent, so the built-up class now occupies about one-fifth of the area, compared with roughly one-seventh three decades earlier. The waterbody share moved from 1.6 to 4.8 per cent, and the open-area share dropped from 4.8 to 2.9 per cent. Vegetation stayed within a narrow band of 21 to 25 per cent throughout, which suggests that the main exchange in this landscape has been between farmland and buildings and not between buildings and trees.

8.2 Decade-wise Pattern

Breaking the record into decades shows that the built-up expansion was not steady but concentrated in the most recent decade. Between 1991 and 2001, built-up area rose moderately from 6.58 to 7.54 sq. km (about 14.5 per cent), consistent with gradual growth around the existing core. Between 2001 and 2011, however, the classified built-up area fell to 6.29 sq. km. This apparent contraction most likely reflects classification sensitivity – differences in scene date, moisture conditions, or the specific training samples used for that year's image – rather than an actual demolition of existing built-up stock, and should be read with appropriate caution; a genuine net loss of built-up land is implausible for a growing district headquarters town. Between 2011 and 2022, built-up area rose sharply to 10.33 sq. km, an increase of over 64 per cent within a single decade. This acceleration coincides with the period in which Bettiah's ring road, highway ribbon development, and the Mithanpura industrial belt would have been actively drawing new construction towards the town's periphery, and is also the decade immediately preceding the town's upgradation to Nagar Nigam status.

Agricultural land shows an almost mirror-image pattern: broadly stable or slightly increasing through 1991–2011, then falling sharply – from 27.31 to 20.52 sq. km, a drop of nearly 25 per cent – in the final decade. This decade-specific concentration of farmland loss strengthens the

interpretation that the 2011–2022 period marks a genuine structural shift in Bettiah's land economy, in which agricultural plots at the urban fringe were converted to construction use at a materially faster rate than in the two preceding decades.

Waterbody area increased steadily across all three decades, more than tripling in total. Some of this increase may represent genuine new water-holding depressions created by borrow-pits and construction activity, and some may reflect differences in the seasonal timing or water level captured in each scene; without ground-truthed accuracy assessment for each date, the two explanations cannot be fully separated. Vegetation cover fell slightly between 1991 and 2011 before recovering by 2022, a pattern that may partly reflect roadside and institutional plantation drives in the more recently built areas, though it does not offset the loss of agricultural green cover in absolute terms. Open/bare land fluctuated, as expected of a transitional class that captures both fallow-cycle agricultural plots and land in the process of being built upon.

8.3 Discussion in Relation to Bettiah's Urban Structure

The results are consistent with the qualitative account of Bettiah's growth given in Section 2 and Section 5. The town's commercial core remains spatially concentrated, so the measured built-up expansion is occurring mainly at the periphery – along the highway corridors, around the outer ring road, and towards the industrial belt – rather than through redevelopment of the historic centre. This pattern is typical of ribbon and corridor-led growth in Indian small towns, in which development first colonises the land immediately adjoining a transport route and only later fills in the intervening blocks. If this pattern continues unchecked, it carries two risks that are already visible in comparable Bihar towns: increased surface runoff and drainage stress as agricultural land that once absorbed monsoon rainfall is sealed under construction, and fragmented, low-density peripheral growth that is more expensive to service with water supply, sewerage, and solid-waste collection than compact infill development would be.

9. SUMMARY, CONCLUSION AND FINDINGS

9.1 Summary and Findings

This study used supervised classification of Landsat imagery for 1991, 2001, 2011, and 2022 to quantify LULC change in and around Bettiah city, West Champaran district, Bihar. The principal findings are:

1. Built-up area expanded from 6.58 sq. km in 1991 to 10.33 sq. km in 2022, an increase of nearly 57 per cent, with the bulk of this growth – over 64 per cent – occurring in the single decade between 2011 and 2022.
2. Agricultural land, the dominant class throughout the study period, declined by close to 20 per cent overall, with almost the entire net loss concentrated in the 2011–2022 decade,

indicating that farmland conversion accelerated sharply as the town approached its upgradation to Nagar Nigam status.

3. Waterbody area more than tripled over the period, while open/vacant land generally declined as it was absorbed into either renewed cultivation or new construction.

4. The spatial pattern of change is consistent with ribbon development along National Highway-28B and State Highway-54, growth around the Outer Ring Road, and expansion towards the Mithanpura Industrial Area, while the commercial core has remained concentrated in the historic town centre.

9.2 Conclusion and Planning Implications

These findings confirm that Bettiah, though a comparatively small district headquarters town, has undergone a measurable and accelerating conversion of agricultural land into built-up use over the last decade of the study period. For planning purposes, this suggests three priorities: first, that the Nagar Nigam should use a classified LULC baseline of this kind to monitor future peripheral growth on an ongoing basis rather than relying on ad hoc observation; second, that drainage and storm-water infrastructure should be planned ahead of, rather than after, further conversion of agricultural land in the urban fringe, given the loss of natural infiltration capacity this conversion implies; and third, that ribbon development along the highway and ring-road corridors should be actively managed through zoning, so that peripheral growth remains serviceable rather than scattered.

9.3 Limitations of the Study

Every study of this kind works within the limits of its data, and the results reported here should be read with the following points in mind.

Different acquisition months. The satellite scenes for the four reference years could not all be obtained for the same month. Cloud cover and the availability of usable scenes decided which date could be downloaded for each year, so each image reflects a slightly different point in the agricultural and hydrological calendar. This matters in a Gangetic-plain town, where the same field can look green under a standing crop, pale after harvest, or dark when freshly irrigated, and where ponds and channels swell and shrink with the season. Some of the year-to-year differences in agriculture, open area, vegetation, and waterbody may therefore reflect the state of the season on the day of the image and not a genuine change in land use. Built-up land, which is far less seasonal, is the most dependable of the five classes.

Spatial resolution. Landsat pixels measure 30 m by 30 m, so a single pixel can contain roofs, trees, and bare ground together. Narrow lanes, small ponds, and individual plots cannot be resolved, and the edges of the built-up class are approximate.

Change of sensor. The earlier images come from the Landsat 4-5 Thematic Mapper and the latest from Landsat 8. Differences in band definitions and radiometric response between the two sensors can produce small classification differences that are not real changes on the ground.

Accuracy and ground verification. Only five broad classes were mapped, and a full accuracy assessment for each date (confusion matrix and kappa coefficient) is not reported here. Direct field verification is also not possible for the older years. Small fluctuations, such as the lower built-up area in 2011 than in 2001, should therefore be read with caution.

Mapped extent. The total classified area varies slightly from one year to the next (about 45.6 to 46.1 sq. km), a result of pixel-level clipping and processing differences. The class-wise comparisons are affected only marginally, but the totals are not exactly identical.

9.4 Scope for Future Research

Future work could extend this record to more recent years, use imagery from the same month of each year, add higher-resolution data for the built-up periphery, and carry out a formal accuracy assessment with field verification. It could also combine the LULC record with land surface temperature and drainage data, and analyse change ward by ward using the 2023 ward boundary, to assess the environmental consequences of Bettiah's continuing expansion in greater detail.

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