MEASURING URBAN EXPANSION AND LAND USE/LAND COVER CHANGES USING REMOTE SENSING AND LANDSCAPE METRICS: A CASE OF REWARI CITY, INDIA

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ABSTRACT

The industrial and economic development has initiated the rapid growth of small and medium-sized towns in India. Rewari City, a part of the National Capital Region of India, is undergoing rapid urban expansion. This study analyzes the process of urban expansion in Rewari city, its effect on land use & land cover dynamics and landscape spatial patterns. The methodology of the study is reliant on open-source Landsat satellite data, GIS-based unsupervised classification, and spatial metrics analysis. The city expansion has been analyzed for a period of 31 years, from 1989 to 2020, and population growth has been studied since 1901. Within the study period, built-up area increased by 704%, with an annual expansion rate of 12.8 %. The other land cover classes, such as agriculture land, vegetation, barren land, and water bodies shrank in size over the years. Between 1989 and 2020, 69.4 % of the increase in built up area came at the expense of vegetation and agricultural land. It was also found that per capita land consumption rate increased significantly from 0.0024 to 0.0084, hinting towards dispersed and low-density development. Built-up land had a growth rate nearly 5 times higher than population, indicating urban sprawl. An evaluation of different landscape metrics revealed that the landscape of Rewari has lost land use diversity. The findings of this study offer information about the present state of urban growth. It also serves as a valuable resource for formulating comprehensive planning and development policies, ensuring the promotion of sustainable urban development.

Keywords: Geospatial technology, urban expansion, landscape metrics, population growth, India

INTRODUCTION

At present, more than 55 % of the global population resides in urban areas, and projections indicate that by 2050, this percentage will surge beyond 68 % (United Nations, 2018). This anticipated growth suggests an addition of 2.5 billion individuals to the global urban population, with approximately 90 % of the expansion limited to less developed countries (Wei & Ewing, 2018). While developing nations initiated the urbanization process later, they are currently experiencing rapid urbanization (Madlener & Sunak, 2011; Gu, 2019). Consequently, over the past decades, the pace of unplanned urban development has significantly increased in less developed countries compared to their developed counterparts (Seto *et al*., 2011). A four-fold increase in the spatial extent of urban areas is expected in developing countries from 2000 to 2050 (Angel *et al*., 2011).

Numerous studies attribute this unplanned urban expansion in developing countries to an acute rise in population (Jiang et al., 2008), economic growth (Seto *et al.*, 2011; Mahtta *et al.*, 2022), a surge in urban employment (Cohen, 2006), rural-urban migration (Tacoli *et al.*, 2015), and big-city favoritism (Choe & Roberts, 2011). The impacts of urban expansion can be extreme and widespread. As urban areas expand and encroach upon the surrounding suburban and rural territories, essential land use categories like agricultural lands, forests, and shrubs are diminishing. Several studies worldwide have reported that urban expansion is happening at the cost of agricultural lands (Seto *et al*., 2011; Shi *et al*., 2016; d'Amour *et al*., 2016), grasslands (Gibson *et al*., 2015; Kantakumar *et al*., 2016), forests (Van Vliet, 2019; Lacerda *et al*., 2021), as well as water bodies (Xiao *et al*., 2022; Marufuzzaman *et al*., 2019).

This extreme change in land use and land cover (LULC) has the potential to adversely affect the urban environment and communities. Studies have reported macro-level implications like habitat loss (Seto *et al*., 2012), heat island effect (Zhao *et al*., 2016) and decline in air and water quality (Shao *et al*., 2006) among others. The management of these environmental and social repercussions is inept in developing countries given the limited resources (Cohen, 2006). Therefore, it is particularly significant to study LULC changes and urban expansion in developing counties. While major cities around the world are somewhat well-studied in terms of urban expansion and consequent changes in LULC (Guangzhou: Wu *et al*., 2016; São Paulo: da Encarnação Paiva *et al*., 2020; New Delhi: Naikoo *et al*., 2020; Shanghai: Li *et al*., 2017; Pune: Kantakumar *et al*., 2017), the same couldn't be said for small-sized cities in developing countries, which have undergone significant expansion. This gap in knowledge is mainly due to the absence of continuous and reliable demographic and spatial data (Cohen, 2006; Fenta *et al*., 2017).

With a rapidly urbanizing population, India stands as a pivotal country in the exploration of urban expansion studies. It is imperative for the future of urban development worldwide that global attention is directed towards understanding the growth of Indian cities. It is projected that in the coming decades, half of India's population will be urban, and by 2036, 73 % of total population growth will be due to urban areas (National Commission on Population, 2019). The unprecedented urbanization of India poses a significant challenge for the administration and the residents, as the development of suitable infrastructure lags behind.

Several studies in India have explored the urban expansion of its major cities. Gumma *et al*. (2017) examined the urban sprawl and land transformation of Hyderabad. Yu *et al*. (2021) studied urban expansion in the megacity of Mumbai since 1970's. Sarkar & Chouhan (2020) modeled urban growth and its determinants in metropolitan city of Siliguri. Urban expansion and its sprawl characteristics were analyzed by Rahaman *et al*. (2019) in urban agglomeration of Kolkata. Chettry & Surawar (2021) studied urban sprawl in three urban agglomerations of Patna, Ranchi and Srinagar. Some other metropolitan cities whose growth characteristics have been studied are Chennai (Padmanaban *et al.,* 2017), Pune (Kantakumar *et al*., 2016) and New Delhi (Naikoo *et al*., 2020). However, the impact of urbanization is not confined solely to Indian megacities; it is conspicuously evident in the surrounding satellite towns and peripheral areas as well. Frequently, additional urban expansion is concentrated in nearby smaller cities or suburban areas that offer enhanced connectivity to the major urban center. Furthermore, as industrialization plays a pivotal role in propelling urbanization in developing nations like India (Jaysawal & Saha, 2014), many industrial plants and factories often choose locations close to major cities as they have geographical advantages. These satellite towns provide large, affordable lands while avoiding the challenges associated with the extreme density of megacities. Additionally, as strict development laws are absent, it is possible to circumvent regulatory controls that are present in the major urban centers (Chatterjee & Chattopadhyay, 2020).

The urban expansion of some small and medium-sized cities in India has also been explored. Dhanaraj & Angadi (2021) quantified urban expansion in Mangaluru, a medium-sized city in India. Shaw & Das (2018) studied the peri-urban growth and LULC changes of a small town, English Bazaar in West Bengal. In the state of Gujarat, Jain & Sharma (2019) analyzed the growth of five small and medium-sized cities. However, these studies are limited in number and highlight the significance of gaining a sustainable outlook towards the growth trajectory of small cities. For effective management urban growth and informed decision-making in these cities, a thorough understanding of their current growth patterns is essential. Unfortunately, the lack of readily available spatial data and comprehensive land-use information for smaller cities often hinders the planning process.

Advancements in remote sensing technology, the accessibility to free satellite imagery, and the integration of geographic information system (GIS) have facilitated detailed analysis of urban expansion. The satellite imagery is consistently updated, covers remote areas, and has enhanced spatial resolution. It allows the mapping and monitoring of the spatio-temporal changes associated with urban expansion (Xiao *et al*., 2006; Kantakumar *et al*., 2016). It also assists in extracting information on urban characteristics, socio-economic attributes relevant to urban management, and urban ecology. Alongside GIS, it is an effective and economical method to study the evolution, process, and extent of urban expansion (Ali *et al*., 2018). Furthermore, the growing availability of open-source remote sensing data allows for long-term monitoring of urban expansion, crucial for informing land-use policy decisions. Remote sensing has become a cornerstone tool for monitoring, characterizing, and understanding urbanization.

Rewari is an important city of India’s National Capital Region (NCR). It is home to a variety of manufacturing firms, including those in the automobile and ancillary industries. The city has experienced significant growth during the last few decades, attributed to its strategic location and investor-friendly government policies. The rapid expansion of the city presents significant challenges, including shrinking agricultural land and a deteriorating environment. Thus far, the dynamics of urban transformation in Rewari have not been explored. This study has the following objectives:

- To measure the rate of urban expansion and its impact on the LULC pattern of Rewari city.
- To analyze the spatial patterns of urban growth in Rewari city.

The study takes place over the past three decades (1989-2020) and uses open-access Landsat data. The selection of the study period was based on the availability of ancillary data required for result interpretation.

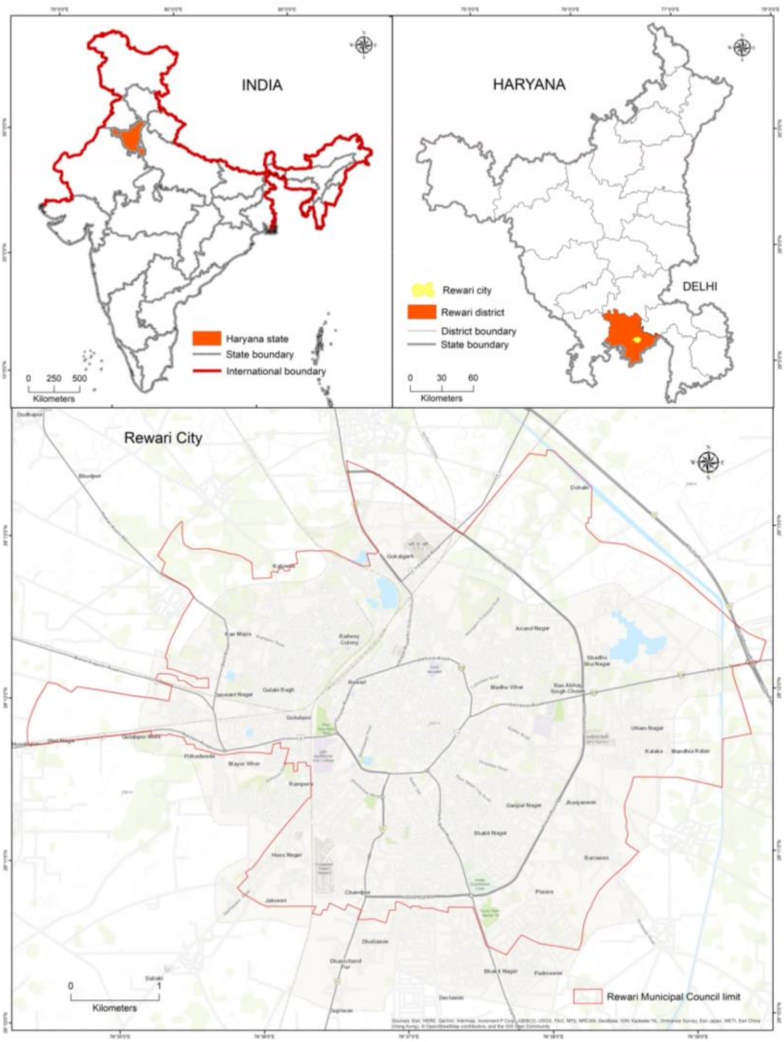
Study area

Rewari city, located in the state of Haryana, has a rich ancient and medieval history. The origins of Rewari can be traced back as a historic trade center between the states of Delhi and Rajasthan. Brass canyons used to be manufactured in the city during the Mughal rule in India; hence it is popularly known as the “Brass City”. For centuries, Rewari remained a small town. Initially under the Marathas, it gained independence but was defeated by the British in 1857. The British incorporated Rewari into Gurugram district until 1989, when it became a separate district.

The city is a Municipal Council which is spread over an area of 25.06 km^2 and divided into 31 administrative wards. As per the 2011 Census, the total population of the city was 143021, exhibiting a 42 % decadal growth rate. Geographically, it is located in south-west Haryana, 82 km from New Delhi, at the intersection of 28° 11' 0" N & 76° 37' 0" E (Fig. 1). The mean altitude of the city stands at 245 m.

Liberal industrial policies adopted after 1991 are playing a significant role in the growth of the region. Since the inception of Foreign Direct Investments (FDI), the area has undergone rapid industrialization and urbanization. Thus, the city accommodates numerous leading industries, including manufacturing, automobiles, metalwork, and ornaments. In 2011, the Government of India initiated the development of a Delhi Mumbai Industrial Corridor (DMIC), catalyzing the transformation of small villages into significant industrial hubs in the surrounding region. The proposal to develop a Multi Modal Logistics Park at Rewari under the DMIC project has further propelled the economic advancement of the region.

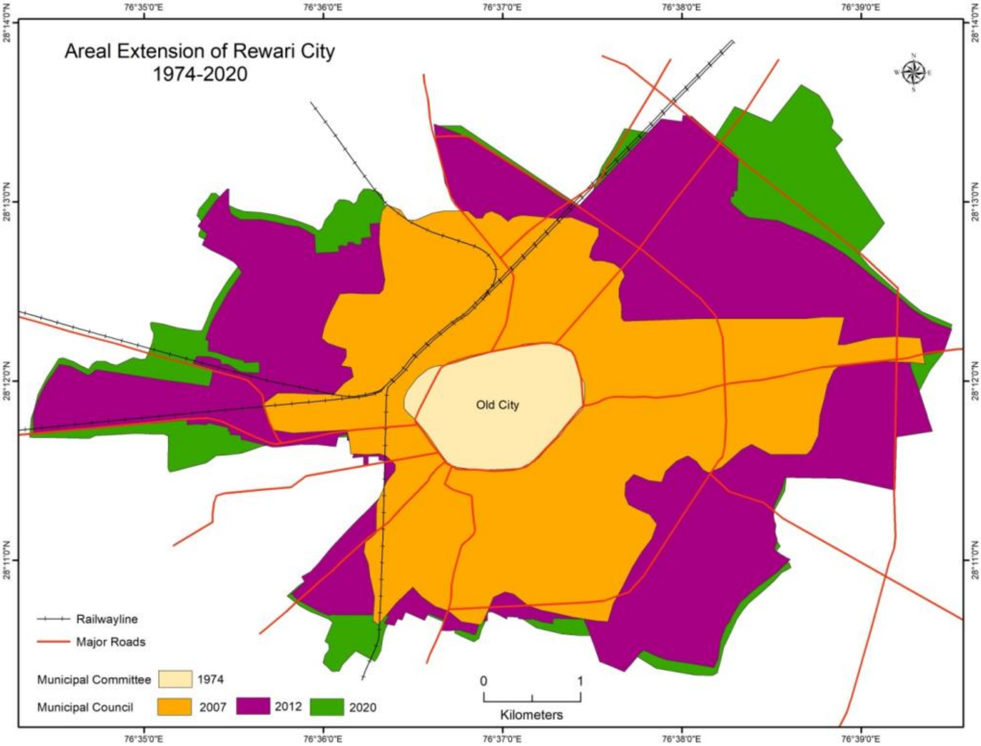
Fig. 1: Location of Study Area



Source: Produced by the authors

Rewari's cityscape today contains three distinct structures. Firstly, the old inner city core i.e. the walled city, is a product of the historical developments (Fig. 2). Secondly, the new industrial areas which contribute to Rewari's economic growth. Lastly, the rapidly evolving peripheries of urban Rewari, characterized encroaching upon the surrounding rural areas. The evolution of Rewari city reflects a shift in the catalysts for urban expansion over time. The current economic progress has not only spurred growth within the city but has also brought about unprecedented repercussions on the rural surroundings resulting from this urban development. Rewari city is experiencing exponential growth in terms of its spatial growth, incorporating new neighboring villages into its sphere (Fig. 2). This expansion is also evident in its economic activities and demographic changes.

Fig. 2: Evolution of Administrative boundaries of Rewari city



Source: Produced by the authors

MATERIALS AND METHODS

Database

The Landsat satellite data used for mapping urban expansion and LULC changes was downloaded from the website of the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/). The choice of Landsat data stems from the freely accessible digital archive, which offers a regularly updated collection with a moderate spatial resolution and consistently reliable spectral and radiometric resolutions. We used the Landsat Thematic Mapper (for 1989 & 2011), the Landsat Enhanced Thematic Mapper (for 2000), and the

Landsat Operational Land Imager (for 2020). While performing LULC change detection, the choice of date of acquisition of satellite images is a crucial aspect of the analysis. Therefore, to ensure the distinct identification of LULC categories through spectral signatures, the selection of dates of acquisition was done carefully, opting for images in the same season that were also free from cloud cover.

The toposheet of the study area (no. H43W12, RF 1:50,000) was obtained from the Survey of India. Administrative maps of the study area were acquired from the Municipal Council of Rewari website. The population data was extracted from the Census of India website (https://censusindia.gov.in/census.website/data/census-tables), and various government websites were visited for additional data about schemes, policies, and planning processes.

Table 1: Data used in the analysis

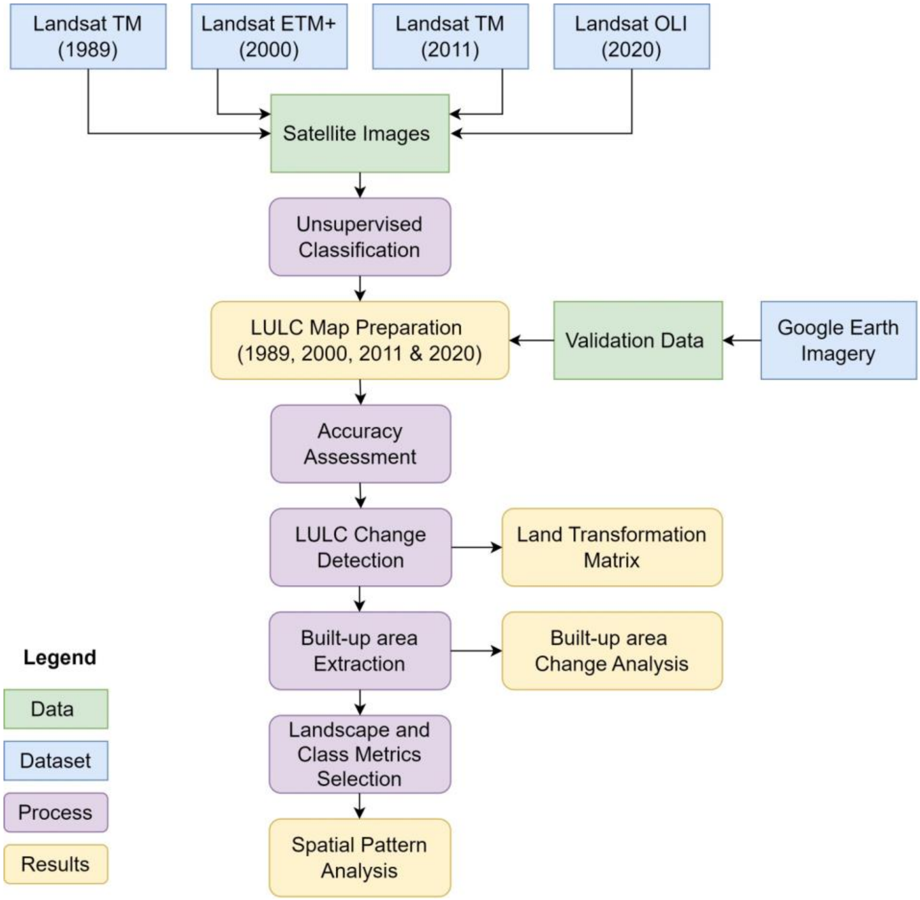
Satellite Data					
Sensor	Resolution	Path/Row	Data format	Date	Purpose
Landsat TM	30 (m)	147/40	Geotiff	09-10-1989	Land-use/land cover analysis
Landsat ETM+	30 (m)	147/40	Geotiff	13-09-2000	Land-use/land cover analysis
Landsat TM	30 (m)	147/40	Geotiff	22-10-2011	Land-use/land cover analysis
Landsat OLI	30 (m)	147/40	Geotiff	14-10-2020	Land-use/land cover analysis
Additional data					
Survey of India (SOI) Toposheet H43 W12 (RF: 1:50,000)				2007	Geo-referencing and base layer
Municipal Council Map (RF: 1:8500)				2012	City boundary
City Development Plan				2007	Interpretation
Google Earth				2020	Interpretation and analysis
Census data				2011	Population analysis

Source: Compiled by the authors

Methods

The satellite images of Landsat TM (1989, 2011), Landsat ETM+ (2000), and Landsat 8 OLI (2020) were downloaded and stacked in four similar bands. The SOI toposheet was geo-referenced in ArcGIS 10.8 and assigned the UTM WGS 84 projection. The Rewari Municipal Council Map (year, 2012) was geo-referenced with the help of the SOI toposheet and assigned the same projection. Then, the geo-referenced boundary of Rewari Municipal Council was drawn in ArcGIS 10.8 and overlaid on the satellite data to extract the spatial extent of Rewari city.

Fig. 3: Flowchart of Methodology



Source: Compiled by the authors

Image Classification

Once the boundary of the study area was obtained in vector format, a subset image was created. We employed the ISODATA algorithm of the unsupervised classification approach for the classification of satellite images for four different dates (Table 1). Unsupervised classification relies on the pixel values and operates under the assumption that each spectral class corresponds to a distinct spectral class. It groups similar pixel values together and allows us to identify and merge them into discrete classes. For each pixel, the spectral distance to all cluster centers is calculated. The pixel is then assigned to the cluster with the *shortest spectral distance*. This essentially means the pixel is grouped with the cluster whose values are most similar to its own.

Following the conclusion of the clustering procedure, the program reduced the initially defined clusters to four, aligning with the number of LULC classes. This reduction was accomplished through a combination of field knowledge and high-resolution Google Earth imagery. Each satellite image underwent classification into five LULC classes: built-up areas, agricultural land, vegetation, barren land, and water bodies, with detailed descriptions provided in Table 2.

Table 2: Description of land use/land cover classes

Land use classes	Description
Built-up area	Residential, commercial or industrial areas, road and railway lines etc.
Agricultural land	Crop land, orchards, nurseries, horticulture areas etc.
Vegetation	Trees, parks, shrub land, sparse vegetation etc.
Barren land	Exposed soil, landfill sites, open space in the built-up land etc.
Water bodies	Ponds, canal, tanks, lakes reservoirs etc.

Source: Compiled by the authors

LULC change detection

The LULC transformation between the periods of 1989-2000, 2000-2011, 2011-2020, and 1989-2020 was examined through the post-classification change detection method in ArcGIS 10.8. Post-classification change detection was chosen because it removes the potential influences stemming from spectral resolution and sensor variations among the four different satellite images. This method allows for the evaluation of temporal shifts in land cover and the quantification of conversion extent resulting from urban expansion. The change percentage between the time periods was given by:

$$\%\ \text{Change} = \left(\frac{A_f - A_i}{A_i}\right) \times 100 \qquad (1)$$

Where A_f signifies the area of final year and A_i signifies the area of initial year (Fenta *et al.*, 2017).

Annual rate of urban expansion

To assess the rate of urban expansion during the periods 1989-2000, 2000-2011, 2011-2020, and 1989-2020, the values of built-up areas was extracted from LULC classification. Built-up areas encompass all residential, commercial and industrial areas of the city, including roads and any other impervious surface. Once the built-up areas were extracted, the annual rate of urban expansion for the time periods was computed using the following equation:

$$\text{Annual rate of urban expansion} = \left[\left(\frac{BA_{i+n}}{BA_i}\right)^{1/n} - 1\right] \times 100 \qquad (2)$$

Where BA_{i+n} and BA_i are the built-up areas (in km^2) at time i+n and i, i is the beginning of study period and n is the time period of the study in years. The formula was adopted from Zhao *et al*. (2015).

Land Consumption Rate

The expansion of urban areas is typically linked to population growth, as it serves as a primary catalyst for the enlargement of built-up regions. Examining the growth rates of both population and built-up areas facilitates the analysis of urban growth characteristics. Jiang *et al*. (2022) expressed the need for making local-scale projections for urban population growth and built-up area expansion. To estimate the progressive spatial expansion of the built-up areas of the city with regards to its population, the land consumption rate (LCR) was calculated as:

$$\text{Land consumption rate} = \frac{\text{Built-up area in hectares}}{\text{Population}} \qquad (3)$$

The equation was adopted from Sharma *et al*. (2012).

Urban Growth Coefficient

To quantify the nature of urban growth as dense (compact) or dispersed (sprawl), Urban Growth Index (UGC) was employed. It combines the rate of urban expansion and population growth as one metric.

$$\text{Urban Growth Coefficient} = \frac{\text{Rate of urban expansion}}{\text{Rate of population growth}} \qquad (4)$$

A UGC higher than 1 implies *dispersed growth*. It means the built-up area is growing faster than the population, and the city is sprawling outward, potentially with lower density development. The higher the value of UGC, the greater is the level of dispersion. A *UGC of less than 1* represents *densification*. It signifies that population growth is outpacing the expansion of built-up land, leading to increased density within existing urban areas. The metric was adopted from Akubia & Bruns (2019).

Landscape metrics

Landscape metrics are employed for the measurement, analysis, and interpretation of spatial patterns of a landscape (Uuemaa *et al*., 2009). They offer a statistical depiction of configuration (spatial arrangement) and composition (number and amount) of an urban area. Given that one spatial metric is unable to encapsulate all facets of the landscape characteristics, employing a set of metrics becomes imperative for interpreting landscape changes comprehensively. For this study, we chose spatial metrics covering various dimensions of urban growth and expansion, including spatial heterogeneity, pattern, shape, and density. The analysis of the landscape metrics was conducted using FRAGSTATS. The selected metrics pertaining to classes: area & edge, shape, aggregation, and diversity are detailed in Table 3.

The ED (Edge density) equals all edges in the landscape in relation to the landscape area. It is calculated by dividing the sum of the lengths of all edge segments in the landscape by the total landscape area (Gabril *et al*., 2019). The largest patch index (LPI) measures the percentage of the total landscape area occupied by the biggest patch (Kubacka *et al*., 2022). A higher LPI signifies a substantial dominance of a specific land-cover patch. Total Class Area (CA) quantifies the proportion of a landscape occupied by a specific patch type. Beyond its inherent value, it aids the computations for numerous class and landscape metrics. It represents the sum of individual patch areas for a given type (Shetty *et al*., 2012).

A shape metric, PAFRAC (Perimeter-Area Fractal Dimension), measures how a patch perimeter increases with respect to the patch area. A higher PAFRAC indicates more complex shapes. The area-weighted mean fractal dimension index (FRAC_AM) serves as an indicator aiming to assess the intricacy of landscape shapes (Shao *et al*., 2022). This index elucidates the association between patch area and perimeter, delineating how patch perimeter changes with each unit rise in patch area (Feng & Liu, 2015). A lower FRAC_AM indicates simple, regular, geometric shapes of the patches, while a higher value suggests greater complexity and irregularity. Contagion Index (CONTAG) measures the extent to which cells of same class are aggregated or grouped together by estimating the likelihood of two randomly chosen cells sharing the same classification.

Table 3: Description of landscape metrics used in the study

Landscape Metric	Formulas
a) Area & Edge	
Edge Density (ED)	$ED = \frac{E}{A}$ E is the total landscape edge in m A is the total landscape area in m^2
Largest Patch Index (LPI)	$LPI = \frac{\max (A_l)}{A} \times 100$ Max (A_l) is the area of largest patch in m^2 A is the total landscape area in m^2
Total Class Area (CA)	$CA = \sum A_i$ A_i is the sum of the areas (m^2) of all patches of the corresponding patch type
b) Shape	
Perimeter-Area Fractal Dimension (PAFRAC)	$PAFRAC = \frac{2}{\beta}$ β is the slope of regression line obtained by regressing the logarithm of patch area (m^2) against the logarithm of patch perimeter (m).
Area-Weighted Mean Fractal Dimension Index (FRAC_AM)	$FRAC\_AM = \frac{2\ln (0.25p_{ij})}{(\ln a_{ij})}$ p_{ij} is the perimeter (m) and a_{ij} is the area (m^2) of patch ij.
c) Aggregation	
Contagion Index (CONTAG)	$CONTAG = 1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[(P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]\left[\ln(P)_i\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\log_e(m)} \times 100$ g_{ik} is the number of adjacencies (joins) between pixels of classes i and k based on the double-count method. P_i is the proportion of the landscape occupied by class i and m is the number of classes.
Mean Euclidean Nearest Neighbour Distance (ENN_MN)	ENN_MN = mean[ENN(patchij)] ENN(patchij) is the euclidean nearest-neighbor distance of each patch.
d) Diversity	
Shannon's Diversity Index (SHDI)	$SHDI = -\sum_{i=1}^{m} (P_i \log_e P_i)$ P_i is the proportion of class i and m is the number of classes.
Simpson's Evenness Index (SIEI)	$SIEI = \frac{1 - \sum_{i=1}^{m} P_i^2}{1 - \frac{1}{m}}$ P_i is the proportion of class i and m is the number of classes.

Source: Compiled by the authors

It is determined by analyzing the spatial co-occurrence of attribute pairs in neighboring pixels. ENN_MN (Mean Euclidean Nearest Neighbor Distance) summarizes each class as the mean of all patches inside the class (Neel *et al*., 2004).

SHDI (Shannon's diversity index) reflects diversity in the landscape (Nagendra, 2002). It is zero when there’s only one class in the landscape. Landscape richness is the number of different land cover types in a landscape. SIEI (Simpson's Evenness Index) quantifies how evenly different classes are spread out in a landscape, considering both the number of classes present and their relative abundance.

RESULTS

Urban Population Growth

The population of Rewari city had a steady growth over the years. Between the decades of 1901-1921, the population of the city declined, recording a negative decadal growth rate (Table 4). After 1931, the population started growing slowly. After that, urban growth took place in the city, but not on a large scale. Up to 1981, the decadal growth rate of population remained below 20 %. After the onset of liberalization in 1991, city showed rapid population growth. The economic reforms unleashed new opportunities for businesses and industries, leading to an influx of investments and migrant workers from nearby villages.

Table 4: Trends of population growth in Rewari city from 1901-2011

Census Years	Population	Absolute Change	Decadal Growth Rate (in %)
1901	27295		
1911	24780	-2515	-9.21
1921	23129	-1651	-6.66
1931	26269	3140	13.58
1941	30673	4404	16.77
1951	34082	3409	11.11
1961	36994	2912	18.54
1971	43885	6891	18.63
1981	51562	7677	17.49
1991	75342	23780	46.12
2001	100684	25342	33.64
2011	143021	42337	42.05
2021	173945*	30924*	31.71*

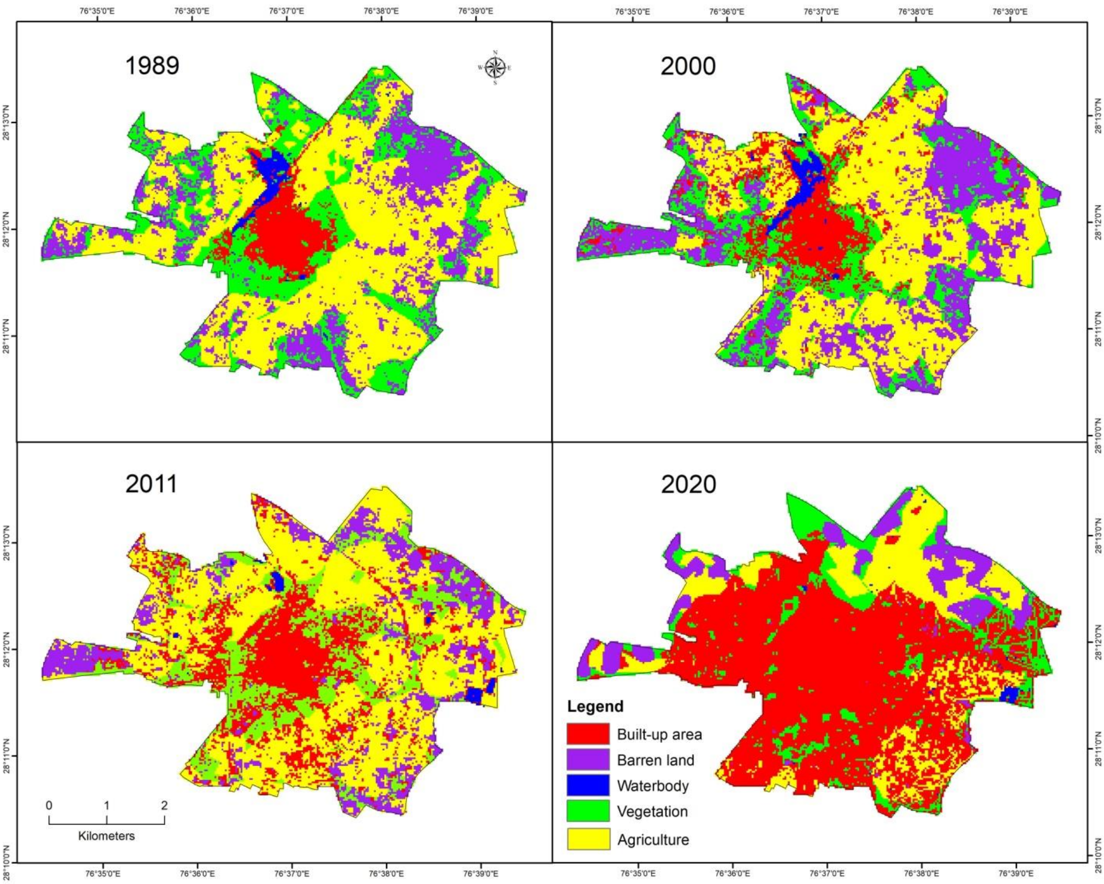
Source: Census Town Directory 2011, Registrar General of India, New Delhi.
*Projected population calculated by Geometrical Increase Method

The city witnessed the establishment of industries, commercial centers, and residential complexes, along with a surge in population. During this period, the decadal population growth rate was very high, reaching the values of 46.12 %, 33.64 %, and 42.1 %, respectively, in the decades of 1981-91, 1991-2001, and 2001-2011 respectively (Table 4). In-migration made up a substantial proportion of population growth from 2001-2011 with 68.5 % of the total growth being attributed to it. A significant number of these in-migrants (20.17 %) moved to Rewari for employment-related reasons.

Land Use/Land Cover Change Analysis

Urbanization is the leading cause of land use changes and land transformation (Garouani *et. al*. 2017). Land use change detection determines the interchanges between different categories of land uses. In this section, the spatial composition of Rewari city has been analyzed by creating LULC maps of different times. The LULC maps, depicted in Fig. 4, were generated through unsupervised image classification. The percentage area of each LULC class was derived from the classified images (Table 5).

Fig. 4: LULC maps of Rewari city for the years 1989, 2000, 2011 and 2020



Source: Produced by the authors

Table 5: Land use/land cover from 1989-2020

LULC Category	1989		2000		2011		2020	
	Area	%	Area	%	Area	%	Area	%
Water body	0.38	1.51	0.41	1.63	0.18	0.71	0.11	0.39
Vegetation	5.93	23.67	4.71	18.79	4.44	17.71	3.1	12.37
Built up	1.83	7.30	3.23	12.88	5.52	22.02	14.72	58.73
Barren land	5.56	21.94	7.01	27.97	3.87	15.43	2.37	9.45
Agricultural land	11.41	45.54	9.7	38.70	11.05	44.09	4.76	18.99
Total	25.06	100	25.06	100	25.06	100	25.06	100

Note: Area in km^2
Source: Compiled by the authors

Fig. 4 illustrates the land use change for Rewari. It is prominently evident that urban built-up areas expanded from 1989 to 2020. In 1989, agricultural land, covering 11.41 km^2 (45.54 %), dominated the land use in the city's administration zone. However, by 2020, its extent had significantly reduced to 4.76 km^2 (18.99 %), marking a substantial shift. Vegetation, the second-largest LULC type in 1989, experienced an eventual decline from 5.93 km^2 (23.67 %) in 1989, 4.44 km^2 (17.71 %) in 2011 to 3.1 km^2 (12.37 %) in 2020. Barren land also declined from 5.5 km^2 (21.94 %) in 1989 to 2.37 km^2 (9.45%) in 2020. Meanwhile, the built-up area witnessed a remarkable surge from 1.83 km^2 (7.3 %) in 1989 to 14.72 km^2 (58.73 %) in 2020. Water bodies also saw a gradual decline from 0.38 km^2 (1.51 %) to 0.11 km^2 (0.39 %) during the same period (Table 6).

Between 1989 and 2020, the built-up area increased by 76.5 %, 70.89 %, and 166.67 % in the periods 1989-2000, 2000-2011, and 2011-2020, respectively. In contrast, agricultural land decreased by 14.98 % initially, increasing slightly by 13.92 %, and again decreasing by 56.92 % during the same periods. The vegetation in the area had a rapid decline, dropping by 47.72 % over the three decades. The annual rate of change for these three decades showed a consistent increase in the built-up area, with an overall increase of 704.37 % from its initial value in 1989. This indicates that, on average, approximately 0.41 km^2 of land was impinged for built-up purposes annually. Barren land decreased by 56.9 % (−3.13 km^2) over the study period, indicating land conversion by human activities. This loss could negatively impact local biodiversity and ecosystems. The change in water body areas is relatively minimal, with only a 71.05 % decrease (−0.28 km^2) over the period.

From Fig. 4 it can be identified that from 1989-2011, the increase in built-up area was slow, but post 2011, built-up area increased exponentially and rapidly. The built-up area increased almost 8 times (about 15 km^2) in the study period, whereas agricultural lands and vegetation decreased by 2.5 times (6.65 km^2) and 2 times (2.83 km^2) respectively. This suggests that rapid urban expansion largely occurred at the expense of agricultural land & vegetation. Other land resources for urban expansion were vegetation, barren land, and water bodies.

The shift in LULC reflects rapid urbanization and infrastructure development in the city space. This growth in built-up areas suggests a shift towards urban living, with potential consequences for the local environment and ecosystems.

Table 6: LULC changes in different decades

LULC Category	1989-2000		2000-2011		2011-2020		1989-2000	
	Area Change	% Change	Area Change	% Change	Area Change	% Change	Area Change	% Change
Water body	0.03	7.89	−0.23	−56.10	−0.07	−38.89	−0.27	−71.05
Vegetation	−1.22	−20.57	−0.27	−5.73	−1.34	−30.18	−2.83	−47.72
Built up	1.4	76.50	2.29	70.89	9.2	166.67	12.89	704.37
Barren land	1.51	27.45	−3.14	−44.79	−1.5	−38.77	−3.13	−56.91
Agricultural land	−1.71	−14.98	1.35	13.92	−6.29	−56.92	−6.65	−58.26

Note: Area in km^2. Source: Compiled by the authors

Land Transformation

The land transformation of Rewari city presented in Fig. 5 elucidates the changes of each LULC category from 1989 to the 2020. In 1989, a total of 11.41 km^2 was designated as agricultural land with only 4.76 km^2 remaining in 2020 (Table 5). Notably, 6.78 km^2 underwent conversion to urban built-up areas, 2.48 km^2 remained under the same category, and the remainder transitioned into vegetation, water bodies or barren land (Table 7). Of the 5.93 km^2 covered by vegetation in 1989, only 0.87 km^2 remained unchanged by 2020, while 3.47 km^2 transformed into built-up areas. Additionally, 2.39 km^2 of barren land was also repurposed for built-up areas.

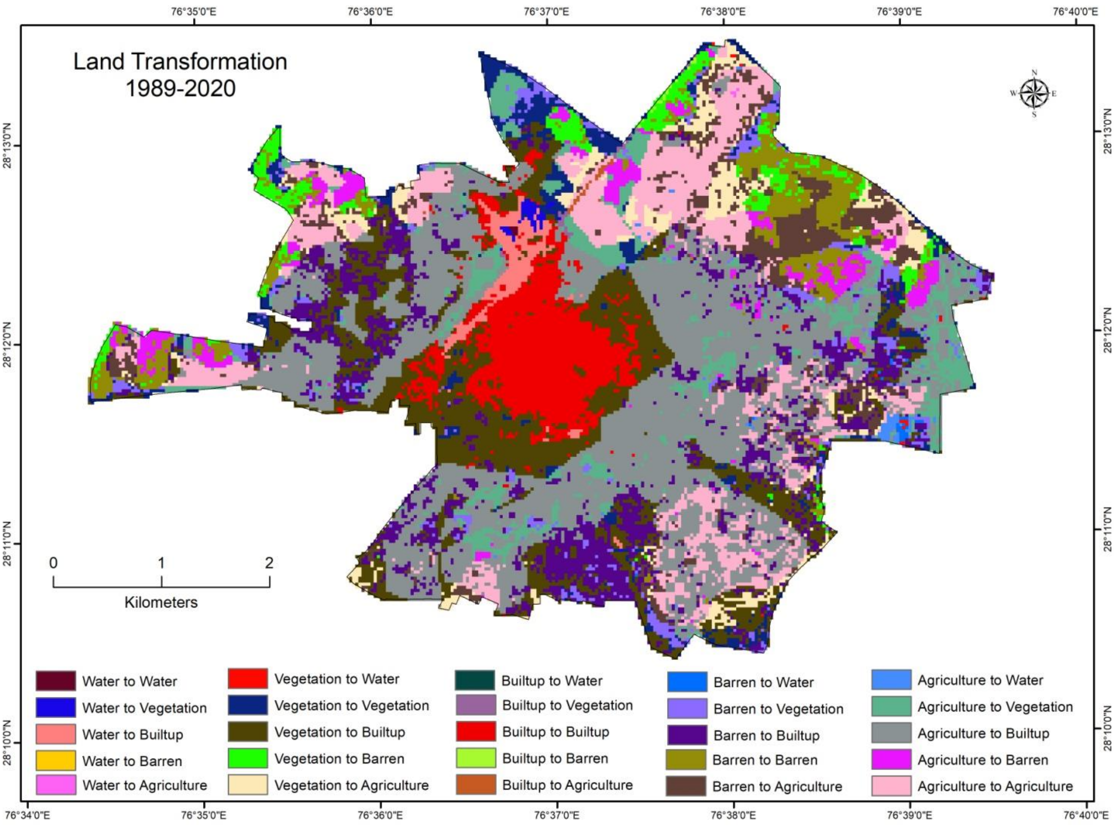
The water bodies saw a decrease from 0.38 km^2 in 1989 to 0.11 km^2 in 2020 (Table 5). Urban built-up areas replaced a substantial portion of water bodies, accounting for 0.32 km^2, while 0.04 km^2 was converted into the agricultural land and the rest remained in the same category. The urban built-up area occupied 7.3 % of the total area in 1989, which increased to 58.73 % in 2020. The built-up area was the only LULC category that did not transform into any other LULC category. Out of the 12.89 km^2 added to built-up area since 1989, 23.5 % came from vegetation and 45.9 % was transformed against agricultural lands. The findings indicate a prevailing tendency towards an increase in urbanization, as the built-up land shows a remarkable and steady increase.

Table 7: Land transformation matrix 1989-2020 of Rewari city

	LULC Category	1989					
		Water body	Vegetation	Built up area	Barren land	Agricultural land	Total
2020	Water body	0.005	0.06	0	0.02	0.005	0.11
	Vegetation	0	0.87	0	0.75	1.45	3.10
	Built up area	0.32	3.47	1.83	2.39	6.78	14.72
	Barren land	0	0.63	0	1.09	0.64	2.37
	Agricultural land	0.40	0.86	0	1.31	2.48	4.76
	Total	0.38	5.93	1.83	5.56	11.41	25.06

Source: Compiled by the authors

Fig. 5: Land Transformation of Rewari city



Source: Produced by the authors

Urban Expansion

The above section has established that urban expansion has occurred in Rewari city, as shown in Fig. 6. It is also necessary to ascertain the speed at which urban land is expanding, to timely meet the resource demands and reduce the environmental impacts. Therefore, the study employs certain metrics to determine the speed of urban expansion which are described in Table 8.

Table 8: Urban Expansion Metrics

Year	Built-up area	Annual rate of urban expansion	Annual rate of population growth	Land consumption rate	Urban growth coefficient
1989	1.83			0.0024	
2000	3.23	4.7%	3.1%	0.0032	1.5
2011	5.52	4.9%	3.4%	0.0038	1.4
2020	14.72	12.8%	2.7%	0.0084	4.7

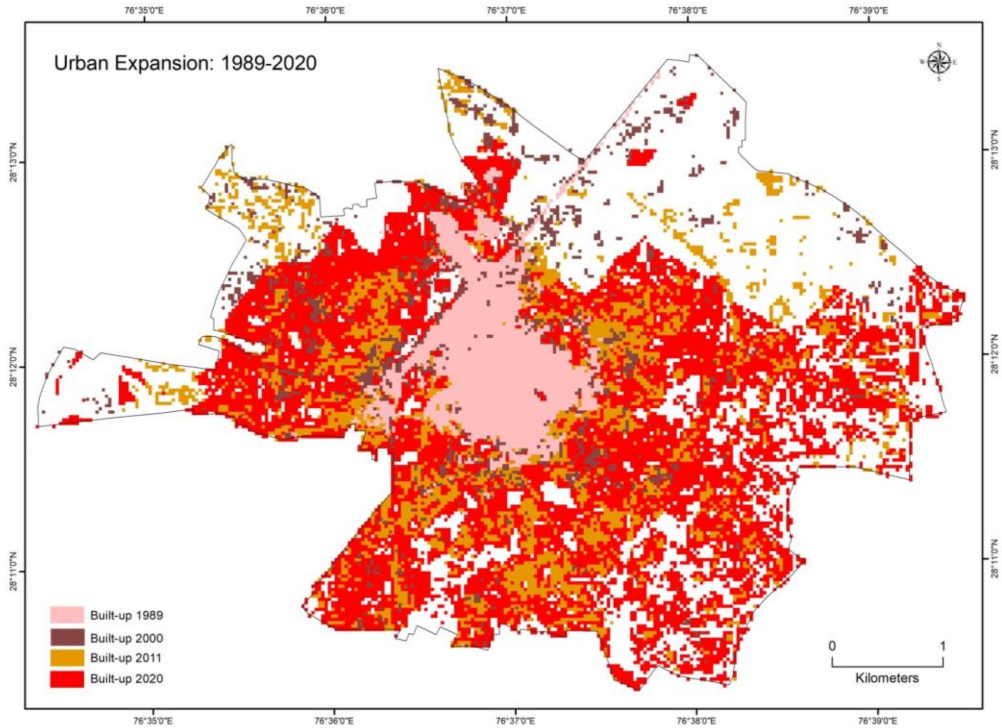
Source: Compiled by the authors

The overall annual rate of urban expansion (ARUE) of Rewari city from 1989-2020 was 9 %. However, the rate was not constant throughout the decades. The ARUE was at 4.7 % from 1989-2000 and remained almost constant till 2011 at 4.9 %. In 2011-2020 it rose significantly to 12.8 %. This analysis shows that the fastest growth of Rewari city was experienced in the decade of 2011-2020. The rate of city's expansion was constant before 2011, but since it has increased exponentially.

The computation of land consumption rate (LCR) is essential for determining the future demands of urban land. It also quantifies urban density by measuring how much built-up area exists per person. For the year 1989, the LCR was 0.0024 and it steadily increased for the next two decades. It was 0.0032 in 2000 and increased to 0.0038 in 2011. The gradual increase pointed towards a lower density urban growth during this period. However in 2021, LCR increased significantly, reaching a value of 0.0084. This sudden increase in LCR indicates towards urban sprawl and a lack of optimal use of land resources in the past decade. The analysis predicts the trend of increasing LCR in the coming future, if measures for dense and vertical urban growth are not adopted.

Urban Growth Coefficient (UGC) categorizes the nature of urban growth as dense or dispersed. The UGC of Rewari city has seen an upward trajectory in the last decade. It went from 1.5 in 2001 to 1.4 in 2011, eventually reaching 4.7 in 2020. The overwhelmingly positive values of UGC correspond to an extremely dispersed growth pattern, indicating urban sprawl especially after 2011. The built-up area of Rewari city is increasing 4.7 times faster than its population, which also indicates inefficient use of land resources.

Fig. 6: Expansion of Built-up LULC category in Rewari city



Source: Produced by the authors

The direction of Rewari's expansion was not unilateral. The city grew in the south, and north-eastern directions. These two directions underwent a major increase in built-up areas towards Bawal and Dharuhera & Bhiwadi industrial areas. The growth can also be attributed to the existence of transit nodes, as shown in Fig. 2. As the topography of the city is conducive to infrastructural development, it is difficult to project the future direction of city growth.

Landscape Change Analysis

Landscape metrics are useful tools for understanding spatial patterns and gaining insights into the structure, connectivity, and diversity of landscapes. For the present study, Table 9 details data on various landscape metrics for the years 1989, 2000, 2011, and 2020. ED has seen fluctuations but ended with an increase from 27.6 in 1989 to 38.26 in 2020. High ED values throughout the study period indicate the presence of many small, irregular patches. The changes suggest a slight reduction in fragmentation, with a notable increase from 1989 to 2000. LPI has seen a significant increase from 16.01 in 1989 to 29.37 in 2020. The change indicates a continuous and substantial reduction in fragmentation of the landscape over the years, particularly from 2011 to 2020. Total CA was at 183.81 in 1989 which doubled in 2000. Over the whole study period, it increased to almost eight times, showcasing the rapid growth of built-up areas.

PAFRAC has remained relatively stable, with only a slight decrease from 1.46 in 1989 to 1.39 in 2020. The variations suggest a minor increase in the number of regular shapes, but the overall values depict moderately complex patch shapes. Similarly, FRAC_AM has remained almost constant at 1.19 from 1989 to 1.29 in 2020. The low value throughout the study period indicates the shape ranging from simple to slightly intricate.

Table 9: Landscape Metrics 1989-2020

Metrics	1989	2000	2011	2020	Δ% 1989-2000	Δ% 2000-2011	Δ% 2011-2020	Δ% 1989-2020
ED	27.6	45.7	52.2	38.26	65.7	14.2	−26.7	38.6
LPI	16.01	9.12	12.88	29.37	−43.04	41.23	128.03	83.45
CA	183.8	323.9	552.9	1479.3	76.23	70.71	167.53	704.81
PAFRAC	1.46	1.48	1.49	1.39	1.37	0.68	−6.71	−4.79
FRAC_AM	1.19	1.20	1.23	1.29	0.84	2.50	4.88	8.40
CONTAG	39.9	33.5	33.56	48.57	−16.20	0.15	44.73	21.46
ENN_MN	117.9	89.1	78.71	80.34	−24.37	−11.74	2.07	−31.87
SHDI	1.28	1.36	1.32	1.13	6.25	−2.94	−14.39	−11.72
SIEI	0.85	0.89	0.87	0.74	4.71	−2.25	−14.94	−12.94

Source: Compiled by the authors

CONTAG has increased significantly from 39.99 in 1989 to 48.57 in 2020. The changes demonstrate a notable increase, especially from 2011 to 2020, suggesting that patches of the same class are eventually being grouped together. ENN_MN has seen a decrease from 117.92 in 1989 to 80.34 in 2020 (Fig. 7). The changes show a consistent decrease followed by a slight rise in value, suggesting a reduction in the mean distance between landscape elements, indicating a more clustered landscape.

SHDI has decreased from 1.28 in 1989 to 1.13 in 2020. The differences suggest a substantial decrease in landscape diversity and an increase in patches of the same class, especially from 2000 to 2011. SIEI has seen a considerable decrease from 0.85 in 1989 to 0.74 in 2020. The changes indicate a consistent decrease, with a significant drop from 2011 to 2020, suggesting a less even distribution of landscape elements. The landscape has become more clumped and contiguous over the years, as indicated by CONTAG. SHDI and SIEI values show less diversity and evenness, indicating a more homogenous landscape. ED has fluctuated but has decreased overall, reflecting changes in landscape boundaries. Overall, the landscape metrics show significant changes in the landscape pattern over time, with an increase in clumpiness and contiguity and a decrease in diversity and evenness.

Accuracy Assessment

The LULC results were verified by creating validation data (20 pixels per class) through high-resolution Google Earth satellite imagery. Through the creation of an error matrix, the values of producer accuracy, user accuracy, overall accuracy, and the kappa coefficient (κ) were calculated. The obtained classification accuracy values (Table 10) revealed overall accuracy values of 85 %, 83 %, 91 %, and 90 %, along with corresponding κ values of 0.81, 0.78, 0.88, and 0.87, were attained for the classified images of 1989, 2000, 2011, and 2020, respectively. These outcomes signify an acceptable level of conformity between the real-world LULC types and image classification. Moreover, the overall accuracy and κ values meet the minimum accuracy standards stipulated for LULC classification studies (Comber *et al.*, 2012).

Table 10: Accuracy assessment of classified images

	Accuracy (%)							
LULC type	**1989**		**2000**		**2011**		**2020**	
	Producer	User	Producer	User	Producer	User	Producer	User
Water body	85	100	90	100	85	94.4	95	95
Vegetation	90	90	95	78.2	85	89.4	90	80
Built Up	85	65.3	80	72.7	95	82.6	95	90.4
Barren	75	78.9	80	76.1	95	95	90	94.7
Agricultural land	90	100	90	93.7	95	95	90	90
Overall Accuracy	85		83		91		90	
κ coefficient	0.81		0.78		0.88		0.87	

Source: Compiled by the authors

DISCUSSION

The study analyzed the urban expansion of Rewari city on the basis of satellite images and population data. Urban expansion is a multifaceted process, driven by several policies, economics, and demographic factors. Economic progress had a central part in driving urban growth and LULC changes in Rewari city. With the initiation of market reforms and favorable policies, the economy experienced rapid expansion, witnessing substantial increases in migration. The expansion of the built-up areas on city space is attributed to natural increase and migration from nearby areas, and growth of secondary and tertiary sectors. The accelerated economic development necessitated additional built-up land for residential, commercial, and industrial purposes.

In Rewari city, the annual rate of urban expansion is on an increasing trend from 4.7 % per year in 2000 to 12.8 % per year in 2020 and the annual population growth rate is currently at 2.7 % per year. It implies that built-up area in Rewari city is growing nearly five times as much as population. Pawe & Saika (2018) found a similar growth trend in Guwahati, India, where built-up land area growth was four times higher than population growth. Similar instances of built-up growth outpacing population have been found in numerous Indian cities, including major urban centers like Hyderabad (Gumma *et al*., 2017), Chennai (Padmanaban *et al*., 2017), Pune (Kantakumar *et al*., 2016), New Delhi (Naikoo *et al*., 2020) and mid-sized cities like Gondal, Palitana (Jain & Sharma, 2019) and Mangaluru (Dhanaraj & Angadi, 2021). Chettry & Surawar (2021) found that despite population increase in Patna, Ranchi and Srinagar, population density decreased in all three cities. Consequently, this has led to noticeable urban sprawl and a corresponding shift in other LULC classes.

One of the primary challenges in spatial planning of growing cities is the phenomenon of urban sprawl (Johnson, 2001). The examination of the evolving patterns of built-up areas in Rewari city indicates rapid urban expansion, and the evidence points towards urban sprawl. An increasing land consumption rate suggests low-density characteristics. Decadal increase in land consumption rate indicates a decline in urban development densities. A sudden increase in land consumption rates in 2020 underscores the necessity of encouraging urban densification efforts to contain the growing future population within the current built-up area limits. High values of urban growth coefficient point towards progressively increasing sprawl characteristic of Rewari city. The low-density sprawling development suggests inefficient expenditure on basic services. The study also suggests towards additional urban land requirement in the coming decades. Considering the current rate of growth, there is a high likelihood of significant spill-over to nearby areas, endangering agricultural lands in the coming years. This encroachment is expected to have detrimental effects on the ecosystem, socioeconomic factors, and the environment.

In Rewari city, almost 27 % of city's prime agricultural land (6.78 m^2) was transformed into built-up land. Vegetation cover reduced by 47 % with majority being lost to new urban growth. The rate of natural land loss is comparable to large Indian cities. Sahana *et al*. (2018) reported that in Kolkata, 66.9 % of agricultural land was transformed for urban use during 2000-2015. Similarly, a 9.47 % decrease in agricultural land due to urban expansion was observed in Dehradun by Bhat *et al*. (2017). The alarming conversion of valuable agricultural and natural lands into built-up areas is a global phenomenon addressed by Indian (Kantakumar *et al*., 2016; Bhat *et al*., 2017; Sahana *et al*., 2018; Naikoo *et al*., 2020), and international studies alike (Dou & Chen, 2017; Akubia & Bruns, 2019). This unsustainable pattern of urban expansion has detrimental environmental consequences. Studies like Akubia & Bruns (2019) point towards the loss of biodiversity and ecosystem services due to the conversion of natural areas. The decrease in water bodies observed by Pawe & Saika (2018) in Guwahati signifies the potential disruption of hydrological cycles and water availability.

The significant impact of rapid urban expansion on nearby agricultural lands also poses challenges for local food security and livelihood.

Changing LULC dynamics may also lead to damaging environmental impacts in the city, including surface water runoff, water quality degradation, and heat island effect. Additionally, the rapid pace of urban growth poses a challenge for the government to deliver essential public amenities to meet the needs of the population. In smaller cities, urban development and expansion often precede planning and service deployments (Cohen, 2006). The absence of government-led infrastructure planning and service provision may contribute to the sprawling development of Rewari. This situation is poised to bring about adverse consequences in the city due to the associated challenges of green space loss, congestion, and an increased burden on solid waste management.

With cities transitioning from predominantly agricultural landscapes to non-agricultural ones, there is increased fragmentation and a decline in landscape regularities, as observed by Padmanaban *et al.* (2017) in Chennai. However, in the case of Rewari city, built-up LULC class has dominated the landscape over the years leading to a loss in landscape diversity. Jain & Sharma (2019) stated that small and medium-sized cities lean towards more scattered development patterns, with growth occurring in numerous fragmented areas, as compared to large cities. We find that in Rewari city, there is some evidence of road-induced growth, occuring from the initial city center towards other major industrial centers located in proximity of the city. This finding is in line with the results of Sarkar & Chouhan (2020) in metropolitan city of Siliguri, in which new growth took place near the old urban areas and alongside major roads.

The direction and trajectory of Rewari city's urban growth is majorly shaped by government interest and city planning policies. Rewari city is a priority town of the National Capital Region Plan (2021). Within a 14 km radius of Rewari city, Bawal and Dharuhera stand as major industrial centres of Haryana. Their growth has also provided impetus for migration to the city. HUDA (Haryana Urban Development Authority) has initiated the planned growth in the city for accommodating growing population. As Rewari city is a part of DMIC project, strong rail and road connectivity has provided a great opportunity to real estate in Rewari and a number of gated communities built up private developers like Sun City, Amangani, Ansal and BMG group have been developed in the city. Many of such developments are primarily located in urban peripheries due to readily available land. Similar strong correlations between economic growth, urban land expansion, and policy interventions have been observed in other studies across the world (Wu *et al*., 2016; Fenta *et al*., 2016).

Primarily, this study contributes to the ongoing discourse on satellite cities as the forefront of new urbanization. While metropolitan cities have traditionally been considered the centres of urban development or hotspots for urbanization within the urban studies literature (Zhao *et al*., 2015; Dou & Chen, 2017), this study reveals smaller town and cities as the focal points for new urban growth.

Recommendations

National Capital Region is India's principal administrative, financial, and commercial centre. The area's planning norms are revised periodically to accommodate the growing population and its needs. There is a need to extend the planning provisions to nearby areas like Rewari, where the escalating trends and patterns of urbanization have heightened the competition for land for built-up purposes, necessitating far-sighted urban land-use planning aligned with the understanding of urban expansion and its driving forces. The study's revelations regarding the future extent and speed of urban growth indicate an intensification of urbanization towards the other major industrial centres of the state. A timely regional development strategy is imperative to absorb development pressure, redirecting it away from the urban fringes, mitigating sprawl of the city.

To achieve a more concentrated urban form, the density of residential areas should be increased around transit nodes of the city by developing more housing units per unit of land. This approach can minimize the outward sprawl of the city and ensure a more compact development pattern conducive to delivery of public services such as transportation, utilities. In addition, a policy focus of infill development, rejuvenation of the existing urban spaces and leveraging the existing infrastructure can maximize the utilization of developed areas. The main objective of the regional plans should be the reduction of land consumption so that valuable natural and agricultural areas that would otherwise be lost to urban expansion can be saved.

CONCLUSION

In this study, the dynamics and patterns of urban expansion were quantified in Rewari city. Through the use of multi-temporal satellite images, different urban development indicators, and landscape metrics, the research unraveled significant insights into urban changes from 1989 to 2020. The findings reveal a substantial increase in urban and built-up areas, soaring from 1.83 km^2 in 1989 to 14.72 km^2 in 2020, marking a total surge of 12.89 km^2 over 31 years. The outlandish increase in urban land came at the expense of agricultural land, vegetation, barren land, and water bodies, with agricultural land witnessing a significant decrease from 11.41 km^2 in 1989 to 4.76 km^2 in 2020. Notably, more than 12.51 km^2 of agricultural & vegetative land was lost and approximately 12.48 km^2 transformed into urban land due to escalating human activities. Landscape metrics also show that there was a decrease in landscape diversity due to the increased prevalence of built-up area. These LULC changes had profound effects on landscape patterns, causing fragmentation as a consequence of widespread urbanization. It was also found that demand for built-up area is expected to increase in the coming decades, due to rising population and low-density development. These changes are likely to have adverse effects on the environment.

Economic development, population growth, and liberal policies emerged as influential factors driving urban expansion and subsequent LULC changes. Rewari city grew mainly towards the direction of transit nodes and nearby industrial centers of Bawal & Bhiwadi. The study employed a holistic approach, integrating satellite imagery, GIS, various indicators and landscape metrics offering a potent means to detect urban sprawl and LULC changes. These methods not only add to scientific knowledge but also offer invaluable insights to support decision-making, regional planning, city administration, and policy implementation. Moreover, for the successful implementation of policies and strategies, it is imperative that all stakeholders, including planners, policymakers, and the public possess a thorough understanding of the degree and rate of urban expansion and its many ramifications. The outcomes of this study offer foundational information to enhance comprehension of the present state of urban growth. Land use plans and regulations must be carefully crafted to mitigate the adversities arising from rampant urbanization, which exploits agricultural land, natural vegetation, and water bodies.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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