Spatio-Temporal Analysis of Zone-Wise Built-Up Area Change in Moradabad City Using Geospatial Techniques: A Three-Decade Study (1994-2024)

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Abstract: ***This study examines the spatio-temporal dynamics of built-up area expansion in Moradabad city, Uttar Pradesh, India, over a 30-year period (1994-2024) using multi-temporal Landsat imagery and supervised classification techniques. The analysis encompasses 70 municipal wards organized into four distinct zones, with built-up area extracted through Maximum Likelihood Classification (MLC) algorithm. Results indicate substantial urban expansion, with the city experiencing heterogeneous growth patterns across different zones. Zone 1 demonstrated the most dramatic transformation, with several wards showing growth rates exceeding 1000%, while Zones 3 and 4 exhibited relative stability, suggesting saturation or planned development constraints. The overall built-up area increased from approximately 8.54 sq.km in 1994 to 26.89 sq.km in 2024, representing a 214.87% increase over three decades. This expansion correlates with population growth to approximately 1.3 million by 2024, driven by economic development, infrastructural improvements, and rural-urban migration. The findings provide crucial insights for sustainable urban planning and management strategies in rapidly urbanizing medium-sized Indian cities.***

Keywords: Urban expansion, built-up area change, Landsat imagery, supervised classification, Spatio-temporal analysis, zone-wise growth

1. Introduction

Rapid urbanization represents one of the most significant demographic and spatial transformations of the 21st century, particularly in developing countries like India (Bhatta et al., 2010; Sharma et al., 2012). The conversion of agricultural and natural landscapes into built-up areas has profound implications for environmental sustainability, resource management, and socio-economic development (Dewan and Yamaguchi, 2009). Medium-sized cities, often overlooked in favour of metropolitan areas, are experiencing unprecedented growth rates that challenge existing infrastructure and planning frameworks (Seto et al., 2011). Moradabad, located in western Uttar Pradesh, India, serves as an important commercial and industrial centre with a population approaching 1.3 million as of 2024. Known historically as the "Brass City" for its metal handicraft industry, Moradabad has witnessed significant urban transformation over the past three decades. Understanding the spatial patterns and temporal dynamics of this transformation is crucial for evidence-based urban planning and sustainable development strategies (Taubenböck et al., 2012). Remote sensing and Geographic Information Systems (GIS) have emerged as powerful tools for monitoring and analysing urban growth patterns (Jensen and Cowen, 1999; Lu et al., 2004). Landsat imagery, with its long-term archive and moderate spatial resolution, provides an invaluable resource for historical urban change detection studies (Weng, 2001). Supervised classification methods, particularly Maximum Likelihood Classification (MLC), have been widely employed for land use and land cover (LULC) mapping and urban area extraction (Richards, 2013; Deng et al., 2019).

1.1 Research Objectives

This study aims to:
1) Quantify zone-wise built-up area changes in Moradabad city from 1994 to 2024
2) Identify spatial patterns and temporal trends of urban expansion across four municipal zones
3) Analyse ward-level variations in built-up area growth rates
4) Contextualize urban expansion patterns within demographic and socio-economic frameworks
5) Provide recommendations for sustainable urban planning and management

1.2 Study Area

Moradabad city is administratively divided into 70 municipal wards, organized into four distinct zones for planning and administrative purposes. The city is situated in the northern Indo-Gangetic plains, characterized by relatively flat terrain conducive to urban expansion. The study encompasses all 70 wards, providing comprehensive coverage of the municipal area and enabling zone-wise comparative analysis of urban growth patterns (Fig. 1).

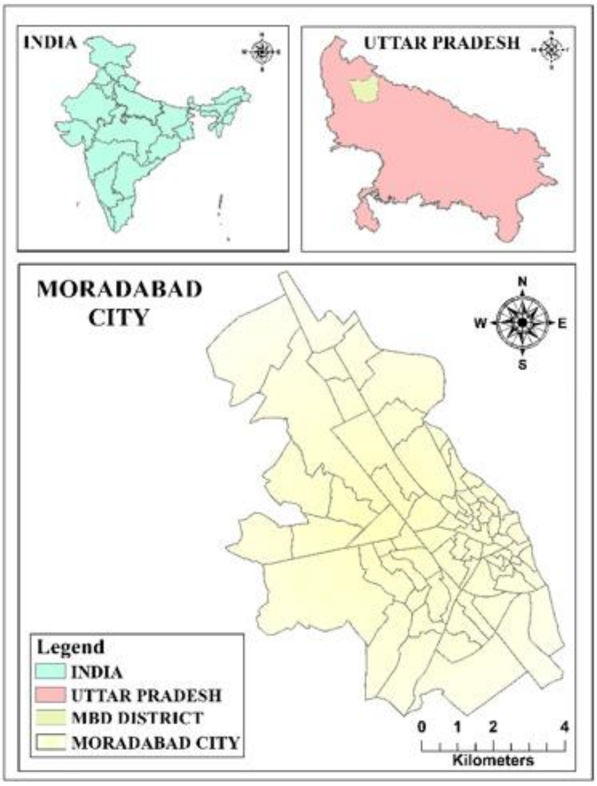

Figure 1: Study Area (Moradabad City).

2. Literature Review

2.1 Urban Growth in Indian Cities

Urban expansion in India has accelerated dramatically since economic liberalisation in 1991, with medium-sized cities experiencing particularly rapid growth (Sudhira et al., 2004). Studies on Indian cities have documented annual urban growth rates ranging from 2% to 8%, often exceeding population growth rates due to decreasing household sizes and changing land use patterns (Joshi et al., 2006; Ramachandra et al., 2012). The spatial manifestation of this growth typically exhibits concentric expansion from city centres, linear development along transportation corridors, and leapfrog development in peripheral areas (Bhatta et al., 2010).

2.2 Remote Sensing for Urban Change Detection

Landsat imagery has been extensively utilized for urban growth monitoring due to its temporal depth, spatial resolution, and free availability (Deng and Wu, 2013). Studies employing multi-temporal Landsat data have successfully documented urban expansion in various Indian cities including Bangalore (Ramachandra and Kumar, 2008), Delhi (Jain et al., 2016), and Lucknow (Rahman et al., 2011). The 30-meter spatial resolution of Landsat TM/ETM+/OLI sensors provides adequate detail for city-scale analysis while maintaining computational efficiency (Schneider, 2012).

2.3 Classification Techniques

Supervised classification methods, particularly Maximum Likelihood Classification, remain widely used for LULC mapping despite the emergence of advanced machine learning techniques (Dutta et al., 2015). MLC assumes normal distribution of training data and assigns pixels to classes based on probability density functions, making it particularly effective when sufficient training samples are available (Richards and Jia, 2006). Recent comparative studies suggest that MLC performs competitively with more complex algorithms for urban-rural classification tasks (Talukdar et al., 2020).

2.4 Research Gaps

While numerous studies have examined urban growth in major Indian metropolitan areas, medium-sized cities like Moradabad remain relatively understudied. Furthermore, most existing research focuses on overall urban expansion patterns without detailed zone-wise or ward-level analysis that could inform localized planning interventions. This study addresses these gaps by providing fine-grained spatial analysis of urban growth across administrative units over a 30-year period.

3. Materials and Methods

3.1 Data Sources

Satellite Imagery: Multi-temporal Landsat imagery was acquired for four time periods (1994, 2004, 2014, and 2024) corresponding to approximately decadal intervals. Imagery selection criteria included: (a) minimum cloud cover (<10%), (b) acquisition during dry season to minimize vegetation phenology variations, and (c) path/row consistency to ensure spatial comparability. **Ancillary Data:** Census records were consulted to correlate built-up area expansion with demographic changes. Municipal ward boundaries were obtained from the Moradabad Municipal Corporation for spatial aggregation and zone-wise analysis.

3.2 Image Preprocessing

Standard preprocessing procedures were applied to all Landsat scenes including:

- **Radiometric Correction:** Conversion of Digital Numbers (DN) to Top-of-Atmosphere (TOA) reflectance to minimize sensor and atmospheric variations (Chander et al., 2009)
- **Geometric Correction:** Image-to-image registration using Ground Control Points (GCPs) to ensure spatial alignment with root mean square error (RMSE) <0.5 pixels
- **Atmospheric Correction:** Applied to reduce atmospheric effects on surface reflectance values

3.3 Land Use and Land Cover Classification

A supervised classification approach using Maximum Likelihood Classification algorithm was implemented to generate LULC maps for each time period. Six land cover classes were identified: Built-up area, Plantation, Cropland, Fallow land, Barren land and Water body.

Training Sample Selection: Training samples for each class were selected through visual interpretation, incorporating local knowledge and high-resolution imagery from Google Earth for recent periods. Training samples were distributed across the study area to capture spectral variability within classes. **Classification Accuracy Assessment:** Classification accuracy was evaluated using confusion matrices derived from independent validation samples, with overall accuracy exceeding 85% for all time periods, meeting standard requirements for LULC mapping (Foody, 2002).

3.4 Built-up Area Extraction

Built-up area was extracted from the classified images for each time period. The built-up layer was overlaid with ward and zone boundaries to calculate area statistics for each administrative unit. Zone-wise and ward-wise built-up areas were computed for 1994, 2004, 2014, and 2024.

3.5 Change Detection Analysis

Temporal change analysis was conducted at both ward and zone levels:

- **Absolute Change:** Calculated as the difference in built-up area between successive time periods
- **Percentage Change:** Computed to enable comparison across wards with varying baseline areas
- **Annual Growth Rate:** Derived to assess the pace of urbanization across different decades

3.6 Statistical Analysis

Descriptive statistics including mean, standard deviation, and coefficient of variation were calculated for each zone to characterize spatial variability in urban growth patterns. Temporal trends were analysed using growth rate calculations and graphical representations.

4. Results

4.1 Overall Built-up Area Change

The aggregate built-up area across all zones in Moradabad city increased from approximately 8.54 sq.km in 1994 to 26.89 sq.km in 2024, representing an absolute increase of 18.35 sq.km and a relative increase of 214.87% over the 30-year study period. The temporal progression shows accelerated growth particularly between 2004-2014, corresponding with India's rapid economic growth phase.

Decadal Analysis:
City-wise built-up area expanded progressively across decades: from 8.54 sq.km in 1994 to 11.63 sq.km in 2004 (36.18% increase, 3.1% annual growth rate), surging to 18.62 sq.km by 2014 (60.10% increase, 4.8% annual growth rate), and reaching 26.89 sq.km in 2024 (44.41% increase, 3.7% annual growth rate). The middle decade (2004-2014) marked the most rapid expansion, likely fueled by economic liberalization, infrastructure development, and improved connectivity.

4.2 Zone-wise Built-up Area Dynamics

Zone 1: High Growth and Peripheral Expansion
Zone 1, comprising 18 wards, demonstrated the most dramatic transformation among all zones, with built-up area surging from 1.32 sq.km in 1994 to 8.73 sq.km in 2024, a staggering 561.36% increase exhibiting clear characteristics of peripheral expansion and new development. Key wards underscored this trend: Paipatpura Lakri (Ward 4) grew from 0.25 sq.km to 1.27 sq.km (408% increase), Lal Nagri (Ward 27) expanded from 0.12 to 0.94 sq.km (683.33% increase), and Prakash Nagar (Ward 28) saw the city's highest percentage rise at 1400%, ballooning from 0.08 to 1.20 sq.km. Wards like Shahpur Tigri (Ward 1) also transitioned from minimal baseline areas, signaling fresh urbanization in previously undeveloped land. Overall, the spatial pattern reveals expansion radiating from established urban cores toward peripheries, guided by transportation corridors as key development axes, positioning Zone 1 as Moradabad city's primary expansion frontier (Tab. 1 & Fig. 2).

Table 1: Zone wise Built-up Expansion (1994-2024) of Zone 1.

Ward No.	Ward Name	Zone No.	Built-up Area (Sq. Km)			
			1994	2004	2014	2024
1	Shahpur Tigri	1	0.05	0.00	0.26	0.55
3	Khushalpur	1	0.08	0.09	0.57	0.85
4	Paipatpura Lakri	1	0.25	0.23	0.76	1.27
9	Mansarover	1	0.07	0.25	0.52	0.53
11	Mainather	1	0.03	0.00	0.09	0.29
14	Gyani Wali Basti	1	0.09	0.22	0.22	0.21
16	Buddhi Vihar (Avas Vikas)	1	0.10	0.24	0.44	0.51
22	Suraj Nagar	1	0.03	0.08	0.28	0.38
23	Fazal Pur	1	0.03	0.02	0.15	0.32
24	Pandit Nagla	1	0.08	0.05	0.23	0.39
27	Lal Nagri	1	0.12	0.20	0.58	0.94
28	Prakash Nagar	1	0.08	0.17	0.20	0.20
29	Hanuman Nagar	1	0.12	0.32	0.41	0.47
30	Shiv Nagar	1	0.08	0.14	0.40	0.51
37	Majhola	1	0.07	0.13	0.30	0.46
43	Sitapuri Dassarai	1	0.06	0.10	0.20	0.24
51	Rehmat Nagar	1	0.15	0.26	0.41	0.48
52	Zahid Nagar	1	0.06	0.09	0.28	0.35
53	Jyantipur	1	0.03	0.03	0.09	0.18
69	Azad Nagar	1	0.07	0.12	0.38	0.48

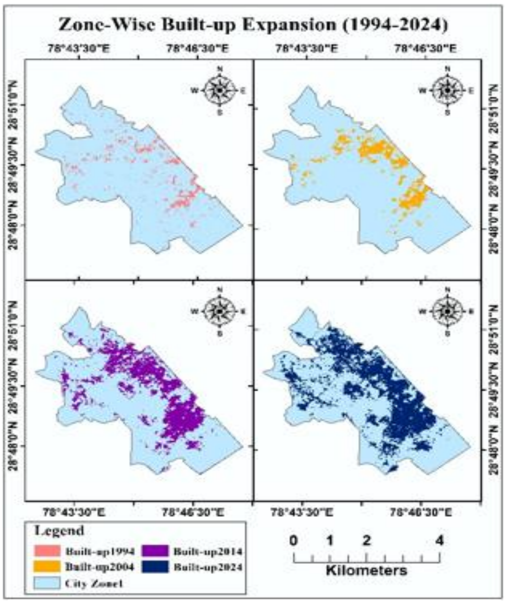

Figure 2: Zone wise Built-up Expansion (1994-2024) of Zone 1.

Zone 2: Moderate to High Growth with Mixed Patterns

Zone 2, containing 16 wards, experienced substantial growth from 1.60 sq.km in 1994 to 6.93 sq.km in 2024, a 333.12% increase displaying more heterogeneous patterns than Zone 1. Notable expansions included Bheemather (Ward 20), which surged from 0.17 to 0.96 sq.km (464.71% increase), and Ramganga Vihar (Ward 34), which grew from 0.10 to 0.74 sq.km (640% increase). In contrast, several wards remained relatively stable: Ashok Nagar (Ward 19) saw a slight decrease from 0.11 to 0.14 sq.km, while Mukarrab Pur (Ward 70) showed minimal change (0.05 to 0.09 sq.km), likely due to development constraints or green space preservation. This variability highlights a mix of infill development in established areas and expansion in underdeveloped wards, with the Ramganga River potentially influencing overall growth patterns in the zone (Tab. 2 & Fig. 3).

Table 2: Zone wise Built-up Expansion (1994-2024) of Zone 2.

	Built-up Area (Sq. Km)					
Ward No.	Ward Name	Zone No.	1994	2004	2014	2024
2	Adarsh Colony	2	0.12	0.16	0.31	0.36
5	Ashiyana	2	0.02	0.03	0.29	0.45
7	Naya Gaon	2	0.18	0.35	0.55	0.57
8	Jhajhanpur	2	0.10	0.18	0.45	0.52
10	Kazipura	2	0.03	0.00	0.16	0.42
13	Civil Line	2	0.08	0.23	0.34	0.34
15	Mau	2	0.08	0.10	0.28	0.42
17	Chandra Nagar	2	0.13	0.33	0.39	0.38
18	Hathala	2	0.11	0.20	0.53	0.60
19	Ashok Nagar	2	0.11	0.18	0.19	0.14
20	Bheemather	2	0.17	0.05	0.58	0.96
25	Chakkar Ki Milak	2	0.13	0.16	0.19	0.20
31	Jigar Colony	2	0.15	0.19	0.24	0.25
34	Ramganga Vihar	2	0.10	0.25	0.61	0.74
70	Mukarrab Pur	2	0.05	0.07	0.09	0.09

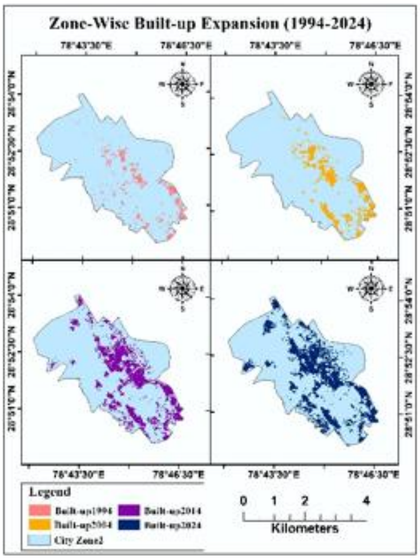

Figure 3: Zone wise Built-up Expansion (1994-2024) of Zone 2

Zone 3: Stability and Saturation

Zone 3, encompassing 23 wards, demonstrated remarkable stability over the 30-year period, with built-up area holding nearly constant from 3.43 sq.km in 1994 to 3.47 sq.km in 2024, a mere 1.16% increase. Most wards exhibited minimal change, including Bangla Gaon (Ward 6), Katra Banshidhar (Ward 56), and Bada Shasafa (Ward 68), which remained essentially unchanged. This consistency points to possible factors such as (a) saturation by 1994, (b) stringent planning regulations, or (c) preservation of historical and commercial areas, suggesting systematic influences rather than random variation. Zone 3 likely serves as Moradabad's historical urban core, where development predated the study period, further constrained by the concentration of the brass handicraft industry that limits residential expansion (Tab. 3 & Fig. 4).

Table 3: Zone wise Built-up Expansion (1994-2024) of Zone 3.

	Built-up Area (Sq. Km)					
Ward No.	Ward Name	Zone No.	1994	2004	2014	2024
6	Bangla Gaon	3	0.12	0.17	0.16	0.16
32	Katra Puran Jaat	3	0.20	0.21	0.21	0.21
35	Peergaib	3	0.15	0.15	0.15	0.15
39	Kanoon Goyan	3	0.16	0.17	0.19	0.20
40	Nawab Pura	3	0.10	0.18	0.19	0.22
41	Ashalat Pura Bhura	3	0.24	0.24	0.24	0.23
42	Baradari	3	0.14	0.18	0.17	0.18
47	Sagar Sarai	3	0.24	0.31	0.28	0.28
49	Dheria	3	0.15	0.15	0.15	0.15
50	Daulat Baag	3	0.10	0.14	0.14	0.14
54	Choumukha Pul	3	0.29	0.32	0.31	0.30
55	Lal Bag	3	0.12	0.14	0.15	0.16
56	Katra Banshidhar	3	0.12	0.12	0.13	0.12
61	Kataar Sheed	3	0.11	0.11	0.11	0.11
64	Kisrol	3	0.10	0.11	0.10	0.10
65	Lakri Walan	3	0.14	0.15	0.15	0.15
67	Tambaku Walan	3	0.17	0.17	0.17	0.17
68	Bada Shasafa	3	0.09	0.09	0.09	0.09

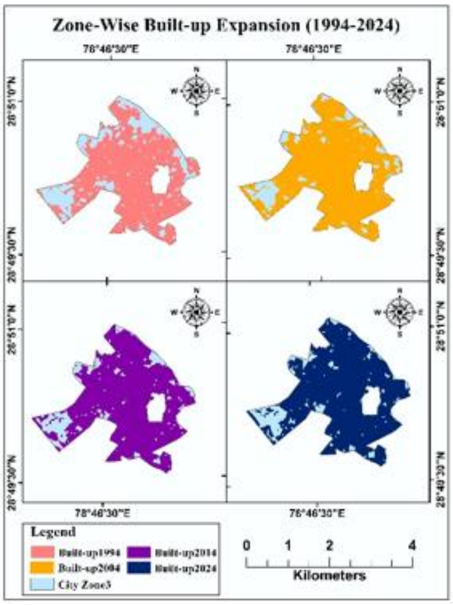

Figure 4: Zone wise Built-up Expansion (1994-2024) of Zone 3

Zone 4: Low Growth in Established Areas

Zone 4, comprising 13 wards, showed modest growth from 2.19 sq.km in 1994 to 2.76 sq.km in 2024, a 26.03% increase reflecting characteristics of established urban areas with limited expansion potential. Most wards maintained stable built-up areas, with Udpura (Ward 48), Asalatpura (Ward 59), and several others experiencing less than 5% change, mirroring the saturation seen in Zone 3. Exceptions included Peetal Basti (Ward 44), which surged from 0.08 to 0.62 sq.km (675% increase), and Gulab Bari (Ward 36), expanding from 0.07 to 0.43 sq.km (514.29% increase). These selective high-growth pockets suggest targeted redevelopment or densification projects rather than broad expansion trends (Tab. 4 & Fig. 5).

Table 4: Zone wise Built-up Expansion (1994-2024) of Zone 4.

	Built-up Area (Sq. Km)					
Ward No.	Ward Name	Zone No.	1994	2004	2014	2024
60	Gandhi Nagar	4	0.44	0.44	0.45	0.48
26	Katghar	4	0.32	0.38	0.40	0.37
21	Lajpat Nagar	4	0.44	0.56	0.55	0.50
46	Eid Gaah	4	0.12	0.13	0.11	0.11
48	Udpura	4	0.19	0.20	0.20	0.19
45	Singhman Hazari	4	0.15	0.17	0.18	0.18
59	Asalatpura	4	0.24	0.25	0.25	0.25
38	Barwalan	4	0.15	0.17	0.16	0.16
66	Mugalpura	4	0.14	0.15	0.15	0.15
63	Jama Masjid	4	0.11	0.13	0.14	0.14
62	Mufti Tola	4	0.16	0.16	0.16	0.16
44	Peetal Basti	4	0.08	0.12	0.38	0.62
12	Dehri Gaon (Govind Nagar)	4	0.12	0.24	0.39	0.43
36	Gulab Bari	4	0.07	0.15	0.37	0.43
33	Bhadaura	4	0.12	0.16	0.21	0.27
57	Ghunya Baag	4	0.10	0.11	0.11	0.11
58	Makbara	4	0.10	0.11	0.10	0.10

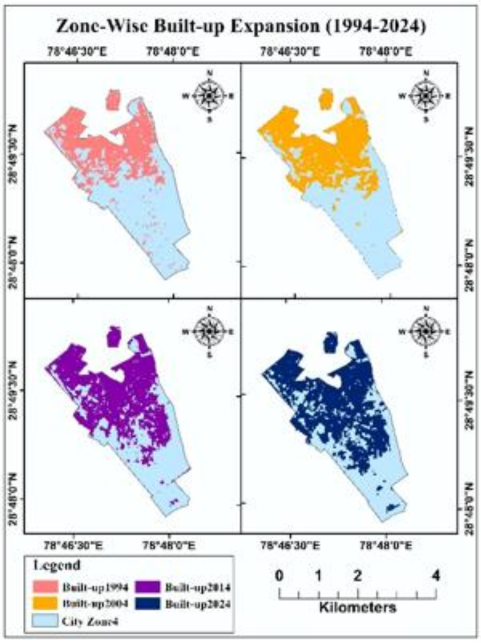

Figure 5: Zone wise Built-up Expansion (1994-2024) of Zone 4

4.3 Spatial Patterns of Urban Growth

Growth Rate Distribution

Analysis of percentage change across all wards reveals distinct growth categories: high-growth wards (>400% increase) numbered 12, predominantly in Zone 1 with selective occurrences in Zones 2 and 4; moderate-growth wards (100-400% increase) totaled 18, distributed mainly across Zones 1 and 2; low-growth wards (10-100% increase) included 15, scattered across all zones; and minimal-change wards (<10% change) comprised 25, concentrated in Zones 3 and 4.

Temporal Growth Phases

Decadal growth patterns unfolded in three distinct phases: Phase 1 (1994-2004) marked an initial expansion with moderate rates, concentrated in areas adjacent to the existing urban core, where Zone 1 began showing early signals. Phase 2 (2004-2014) brought rapid acceleration amid India's high economic growth period, with Zone 1 wards experiencing explosive expansion, several doubling or tripling built-up areas and achieving the city's maximum annual growth rates. Phase 3 (2014-2024) shifted to consolidation, featuring continued but slightly decelerated growth; Zone 1 expansion persisted amid diminishing available land, while infill development gained prominence across the city.

4.4 Ward-level Analysis of Extreme Cases

Highest Growth Wards:

Standout wards exemplify diverse expansion dynamics: Prakash Nagar (Ward 28, Zone 1) achieved a 1400% increase from 0.08 to 1.20 sq.km, epitomizing peripheral expansion; Lal Nagri (Ward 27, Zone 1) underwent a 683.33% surge from 0.12 to 0.94 sq.km, marking rapid rural-to-urban transformation; and Peetal Basti (Ward 44, Zone 4) grew 675% from 0.08 to 0.62 sq.km, signaling targeted urban renewal.

Stable/Declining Wards:

Certain wards bucked the overall growth trend, exhibiting stability or decline: Ashok Nagar (Ward 19, Zone 2) saw a slight increase from 0.11 to 0.14 sq.km, while Gyani Wali Basti (Ward 14, Zone 1) experienced a minor decline from 0.22 to 0.21 sq.km; additionally, multiple Zone 3 wards demonstrated less than 1% change over the full 30 years.

5. Discussion

5.1 Drivers of Urban Expansion

The observed urban growth patterns in Moradabad stem from multiple interacting factors. Economic development, anchored by the brass handicrafts and manufacturing base, has drawn migrant workers and spurred demand for residential and commercial spaces (Sharma et al., 2024; Shaw and Satish, 2007). Infrastructure improvements, such as national highway connectivity and intra-city road expansions, enhanced accessibility to peripheral areas, fueling Zone 1's dramatic growth (Sridhar and Reddy, 2014). Population pressures, with numbers nearing 1.3 million by 2024 and average household sizes of 5-6 persons (Census of India, 2011), necessitated spatial expansion to meet housing needs. Land availability and costs further differentiated patterns, offering abundant affordable options in peripheral Zone 1 while constraining established Zones 3 and 4 (Brueckner and Sridhar, 2012). Planning policies likely contributed too, with Zone 3's stability reflecting heritage conservation or zoning regulations in the historic core, contrasted by designated growth zones enabling Zone 1's expansion.

5.2 Spatial Growth Patterns and Urban Form

Spatial analysis reveals a concentric-linear hybrid growth model in Moradabad. Concentric expansion dominates in Zone 1, radiating outward from the established core (Zones 3 and 4) toward peripheries, aligning with von Thünen's location theory adapted to urban contexts where land use intensity diminishes with distance from the centre (Alonso, 1964). Linear development appears in exceptional wards like Lal Nagri and Prakash Nagar, which track major transportation corridors, a pattern seen in other Indian cities (Taubenböck et al., 2009). Leapfrog development also emerges, as in Shahpur Tigri's growth from 0.05 to 0.55 sq.km in previously undeveloped areas, skipping intermediates and risking service provision inefficiencies (Bhatta et al., 2010).

5.3 Temporal Dynamics and Growth Phases

The three identified growth phases align with broader national trends: the 1994-2004 moderate growth period followed India's 1991 economic reforms, with urbanization accelerating gradually in medium-sized cities like Moradabad as benefits percolated downward (Shaw and Satish, 2007). The 2004-2014 rapid growth phase matched India's peak GDP rates, infrastructural investments, and globalization impacts extending to tier-2 and tier-3 cities, driving Moradabad's maximum expansion in line with national patterns (Denis et al., 2012). Finally, the 2014-2024 consolidation phase featured sustained but decelerated growth, signaling saturation of developable land and a shift toward infill and vertical development over horizontal sprawl (Schneider and Woodcock, 2008).

5.4 Zone-wise Comparative Analysis

Zone 1 versus Zone 3 represents opposite ends of the urban development spectrum: Zone 1's explosive 561% growth starkly contrasts Zone 3's mere 1% change, highlighting simultaneous peripheral expansion and core stabilization, a dual pattern echoed in Indian cities like Bangalore and Pune (Sudhira et al., 2004; Dutta, 2012). Similarly, Zone 2 versus Zone 4 both exhibit moderate growth but diverge spatially: Zone 2's heterogeneous 333% increase with high variability marks it as a transitional buffer between expanding periphery and stable core, while Zone 4's modest 26% overall growth features outlier wards like Peetal Basti and Gulab Bari, signaling selective redevelopment amid general saturation.

5.5 Implications for Urban Planning

Urban growth patterns in Moradabad demand targeted interventions across multiple domains. Infrastructure planning must proactively scale services like water, sewerage, and electricity in rapidly expanding Zone 1 to avert slum proliferation and service gaps common in Indian cities (Kundu, 2011). Environmental safeguards are essential to mitigate agricultural land loss and green space erosion from cropland conversion, balancing development with sustainability and food security (Dutta et al., 2015). Transportation investments should expand networks along linear growth corridors, prioritizing public options to enhance connectivity and curb car dependency (Tiwari, 2002). Zonal planning requires tailored strategies to managed growth in Zone 1, infill in Zone 2, heritage preservation in Zone 3, and densification in Zone 4, rather than uniform policies (Sridhar, 2010). Finally, Zone 1's peripheral expansion presents affordable housing opportunities on cheaper land, provided connectivity and services prevent marginalizing low-income groups (Kundu and Sharma, 2001).

5.6 Comparison with Similar Cities

Moradabad's growth trajectory mirrors other medium-sized Indian cities: its 214.87% built-up area increase over 30 years aligns with 150-250% expansions in Meerut, Agra, and Varanasi (Rahman et al., 2011; Singh et al., 2018). The concentric-linear hybrid spatial model echoes patterns in Lucknow, Kanpur, and other Uttar Pradesh cities, driven by shared regional factors (Joshi et al., 2006). Temporal acceleration during 2004-2014 matches national urbanization trends, as India's rate rose from 28% to 31%, with medium-sized cities bearing disproportionate growth (Census of India, 2011).

5.7 Study Limitations

Several limitations merit acknowledgment. Classification accuracy exceeded 85% overall, yet mixed pixels at urban-rural interfaces and Landsat's 30-meter resolution may introduce uncertainties in detecting small-scale built-up features (Lu and Weng, 2007). Decadal temporal gaps risk missing short-term fluctuations or non-representative image captures, where annual or bi-annual monitoring would offer finer resolution (Jain et al., 2016). While growth patterns and drivers are explored, causality remains unestablished; integrating socio-economic data via regression could bolster inference (Deng et al., 2008). Finally, the analysis focuses on horizontal expansion, overlooking vertical densification, which building height data would better illuminate (Taubenböck et al., 2012).

6. Conclusions

This comprehensive spatio-temporal analysis of built-up area change in Moradabad city reveals significant urban transformation over the 1994-2024 period, with the city experiencing a 214.87% increase in built-up area. The zone-wise analysis demonstrates highly heterogeneous growth patterns, with Zone 1 functioning as the primary expansion frontier (561% increase) while Zone 3 exhibits characteristics of a saturated historic core (1% change). The temporal analysis identifies three distinct phases such as moderate growth (1994-2004), rapid acceleration (2004-2014), and consolidation (2014-2024) corresponding to broader national economic and urbanization trends.

The findings underscore the utility of remote sensing and GIS techniques for monitoring and analyzing urban growth in medium-sized Indian cities. The detailed ward-level analysis provides actionable information for urban planners and policymakers to develop zone-specific strategies addressing the diverse needs of expanding, transitional, and established urban areas.

7. Key Recommendations

Future planning for Moradabad should adopt zone-specific approaches: proactive master planning in Zone 1 to manage expansion through infrastructure, environmental safeguards, and orderly growth; infill and vertical densification in Zones 2 and 4 to optimize land use and protect peripheral greens; heritage conservation with adaptive reuse in Zone 3's historic core. Integrated transportation networks must connect peripheries to the core, curbing car reliance and boosting accessibility. Broader priorities include green space preservation amid built-up encroachment, affordable housing in peripheral zones to foster inclusive growth and curb informal settlements, and continuous GIS-satellite monitoring for adaptive responses. Moradabad's urbanization challenges present opportunities for sustainable, planned development as a potential model for other medium-sized Indian cities to leveraging remote sensing for evidence-based governance.

8. Future Research Directions

Future studies could enhance understanding through: (1) integration of socio-economic data for multivariate analysis of growth drivers, (2) higher resolution imagery for detailed urban form analysis, (3) modeling and prediction of future growth scenarios, (4) assessment of environmental impacts including urban heat island effects and air quality changes, and (5) evaluation of infrastructure adequacy in rapidly growing areas.

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