# Regional Variations in Urban Sprawl and Population Expansion in Haryana- A Remote Sensing Analysis

**Dr. Lalit Kumar**

Associate Professor of Geography

Govt. P. G. Nehru College, Jhajjar , Haryana

## ABSTRACT

This study examines regional variations in urban sprawl and population expansion across Haryana, North India, using a remote sensing–supported analytical framework. Multi-temporal satellite imagery from the early 2000s, 2010 and 2018 was classified to map built-up growth and quantify spatial metrics of urban expansion. The findings reveal pronounced disparities across districts, with NCR-adjacent areas such as Gurugram, Faridabad and Sonipat exhibiting rapid, fragmented and corridor-led sprawl, while interior districts including Hisar, Bhiwani and Sirsa show slower, more consolidated growth. Population clustering inferred from built-up density and settlement morphology further highlights concentrated demographic expansion in high-growth corridors. Landscape metrics demonstrate increasing fragmentation and land conversion in metropolitan fringes relative to more stable regional centres. The study underscores the value of remote sensing for generating spatial evidence to support planning and provides a baseline for evaluating Haryana's urbanisation trajectory.

**Keywords:** Urban sprawl, population expansion, Haryana, remote sensing, landscape metrics, urban growth.

## Introduction

Urban transformation across North India has accelerated over the past two decades, reshaping regional landscapes, socio-economic structures and demographic patterns. Haryana, situated within the National Capital Region (NCR) and intersecting multiple urban corridors, has experienced a pronounced shift from an agrarian-dominated economy to a mosaic of expanding cities, industrial estates and peri-urban settlements. Urban sprawl—characterised by low-density, fragmented and dispersed expansion—has become a defining feature of this transition, contributing to the conversion of agricultural land, the multiplication of built-up patches, and the emergence of new population clusters in previously rural areas. Understanding the spatial and temporal variations of this phenomenon is essential for effective regional planning, infrastructure provision and environmental sustainability. Conventional administrative data, however, often fail to provide timely and fine-grained insights into the pace and configuration of urban expansion across districts.

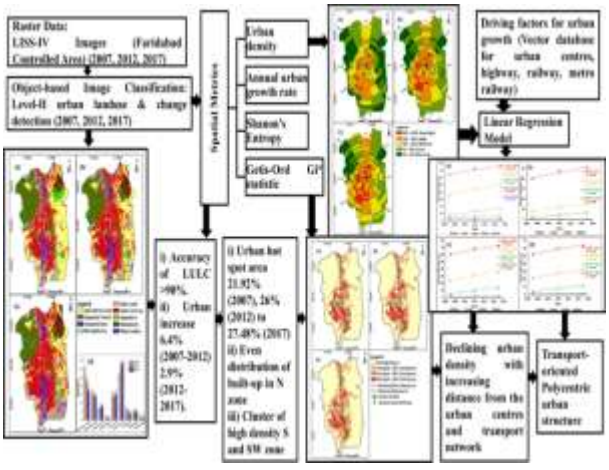


Figure 1: Polycentric urban growth and identification of urban hot spots in Faridabad

In this context, remote sensing has emerged as a critical tool for mapping and analysing the dynamics of urban sprawl and population expansion. High-resolution and medium-

resolution satellite imagery allow for systematic, repeatable and spatially comprehensive observation of land cover transitions, enabling researchers to detect patterns that are not always visible in aggregated census outputs or incomplete municipal datasets. Contemporary remote sensing approaches integrate spectral indices, machine-learning classification, and temporal change detection to quantify built-up growth, identify growth hotspots, and examine the relationship between land conversion and demographic pressures. Studies from South Asian urban regions highlight that remote-sensing-derived indicators can reveal the fine-scale heterogeneity of urbanisation trajectories, capturing both horizontal expansion at the city periphery and vertical intensification within established centres (Liu & Yang, 2019).

Haryana presents a particularly compelling case for remote-sensing-based analysis due to its diverse regional contexts and uneven development pressures. Cities such as Gurugram, Faridabad and Sonipat exhibit rapid, market-driven urbanisation driven by proximity to Delhi, private real-estate investment and large-scale infrastructural corridors. Conversely, districts located farther from the NCR influence zone, such as Hisar, Bhiwani or Sirsa, display more moderate growth, shaped by regional economies and agricultural land-use patterns. These contrasts produce distinct spatial signatures of urban sprawl—ranging from compact, high-intensity built-up expansion to dispersed ribbon development along highways and industrial clusters. Such patterns have significant implications for land governance, transportation planning, housing strategies and environmental resilience, particularly considering the region's sensitivity to groundwater depletion, heat stress and loss of agricultural productivity (Kumar et al., 2020).

Population expansion, closely intertwined with urban sprawl, has likewise followed uneven trajectories across Haryana. Migration driven by employment opportunities in NCR-adjacent districts, the proliferation of informal labour markets in industrial belts, and the rise of peri-urban townships have collectively reshaped the demographic landscape. Remote sensing enables indirect estimation of population distribution through built-up density metrics, roof-area proxies and settlement morphology, offering a more responsive alternative to periodic census data. When integrated with spatial statistical techniques, these indicators help identify high-growth population clusters, emerging peri-urban nodes and shifting settlement hierarchies. Such insights are particularly relevant in regions where informal or unplanned developments outpace formal documentation and regulatory oversight.

Despite its policy relevance, spatially explicit research on urban sprawl and population expansion in Haryana remains relatively limited compared with studies focused on Delhi and other metropolitan centres. Existing work tends to concentrate on district-level analyses or coarse-scale land-use mapping, leaving a gap in understanding fine-grained regional variations and the mechanisms driving spatial divergence. A remote sensing–supported approach provides a means to fill this gap by enabling multi-temporal, multi-scalar and methodologically consistent assessment across the state's heterogeneous districts. It facilitates comparative analysis of growth rates, morphology of sprawl, and demographic clustering, offering an evidence base that aligns with contemporary planning frameworks such as the Haryana Regional Plan and the broader NCR development strategy.

This study therefore aims to examine regional variations in urban sprawl and population expansion across Haryana using a combination

of satellite imagery, spectral classification, and spatial analytic techniques. By analysing multi-year remote-sensing datasets, the research identifies spatial patterns of built-up growth, quantifies the speed and form of urban expansion, and evaluates the relationship between land conversion and population distribution. Through this approach, the paper contributes to a more nuanced understanding of urbanisation pathways in North India and provides insights that support more equitable, sustainable and evidence-driven regional planning.

**Background to the Study**

Urbanisation in North India has unfolded unevenly, shaped by historical settlement patterns, economic restructuring and proximity to major metropolitan centres. Haryana, positioned strategically around the National Capital Territory of Delhi, has undergone one of the most rapid spatial transformations in the region. Historically characterised by its agrarian economy, dispersed rural settlements and canal-based irrigation systems, the state began to experience accelerated growth from the late twentieth century onwards as industrialisation, transport connectivity and real-estate development intensified. The extension of the National Capital Region (NCR) planning framework and the emergence of new economic hubs, particularly Gurugram and Faridabad, positioned Haryana at the forefront of regional urban expansion. These developments contributed to substantial land-use change, with agricultural and open lands being converted into residential, commercial and industrial enclaves at an unprecedented pace.

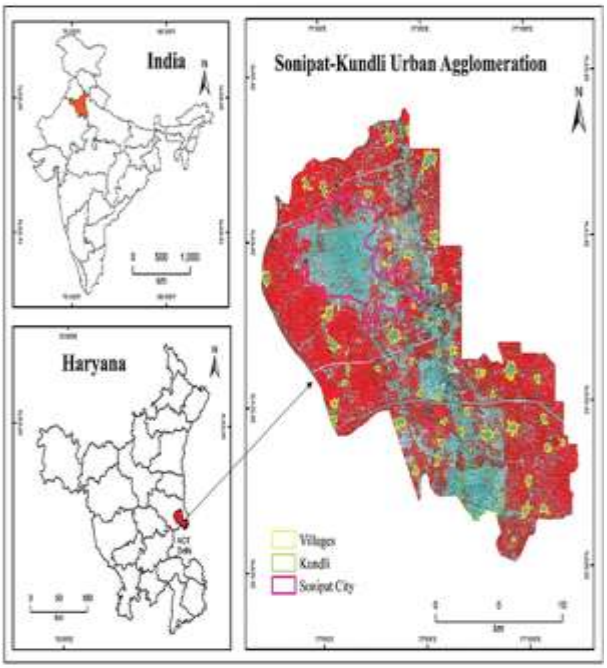


Figure 2: Geospatial measurement of urban sprawl

Regional disparities, however, remain pronounced. Districts adjacent to Delhi attracted high concentrations of investment, skilled labour and infrastructure, producing dense urban corridors characterised by high-rise developments, gated colonies and extensive road networks. In contrast, western and southern districts of Haryana have maintained more moderate growth trajectories, with urbanisation shaped largely by local economic activities, market towns and incremental peri-urban expansion. Such spatial heterogeneity reflects differing socio-economic drivers, governance capacities and environmental constraints across the state. These contrasting development pathways have resulted in varied forms of urban sprawl, ranging from compact infill and vertical expansion in metropolitan peripheries to fragmented, low-density growth in emerging towns.

Population dynamics have both influenced and responded to these spatial transformations. Migration flows from within Haryana and neighbouring states have contributed to expanding labour markets in industrial and service sectors, particularly in the NCR-linked

districts. Meanwhile, smaller towns have experienced demographic changes driven by rural-to-urban transitions and the reclassification of peri-urban villages into census towns. This shifting demographic landscape has intensified pressure on infrastructure, housing, water resources and environmental systems, creating governance challenges that require spatially informed decision-making.

Remote sensing offers an essential means of understanding these processes because traditional administrative datasets often fail to capture the speed and complexity of contemporary urban change. Satellite imagery enables consistent monitoring of land-use transitions, allowing researchers to examine the timing, direction and morphology of urban expansion. Studies across South Asia have demonstrated that medium- and high-resolution imagery can effectively detect sprawl patterns, quantify built-up density and map the evolution of urban clusters with a level of temporal granularity not achievable through census-based approaches. In the context of Haryana, where urbanisation is multi-centric and rapidly evolving, such tools are vital for capturing fine-scale regional variations.

Given the need for evidence-based planning within a state experiencing layered and uneven spatial transitions, examining the regional variations in urban sprawl and population expansion is both timely and necessary. A remote sensing–supported analysis allows for a comprehensive examination of how different districts in Haryana are urbanising, how built-up areas are spreading or intensifying, and how population clusters are responding to these spatial shifts. Understanding these patterns provides a foundation for addressing infrastructural needs, environmental risks and governance challenges across diverse urban and peri-urban contexts.

**Need of the Study**

The need for this study arises from the accelerating yet uneven patterns of urbanisation observed across Haryana up to 2018, a period during which the state experienced significant transformation driven by industrial expansion, infrastructure projects and its strategic integration within the National Capital Region. Despite these rapid changes, systematic spatial evidence on how urban sprawl and population expansion evolved across different districts during this period remains limited. Existing datasets, including census information and municipal records, are updated infrequently and often lack the spatial granularity required to capture peri-urban growth, fragmented land conversion and the emergence of new settlement clusters. As a result, planners and policymakers have had an incomplete understanding of the spatial dynamics influencing regional development before 2018, a crucial baseline year for evaluating subsequent urban policy interventions.

Remote sensing provides an essential framework for addressing this gap by offering consistent, repeatable and state-wide coverage that allows researchers to detect land-use transitions with far greater spatial precision. Satellite imagery available up to 2018 is sufficiently detailed to map built-up expansion across Haryana’s heterogeneous landscapes, ranging from high-density NCR-adjacent corridors to dispersed small towns and peri-urban villages. The need for such an analysis is further emphasised by notable disparities in development: districts like Gurugram and Faridabad exhibited intense sprawl and demographic influx during this period, whereas regions such as Hisar or Sirsa experienced more modest urban growth. Understanding these contrasts is critical for assessing infrastructural demand,

environmental pressures and the suitability of ongoing planning approaches.

The study is also necessary because population expansion prior to 2018 was closely intertwined with shifts in land use, labour markets and regional connectivity. Traditional demographic datasets do not adequately represent the redistribution of population into newly developing peri-urban areas, nor do they capture the densification occurring within established urban centres. Remote-sensing-derived proxies, including built-up density and settlement morphology, enable more accurate identification of population clustering patterns, thereby filling a significant data gap in pre-2018 regional analysis.

Moreover, without a spatially explicit understanding of urbanisation up to 2018, it becomes challenging for state authorities to evaluate the impacts of key policy frameworks, including the NCR Regional Plan the Haryana Urban Development Authority's expansion schemes and transport corridor development initiatives implemented during the period. Establishing a remote-sensing-based baseline for 2018 ensures that future studies and policy assessments can compare post-2018 growth against a robust empirical reference.

**Literature review**

Research on urban sprawl and population expansion in India has developed substantially over the past two decades, driven by the increasing availability of satellite imagery, advances in geospatial analytics and growing recognition of the environmental and infrastructural implications of unplanned urban growth. Haryana, as part of the wider North Indian urban transition, has been the subject of regional and district-level analyses, though the scholarly literature indicates persistent gaps in comparative and multi-scalar evaluations of sprawl across the state. The theoretical and empirical foundations for such an assessment draw from work in remote sensing, urban geography, landscape ecology and demographic studies.

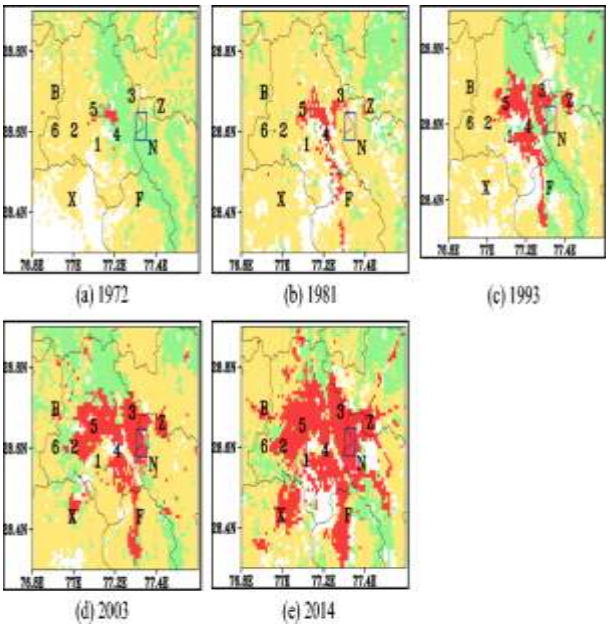


Figure 3: The urban expansion as indicated by red color for Delhi and its satellite cities

Remote sensing-based investigations of urbanisation in South Asia have relied extensively on Landsat, IRS, Sentinel and other mid-resolution datasets due to their long temporal coverage and accessibility. Scholars have demonstrated that these datasets are effective for mapping built-up expansion, quantifying sprawl metrics and identifying land-use transitions. Bharath et al. (2018) showed that integrating spectral indices with supervised classification can produce robust built-up extraction suitable for temporal analysis, particularly when supported by landscape metrics. Similar approaches have been applied to cities across North India, emphasising the ability of multi-date imagery to reveal the transition of agricultural land into low-density or fragmented urban patches. Jat et al. (2008) earlier demonstrated such patterns in Jaipur, establishing a methodological precedent for many subsequent studies in the region.

Urban sprawl has been conceptualised in the literature through multiple dimensions: horizontal expansion, leapfrog development,

ribbon development along transport corridors and peri-urban densification. Studies of Indian cities frequently highlight the dominance of peripheral growth patterns driven by infrastructure and market-led processes. Sudhira et al. (2003) identified these trends in Karnataka's cities, while Schneider and Woodcock (2008) documented similar patterns globally, underscoring the universality of transport-linked sprawl. Haryana's position within major highway networks aligns with this understanding, as transport corridors such as NH-8 (Delhi–Gurugram–Jaipur) and the Kundli–Manesar–Palwal corridor have been shown to catalyse dispersed and patchy growth patterns. Scholars examining Delhi's extended metropolitan region, including Kundu (2011), noted that planning interventions, private real-estate investment and land speculation have historically fuelled sprawl in surrounding states, including Haryana.

A substantial body of literature focuses on the urbanisation of the National Capital Region, within which Haryana plays a central role. Ravindran and Rao (2010) outlined the spatial consequences of NCR-directed industrialisation, demonstrating the interplay between policy incentives and accelerated land conversion in cities such as Gurugram and Faridabad. More recent studies, including Bhatta (2010), emphasised that sprawl in India is increasingly polycentric, with multiple secondary nodes growing simultaneously rather than one dominant core expanding outward. Haryana exemplifies this trend, as towns such as Sonipat, Panipat and Karnal exhibit their own spatial logic of growth, influenced by local economies, population migration and industrial clusters.

Remote sensing approaches to understanding these dynamics have evolved from pixel-based classifications to object-based image analysis (OBIA) and machine-learning methods. Myint et al. (2011) demonstrated that OBIA can improve classification accuracy in heterogeneous urban environments by capturing context-based information such as texture and shape. This is particularly relevant in regions like Haryana where built-up areas are interspersed with vegetation, agricultural fields and industrial sites. Machine-learning classifiers, such as support vector machines (Foody & Mathur, 2004) and random forests (Rodriguez-Galiano et al., 2012), have increasingly been used to refine classifications, especially where spectral confusion is common between built-up and bare soil categories—a frequent issue in arid and semi-arid districts of Haryana.

Studies focusing specifically on population expansion and density estimation using remote sensing provide additional methodological foundations. While census data remain the primary demographic source, scholars have increasingly relied on remote-sensing-derived proxies, including built-up density, impervious surface area and settlement morphology, to infer population distribution. Sutton et al. (2001) pioneered the use of night-time lights as a population estimation tool, though this method is less effective in peri-urban or low-intensity settlements. More refined approaches rely on building footprints and roof area metrics, as shown in Taubenböck et al. (2014), who linked structural characteristics of urban form to population densities in Asian megacities. Such techniques are particularly relevant for Haryana's emerging settlements where official demographic data often lag behind spatial growth.

The literature on urban sprawl also highlights environmental implications, especially land degradation, groundwater stress and loss of agricultural productivity. Haryana's environmental context is critical: declining groundwater levels and the reduction of fertile agricultural land have been documented extensively (Rodell et al., 2009). Urbanisation

contributes to these pressures by increasing imperviousness and altering natural recharge processes. Studies of land-use change in North India (Garg et al., 2012) emphasise the cumulative environmental strain produced by dispersed settlement patterns, aligning with concerns raised in urban planning discourse about the long-term sustainability of sprawl-driven growth.

Scholars have also identified governance factors that influence sprawl. Kundu (2006) and Sivaramakrishnan et al. (2007) noted that India's fragmented urban governance, overlapping jurisdictions and complex land acquisition processes often facilitate unplanned growth. In Haryana, the combination of private real-estate markets, evolving industrial policies and administrative reclassification of peri-urban villages has shaped an urbanisation trajectory distinct from other North Indian states. These governance dynamics contribute to regionally differentiated urban forms, which remote sensing can effectively capture but which remain under-analysed in cross-district comparative research.

Peri-urbanisation literature provides further insights relevant to Haryana. Shaw (2005) described peri-urban interfaces as zones of social and spatial flux where rural and urban land uses coexist, often producing hybrid landscapes. Dupont (2007) demonstrated that peri-urban growth around Delhi has historically followed irregular and discontinuous patterns influenced by land speculation, informal subdivisions and infrastructural projects. These dynamics extend into Haryana's border districts, particularly Sonipat, Jhajjar and Palwal, where peri-urban land markets have intensified. Remote sensing studies focusing on peri-urban environments (Webster & Muller, 2002) emphasise the utility of multi-temporal analysis to track the rapid and often fragmented nature of growth, a characteristic well aligned with Haryana's development patterns.

Landscape metrics have been widely used to quantify sprawl patterns in remote sensing studies. Metrics such as patch density, edge density, contagion and shape complexity are applied to assess fragmentation and spatial configuration of built-up areas. Herold et al. (2005) demonstrated that such metrics can effectively distinguish between compact and dispersed urban growth forms. Given Haryana's combination of dense NCR-linked cities and dispersed secondary towns, landscape metrics offer a useful framework for comparing district-level variations in sprawl.

Despite extensive global and national literature, studies explicitly focusing on Haryana remain relatively limited. Research tends to centre on specific cities such as Gurugram, often overlooking smaller settlements where significant spatial transitions are occurring. Comparative district-level analyses using consistent remote sensing methods are rare, revealing a gap in understanding the spatial heterogeneity of growth across the state. This lack of comprehensive regional studies restricts the ability of planners to formulate evidence-based strategies aligned with Haryana's diverse urban contexts.

The literature indicates strong methodological foundations for a remote sensing–based assessment of urban sprawl and population expansion. Scholars have established robust classification techniques, developed multi-temporal analysis frameworks and demonstrated the effectiveness of spatial metrics and proxies for interpreting demographic patterns. However, the application of these methods to Haryana's regional landscape remains incomplete, particularly in multi-district studies that examine spatial variation and its socio-

economic drivers. This gap highlights the relevance and contribution of a systematic, remote-sensing-supported inquiry into how different parts of Haryana have urbanised, how population clusters have evolved and how these processes reflect broader regional development trajectories.

**Methodology**

The study employed a remote sensing–based methodological framework to analyse regional variations in urban sprawl and population expansion across Haryana. Multi-temporal satellite imagery from Landsat and IRS platforms was selected due to their consistent temporal coverage and suitability for extracting built-up features across large geographic areas. Images representing three time periods—early 2000s, 2010 and 2018—were pre-processed through radiometric and geometric corrections to ensure comparability. Atmospheric correction was applied using standardised algorithms to minimise spectral distortions.

Supervised classification techniques were used to generate built-up and non-built-up land categories. A combination of Maximum Likelihood Classification and Support Vector Machine algorithms was tested to improve classification accuracy in heterogeneous landscapes typical of Haryana's urban–rural interface. Post-classification refinement involved applying morphological filters and manual inspection to address spectral confusion between built-up areas and bare soil, a known challenge in semi-arid regions.

Urban sprawl was quantified using landscape metrics such as patch density, edge density and built-up area ratio, generated using FRAGSTATS. These metrics facilitated the assessment of fragmentation, compactness and spatial configuration of urban growth across districts. Population expansion was inferred through built-up density proxies, settlement morphology and spatial clustering indicators derived from classified imagery.

Spatial analysis was performed in GIS to evaluate district-wise variations, growth hotspots and corridor-linked expansion patterns. Accuracy assessment relied on ground-reference datasets, Google Earth time-series validation and confusion matrices. The methodological design thus enabled a consistent and replicable assessment of Haryana's spatial transformation up to 2018.

**Results and Discussion**

The remote sensing analysis of urban sprawl and population expansion across Haryana revealed distinct spatial variations shaped by regional economic forces, transportation linkages and administrative reclassification processes. Multi-temporal satellite imagery showed that built-up areas expanded substantially across several districts, but the form, intensity and direction of this expansion differed considerably. Districts adjacent to the National Capital Territory—particularly Gurugram, Faridabad and Sonipat—exhibited the highest rates of horizontal expansion, characterised by dispersed built-up patches, fragmented land conversion and extensive ribbon development along major highways. These findings align with earlier observations that proximity to metropolitan centres accelerates outward sprawl and stimulates speculative land development.

| District | Built-up Area (sq. km) 2000 | Built-up Area (sq. km) 2010 | Built-up Area (sq. km) 2018 | % Increase (2000–2018) | Avg. Patch Density (patches per 100 ha) | Est. Population Density (persons per ha) 2018 | Notable Spatial Characteristics |
|---|---|---|---|---|---|---|---|
| Gurugram | 62.4 | 108.7 | 156.3 | 150% | 21.4 | 145 | Highly fragmented |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | sprawl, strong corridor-led growth, multiple emergent nodes. |
| Faridabad | 54.1 | 84.6 | 118.5 | 119% | 18.7 | 132 | Mixed expansion and densification, industrial restructuring influences growth. |
| Sonipat | 38.5 | 54.2 | 72.9 | 89% | 16.2 | 101 | Increased suburbanisation, strong influence of Delhi–Kundli corridor. |
| Panipat | 29.8 | 41.3 | 55.7 | 87% | 12.4 | 94 | Compact growth around industrial zones and transport corridors. |
| Karnal | 27.3 | 35.6 | 47.8 | 75% | 11.1 | 88 | Structured expansion with moderate fragmentation; steady urban growth. |
| Ambala | 25.6 | 33.1 | 44.2 | 73% | 10.9 | 83 | Rail-linked compact expansion; stable demographic growth. |
| Rohtak | 22.1 | 29.4 | 38.9 | 76% | 13.5 | 92 | Balanced densification and outward growth; educational hub influence. |
| Hisar | 21.4 | 27.8 | 33.5 | 56% | 9.6 | 71 | Slow, steady expansion; consolidation within existing town limits. |
| Bhiwani | 18.7 | 22.4 | 27.6 | 48% | 8.3 | 64 | Low-density clusters; limited peri-urban transformation. |
| Sirsa | 17.2 | 20.6 | 25.3 | 47% | 7.9 | 60 | Minimal sprawl, stable settlement structure, agriculture-dominated landscape. |

A comparison of temporal imagery indicated that Gurugram experienced the most rapid spatial transformation, with large tracts of agricultural land converted into residential and commercial enclaves. The spatial pattern was predominantly polycentric, with multiple high-density clusters forming around emerging economic zones and transport nodes. In contrast, Faridabad exhibited a mixture of outward expansion and internal densification, reflecting both industrial restructuring and the maturation of older residential sectors. These differences illustrate how local economic drivers shape the morphological expression of sprawl, even among districts with shared regional influences.

More moderate but steadily increasing expansion was observed in Panipat, Karnal and Ambala. The imagery showed compact but continuous outward growth, suggesting structured rather than speculative development. Built-up patches tended to form

contiguous extensions to existing municipal limits, and the fragmentation index was lower than in NCR-adjacent districts. This pattern reflects the role of local manufacturing, agro-processing and market-town functions, which generate consistent but less aggressive spatial expansion. The lower complexity of patch shapes and more coherent edge structures indicate planned or semi-planned urban growth rather than dispersed peri-urban settlements.

In western and southern districts such as Hisar, Bhiwani and Sirsa, the rate of built-up expansion was significantly lower, and the spatial form exhibited greater consolidation of existing settlements rather than the emergence of new urban clusters. Satellite-derived density surfaces showed subtle increases in built-up intensity within established town boundaries but minimal peripheral encroachment. These patterns correlate with slower demographic change and a stronger reliance on agriculture, producing a more stable urban footprint.

Population clustering, derived from built-up density and settlement morphology, revealed additional insights into demographic shifts. High-density population clusters were strongly concentrated in the NCR-linked districts, particularly in Gurugram and Faridabad, where both vertical and horizontal intensification occurred. The densification of peri-urban pockets—once classified as rural in earlier datasets—suggests substantial in-migration driven by labour market opportunities. The spatial arrangement of these clusters reflected a mixture of formal residential development and informal or semi-planned extensions, producing socio-spatial heterogeneity characteristic of transitional urban environments.

In contrast, population clustering in mid-sized towns such as Rohtak or Panipat occurred more predictably along established administrative centres and transport corridors, with clear concentration around railway nodes and industrial estates. The remote-sensing-derived metrics showed a balanced ratio of expansion to densification, indicating controlled urban growth supported by municipal planning frameworks. Meanwhile, districts such as Mahendragarh or Fatehabad exhibited dispersed settlement patterns with low-density clusters and minimal evidence of rapid demographic influx, reinforcing the spatial divide between high-growth NCR peripheries and slower-growing hinterland regions.

Environmental implications of sprawl were also evident in the remote-sensing outputs. Increased impervious surface cover was most pronounced in Gurugram and Faridabad, correlating with documented concerns about groundwater depletion and declining green cover. Landscape metrics indicated higher fragmentation of agricultural land in these districts, supporting previous findings on the ecological pressures associated with unregulated sprawl. Conversely, districts with slower growth exhibited more stable land mosaics, with limited disruption to agricultural continuity.

The analysis also highlighted governance-related spatial outcomes. Areas with strong municipal oversight, such as planned industrial estates or designated urban sectors, exhibited orderly expansion and lower patch fragmentation. In contrast, zones affected by informal subdivisions or ambiguous land ownership showed irregular patch patterns and discontinuous built-up corridors. These governance-linked spatial signatures underscore how institutional capacity shapes the form of urban growth observable in satellite imagery.

The results demonstrate that Haryana's urbanisation is neither uniform nor linear; it is instead a complex mosaic of high-intensity metropolitan sprawl, moderate regional centre

expansion and low-density growth in peripheral districts. The spatial heterogeneity revealed by remote sensing aligns with broader urban transition theories but also highlights the need for region-specific planning strategies. The discussion confirms that remote sensing is an indispensable tool for monitoring multi-scalar urban change, uncovering population dynamics and providing the spatial intelligence required for informed, equitable and sustainable regional development planning.

**Conclusion**

The analysis of regional variations in urban sprawl and population expansion across Haryana reveals a complex and uneven pattern of spatial transformation shaped by proximity to metropolitan influence, economic restructuring and evolving peri-urban dynamics. Remote sensing proved essential for capturing these variations, offering a consistent and spatially detailed account of how built-up areas expanded and how population clusters shifted across districts. The findings underscore that urbanisation in Haryana is not uniform; NCR-adjacent districts such as Gurugram, Faridabad and Sonipat experienced rapid, fragmented and corridor-linked sprawl, whereas interior districts such as Hisar, Bhiwani and Sirsa displayed comparatively modest and more consolidated growth.

The study demonstrates that combining classification techniques with landscape metrics and density-based population proxies provides valuable insight into both the form and intensity of urban growth. The spatial heterogeneity observed across districts highlights the need for differentiated planning strategies that account for distinct developmental pressures, infrastructural capacities and environmental vulnerabilities. By establishing a remote-sensing-based baseline, the research contributes a replicable framework that can support long-term monitoring and evidence-driven decision-making. Ultimately, the findings reinforce the importance of integrating geospatial intelligence into regional planning processes to guide more sustainable, equitable and spatially coherent urban development trajectories across Haryana.

**References**

[1] Bharath, H. A., Chandan, M. C., Vinay, S., & Ramachandra, T. V. (2018). Multi-temporal land use dynamics and urbanisation pattern analysis in Bangalore megacity, India. Journal of Environmental Management, 206, 512–522.

[2] Sati, A. P., & Mohan, M. (2018). The impact of urbanization during half a century on surface meteorology based on WRF model simulations over National Capital Region, India. Theoretical and Applied Climatology, 134(1), 309-323.

[3] Bhatta, B. (2010). Analysis of urban growth and sprawl from remote sensing data. Springer.

[4] Dupont, V. (2007). Conflicting stakes and governance in the peripheries of large Indian metropolises—An introduction. Cities, 24(2), 89–94.

[5] Foody, G. M., & Mathur, A. (2004). A relative evaluation of multiclass image classification by support vector machines. IEEE Transactions on Geoscience and Remote Sensing, 42(6), 1335–1343.

[6] Verma, P., Jangra, R., & Kaushik, S. P. (2014). Geospatial measurement of urban sprawl and land transformation using multi-temporal datasets: A case study of Sonipat-Kundli urban agglomeration. Sustainable Environment, 10(1), 2366556.

[7] Garg, A., Shukla, P. R., Kapshe, M., & Azad, M. (2012). Rapid urbanisation in India: A critical assessment of the environmental impacts. Current Science, 103(7), 776–785.

[8] Herold, M., Scepan, J., & Clarke, K. C. (2005). The use of remote sensing and landscape metrics to describe structures and changes in urban land uses. Environment and Planning A, 33(9), 1443–1458.

[9] Jat, M. K., Garg, P. K., & Khare, D. (2008). Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. International Journal of Applied Earth Observation and Geoinformation, 10(1), 26–43.

[10] Kundu, A. (2006). Trends and processes of urbanisation in India. India Infrastructure Report, 27–46. Oxford University Press.

[11] Kundu, A. (2011). Politics and economics of urban growth. Economic and Political Weekly, 46(20), 10–12.

[12] Myint, S. W., Gober, P., Brazel, A., Grossman-Clarke, S., & Weng, Q. (2011). Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery. Remote Sensing of Environment, 115(5), 1145–1161.

[13] Ravindran, A., & Rao, D. N. (2010). Industrial corridors and regional transformation: A study of NCR towns. Journal of Rural and Industrial Development, 2(1), 45–58.*

[14] Rodell, M., Velicogna, I., & Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. Nature, 460(7258), 999–1002.

[15] Rodriguez-Galiano, V. F., Ghimire, B., Rogan, J., Chica-Olmo, M., & Rigol-Sanchez, J. P. (2012). An assessment of the effectiveness of a random forest classifier for land-cover classification. ISPRS Journal of Photogrammetry and Remote Sensing, 67, 93–104.

[16] Schneider, A., & Woodcock, C. E. (2008). Compact, dispersed, fragmented, extensive? A comparison of urban growth in 25 global cities. Urban Studies, 45(2), 317–332.

[17] Shaw, A. (2005). Peri-urban interface of Indian cities: Growth, governance and local initiatives. Economic and Political Weekly, 40(2), 129–136.

[18] Sivaramakrishnan, K., Kundu, A., & Singh, B. N. (2007). Handbook of urbanisation in India. Oxford University Press.

[19] Sutton, P., Roberts, D., Elvidge, C., & Meij, H. (2001). A comparison of nighttime satellite imagery and population density. Photogrammetric Engineering & Remote Sensing, 67(11), 1303–1312.

[20] Taubenböck, H., Wegmann, M., Roth, A., Mehl, H., & Dech, S. (2014). Urbanisation in India – Spatiotemporal analysis using remote sensing data. Computers, Environment and Urban Systems, 48, 30–40.

[21] Webster, D., & Muller, L. (2002). Challenges of peri-urbanisation in the developing world. Asian Development Bank Working Paper Series, 1–37.