An Integrated Geospatial Framework for Monitoring Built-Up Area Growth in Historic Cities Using Archival Maps and Remote Sensing

Madhavan Sridhar[1*], Om Singh Lilhare[1], Hina Pande[1], Poonam S. Tiwari[1]
[1]Indian Institute of Remote Sensing, Dehradun-248001, Uttarakhand
*Corresponding author e-mail: maddysridhar12345@gmail.com

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Abstract: Indian historic cities serve as cultural anchors and are vital to heritage tourism, yet their unregulated urban expansion has become a major concern. Long-term monitoring of built-up area growth is crucial for informed and sustainable urban governance. However, the absence of satellite data before 1975 limits the ability to track historical urbanization trends. To bridge this temporal data gap and enhance the accuracy of future urban growth predictions, this study develops a semi-automated methodology that integrates georeferenced and vectorised historical maps with remote sensing data. Focusing on the historic cities of Varanasi and Hyderabad, the study reconstructs two centuries of built-up area growth. Varanasi exhibited an average annual built-up growth rate of approximately 3.35%. A discernible north-westward shift in the urban centroid was observed, with buffer analysis around the Kashi Vishwanath Temple indicating intensified urbanization within the 5–10 km and >20 km zones. Hyderabad showed an average annual built-up growth rate of about 3.04%. The city's centroid exhibited a northward drift until 1995, followed by a south-eastward shift, aligning with the growth of the IT corridor and associated infrastructure in that region. Buffer analysis further revealed that urbanization in Hyderabad has been more prominent beyond the 20 km radius, underscoring peripheral expansion driven by economic clustering. This study demonstrates the efficacy of combining historical cartographic archives with satellite imagery for reconstructing long-term urban dynamics. The proposed methodology not only enhances the temporal depth of urban change analysis but also provides actionable insights for planners and policymakers to promote resilient, culturally sensitive urban development strategies.

Keywords: Historic Cities, Historic Paper Maps, Remote Sensing Data, Built-Up Area Expansion, Historic Site Conservation.

1. Introduction

Historic cities are enduring legacies of the past, embodying the cultural, architectural, and social identities of successive civilizations. These cities not only preserve tangible heritage but also serve as dynamic records of urban transformation across centuries (Boussaa and Madandola, 2024). Moreover, they significantly contribute to the national economy through heritage tourism, creative industries, and cultural services, making their preservation not just a cultural imperative but also an economic priority. According to various policy reports, the heritage tourism sector is a major contributor to GDP in countries like India, where historic cities attract millions of visitors annually. However, with rapid urbanization, historic cities face unprecedented pressures. Urban growth often encroaches upon culturally significant sites, leading to the irreversible loss of architectural heritage and eroding the historic character of urban cores (Vaz *et al.*, 2012). Managing urban expansion in such contexts presents a dual challenge: accommodating development while ensuring the conservation of heritage structures. This activity is made worse by a lack of reliable long-term spatial data, which hampers understanding of accumulated historic patterns of urban development and the development of informed planning policy (Dong and Shen, 2023). The absence of a unified policy guide and ineffective means of containing urban sprawl have resulted in haphazard development, inadequate infrastructure, and the destruction of heritage environments (Buenaño *et al.*, 2023).

Within this context, historical maps are valued as important assets. These early cartographic records offer remarkable insights into the spatial configurations of cities in historic time periods, often before the sophisticated documentation era. Although traditionally not utilised in scholarly research, historical urban cartography remarkably depicts the transformation of city landscapes in ways that narrative descriptions cannot accomplish (Lobel, 1968; Churchill, 2004). Collections consisting of these maps, along with corresponding archaeological schematics, allow the reconstruction of the designs of cities and how they changed through time (Laycock *et al.*, 2011). Through the ability of remote sensing in detecting existing land use and city morphology, and historical maps to supply a temporal depth, collectively enabling a broad spatiotemporal investigation into urban area growth analysis. Modern developments in the field of geospatial techniques offer new opportunities to collectively overlay these historical data with modern-day remote sensing data. This integration of georeferenced historical maps and satellite-based settlement data allows the reconstruction of patterns in city development across a broad temporal period, stretching from the historic into the modern and projecting into the future through the use of predictive modeling (Udeaja *et al.*, 2020).

This study addresses the crucial problem of unrestrained development in historic cities, which compromises both sustainable growth and cultural heritage. The study proposes a very reliable way to track more than 200 years of urban growth through the integration of georeferenced archive maps with the latest remote sensing data. Given that the majority of today's satellite data sets start only after the 1970s, leaving out a significant amount of historical data, this broad time frame is crucial. In addition to providing quantitative data on changes in urban patterns and the growth of built-up areas, the method provides a more detailed picture of the role that historic city centers played in the current urban sprawl. In turn, this research offers a unique spatial framework that may guide policy, aid in the preservation of cultural heritage, and guide long-term development planning in regions of great historical and cultural importance.

2. Literature Review

Historically, people have gathered around historic locations, which has fuelled urban expansion. Many case studies have analyzed the spatial development of historic cities and the impact of historic sites on urbanization processes. For instance, some case studies have reviewed new strategies for historic urban sites' regeneration, focusing on areas in Asia and Europe (Pulles *et al.*, 2023; Boussaa and Madandola, 2024). Researchers have reviewed Africa-based urban growth modeling, considering the dynamics, driving mechanisms, and challenges faced (Korah, Koch and Wimberly, 2024). Hassan (2023) proposed a sustainable development scheme of historic city districts, highlighting mobility and the streetscape, and used a case study of Egypt, the city of Alexandria, as a reference example (Hassan *et al.*, 2023). Furthermore, a case study showed the potential application of the space syntax method in revitalizing historic city areas, as part of a strategy aiming at stimulating urban vitality and protecting heritage sites' identity, especially in China, in the city area of Yushan (Lyu *et al.*, 2023).

A multitude of research efforts have concentrated on the analysis and forecasting of urban growth, underscoring the effectiveness of remote sensing in extensive urban investigations. For instance, Wang et al. (2021) utilized built-up area maps generated from a variety of high-resolution satellite datasets to examine urban development through the Transferable Built-up Area Extraction (TBUAE) algorithm (Wang *et al.*, 2021). Furthermore, (Zhang, Kwan and Yang, 2023) evaluated the six most prevalent urban growth models, contrasting their efficacy and validating them against their documentation. (Güneralp *et al.*, 2020) investigated patterns in urban land expansion, density, and transitions on a global scale spanning from 1970 to 2010. (Hussain *et al.*, 2024) forecasted urban growth and the effects of climate change in the Multan district of Pakistan employing the CA-Markov method. In addition, sophisticated machine learning methodologies have been implemented to analyze the urban growth of five historical Greek cities utilizing an artificial neural network (ANN) model, with projections extending to urban growth by the year 2030 (Tsagkis, Bakogiannis and Nikitas, 2023).

However, there are limited studies that utilize historic maps for urban growth analysis. This lack can be attributed to a variety of aspects, viz., the availability of accurate maps with clearly demarcated urban areas, differences in scale, and issues with the faithfulness of cartographic depictions. Despite these challenges, a few researchers made use of paper maps in different applications. For instance, studies have utilized the historical paper maps in determining and assuring the positional accuracy of historical landscapes (Frajer and Geletič, 2011). Studies like (Schulten, 2021) explored the development of cartography in the United States in order to recognize the value of paper maps. Recognizing their value, these maps are now globally obtainable via online resources such as Old Maps Online (Southall and Přidal, 2012). Studies like (Fuchs *et al.*, 2015) showed the added value in model-based reconstructions of the historical land use and land cover (LULC) in Central Europe, with a potential history dating as old as 1900. These efforts highlight the potential of historical maps in the understanding of the development of urban growth and changes in historical landscapes.

Studies on combining historical maps with remote sensing data are sparse; some case studies show how beneficial and promising they are for improving analytical procedures in urban settings. (Orabi, 2024), for instance, presented an analog-digital workflow that utilizes high-resolution orthomosaics and digitized historical maps in observing Aleppo's urban transformations. An investigation in Nanjing combined Landsat images with historical maps in estimating spatial growth and development patterns of traditional forms in the city (Bai and Xu, 2023). Another study used remote sensing data on settlements and geo-referenced historical maps to map city boundaries on four continents in the early 20th century. The results were compared to the HISDAC-US and HYDE datasets (Uhl *et al.*, 2021). A team of researchers used satellite data, monochromatic aerial photos, and historical cadastral maps to map LULC changes in Bursa, Turkey, between 1858 and 2020 (Ettehadi Osgouei, Sertel and Kabadayı, 2022). These studies highlight how historical and remote sensing data can be combined to conduct research on urban areas, but better methodologies are still required. By developing a new, integrated workflow for examining long-term development in historic cities, this study aims to close that gap.

3. Methodology

Historical maps serve as a vital resource in the reconstruction of urbanization spanning long periods and allow the identification of urban centre space transformations and the effect of heritage monuments on the expansion of cities. However, the historical maps often present distortions and inconsistencies in scale, projection, and level of detail such that using them in the wrong state may compromise spatial accuracy. To correct such disadvantages, the georectification process was used to bring historical cartographic maps into alignment with the contemporary geospatial data sets, such that cartographic errors are eliminated.

In order to provide reliable georeferencing, lasting cultural landmarks such as temples, churches, and forts that continue to be evident in the modern landscape provide Ground Control Points (GCPs). The reference features helped to obtain spatial alignment among historical cartographic evidence and remote sensing data, and thus enabled accurate spatial correspondence independent of change in topography or landform (Laycock *et al.*, 2011). One challenge presented in the processing of historical maps derives from textual markings (e.g., place names), which often complicate automated feature extraction. To compensate for such a challenge, object-based image analysis (OBIA) methodology was used, such that urban areas and textual elements were differentiated by means of segmentation depending on color, texture, and shape. The complete data pre-processing and extraction workflow is summarized in Figure 1.

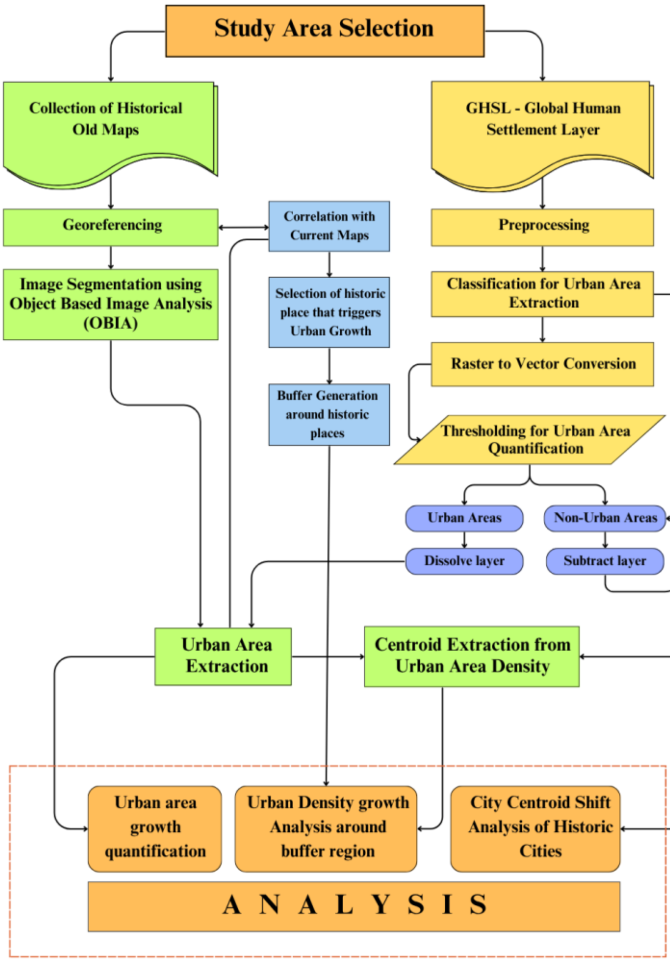


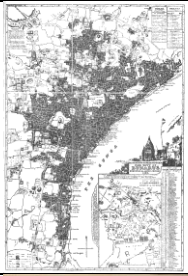
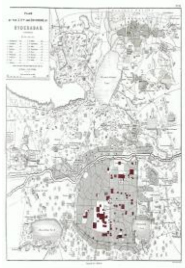
Figure 1. Project Methodology Workflow

3.1 Study Area and Dataset

This study focuses on two prominent historic cities in India. Varanasi in Uttar Pradesh and Hyderabad in Telangana. Varanasi, regarded as one of the world's oldest continuously inhabited cities, has documented settlements dating back to around 1000 BCE (Singh, 2018). Hyderabad, known for its rich cultural heritage and historical significance, has evolved into a major urban centre while retaining remnants of its royal past. Both cities exemplify the dual pressures of heritage preservation and rapid urbanization. These sites were selected for their relevance in understanding the spatial dynamics of urban expansion in historically significant urban cores. Figure 2 illustrates the selected study areas made from the Indian boundary layer taken from the Survey of India Portal (Product code: OVSF/1M/7) (*Survey of India: Online Maps Portal*), which serve as critical case studies for evaluating the challenges and opportunities of managing built-up growth while safeguarding cultural heritage.

The collection of historical archival maps posed significant challenges due to the absence of a centralized or universal repository. To address this, maps were sourced from a wide range of verified materials, including academic publications, ancillary documents, historical texts, and archival repositories. One major challenge faced was the identification of maps that had clearly defined urban areas and a suitable scale, since many available maps lacked the requisite level of detail or positional accuracy and were thus not used. However, in spite of such constraints, suitable archival maps were located for both Hyderabad and Varanasi. The maps, selected for clarity and positional accuracy in cartography, form the necessary foundation for the analysis of long-term urban development in the selected historic cities. A detailed overview of the historical paper maps used in this study is presented in Table 1.

Table 1. Historical Maps Used in the Study

City	Reference Year	Creator	Map Scale	Print Colors	Urban Built-Up Area Depiction	Source	Preview
Varanasi	1822	James Prinsep	8 inches to a mile	2	Dark black tone	Prinsep, James 1825, Views and Illustrations of Benares. London	
Varanasi	1911	John Murray (Firm)	Scale of one mile	4	Red color tone	Image from page 186 of "A handbook for travellers in India, Burma, and Ceylon ." (1911)	
Hyderabad	1854	J. & C. Walker; Pharoah and Co. Madras	2000 feet to an inch	3	Gray and dark brown tone (nobility residential)	An atlas of the southern part of India : including plans of all the principal towns and cantonments, reduced from the Grand trigonometrical survey of India showing also the Tenasserim Province	
Hyderabad	1914	Published by Verlag von Karl Baedeker in Leipzig, 1914	1:150,000	3	Red tone	http://www.lib.utexas.edu/maps/historical/baedeker_indien_1914/txu-pclmaps-hyderabad_1914.jpg	

1

The current study has derived built-up area data from the Global Human Settlement Layer (GHSL) dataset, which was created by the Joint Research Centre (JRC) of the European Commission using remote sensing data (Melchiorri and Kemper, 2023). At 5-year intervals, the GHS-BUILT-S spatial raster dataset charts the prevalence of built-up surfaces from 1975 to 2030. The information is derived from the spatial–temporal interpolation of the five sets of multi–sensor, multi–platform satellite image collections that were observed. The data for the epochs 1975, 1990, 2000, and 2014 are supplemented by Landsat's (MSS, TM sensor) and (ETM sensor) data, whereas the epoch 2018 is supplemented by a Sentinel-2 (S2) (GHS-composite-S2 R2020A) image composite (Pesaresi, Martino; Politis, 2023). GHSL thematically mapped layers are extensively used for urbanization-related matters, disaster risk reduction, and sustainable development at different geographic scales. The dataset offers a good linkage to satellite images and offers the best option for the analysis of urban growth since 1975. The South Asia region-specific values for the measures precision and recall and the overall accuracy for this data are said to be 90.3%, 91.76%, and 90.8%, respectively (Pesaresi, Martino; Politis, 2023). This offers the dataset good credibility for the assessment of urban areas.

In this study, GHSL data for the years 1975, 1995, and 2025 are being used for Varanasi and Hyderabad. A detailed description of this data is presented in Table 2. This integrated approach not only enhances the understanding of past built-up area growth but is also useful in predicting future built-up growth, aiding in urban planning and heritage conservation efforts. The collected maps form the cornerstone of this research, bridging the gap between historical cartographic records and contemporary geospatial analysis.

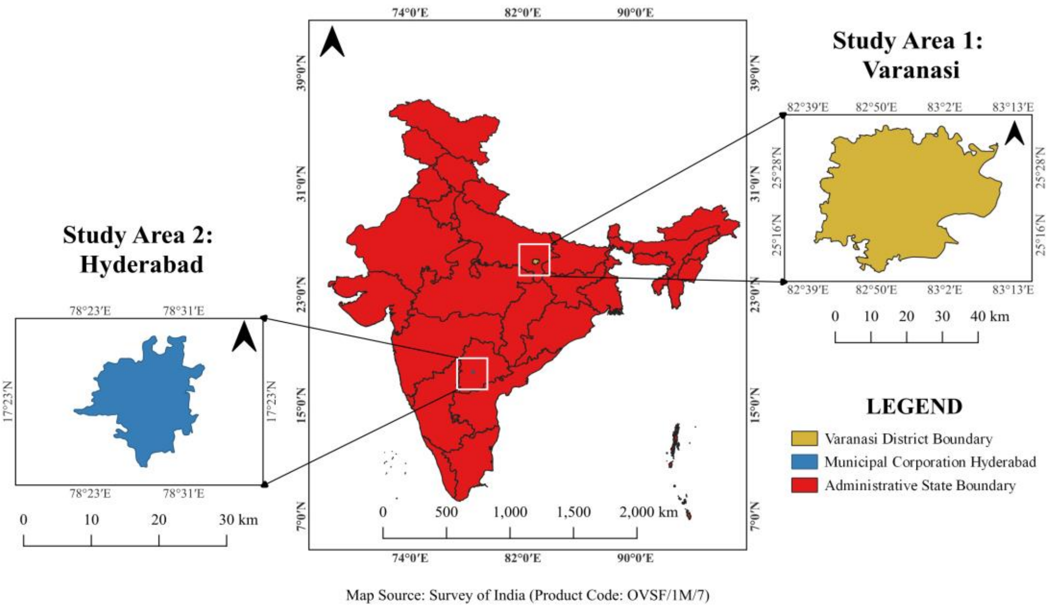


Figure 2. Study Area Map

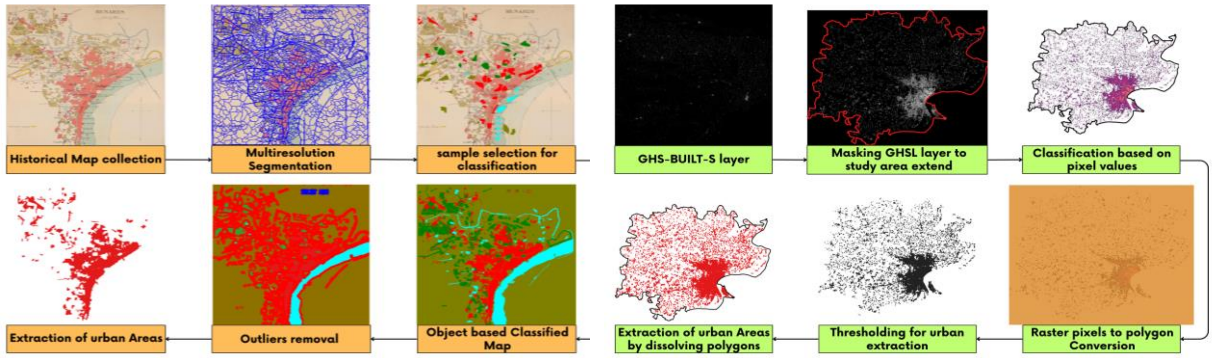
Table 2. Remote Sensing Data Used in the Study

City	Tile ID	Coordinate System	Resolution	Epoch	Product	Source
Varanasi	R7_C27	WGS84	3arc seconds	1975, 1995, 2025	GHS-BUILT-S	https://human-settlement.emergency.copernicus.eu/download.php (Melchiorri and Kemper, 2023)
Hyderabad	R8_C26					

3.2 Data Pre-processing

To extract urban areas from these maps, a multiresolution segmentation approach was implemented. This method, preferred over traditional pixel-based classification, enabled segmentation based on spectral characteristics such as color, tone, and texture. Key parameters, including scale, shape, and compactness, were optimized iteratively through a trial-and-error process to yield the most accurate segmentation. Post-segmentation, object-level classification was performed by assigning training samples through visual interpretation. A notable challenge involved the segmentation of textual map elements like city names in map, which were not representative of urban features. These were manually reviewed, and underlying land features were used to assign appropriate training classes. Supervised classification was performed, and the resulting outputs were validated by comparing them with the original reference maps to assess classification accuracy. The final classified urban objects were exported with attribute labels and further processed. In this stage, non-urban elements such as map scales, legends, annotations, and inset maps were removed. Urban polygons were then dissolved into a unified class layer. This process was applied uniformly across all collected historical maps to ensure consistency in urban area extraction.

For the delineation of contemporary built-up extents, the GHS-BUILT-S dataset was utilized. GHSL raster tiles for the years 1975, 1990, and 2025 corresponding to the study areas were extracted and spatially subset using the administrative boundaries of the respective cities. A classification threshold was applied to the raster data, wherein pixels with digital number (DN) values exceeding a predefined threshold were categorized as built-up, and those below were classified as non-built-up. The resulting binary raster was subsequently converted to vector format to facilitate spatial analysis. Non-urban features (polygons with DN values below the threshold) were excluded, and the remaining urban polygons were dissolved to produce a generalized built-up footprint for each time epoch. The complete workflow for urban extent extraction from both historical maps and remote sensing data is illustrated in Figure 3.



(a) (b)

Figure 3. Extraction of Built-Up Areas: (a) From GHSL, (b) From Historical Maps

3.3 Data Processing and Analysis

The built-up areas extracted from historical maps and GHSL data were used to compute the centroids of urban extents for each time period. A centroid algorithm was applied to the dissolved urban polygons, generating a point layer representing the geometric centres of urban expansion. These centroid points were stored separately and analysed to assess spatial shifts in the urban core over time.

In the case of Varanasi, urban expansion was studied in relation to key cultural and religious landmarks, particularly the Kashi Vishwanath Temple, a historical nucleus of the city. Buffer zones were generated at 5 km, 10 km, and 20 km radii from the temple. These buffers were clipped to the Varanasi district boundary to maintain geographical consistency. Urban areas within each buffer ring (0–5 km, 5–10 km, 10–20 km, and 20 km to the district boundary) were extracted to examine the spatial and temporal patterns of urban growth outward from the heritage core.

In Hyderabad, the Charminar monument was selected as the focal point due to its cultural significance and centrality in the city's historical development. Unlike Varanasi, buffer zones at 5 km, 10 km, and 20 km radii were analysed without clipping to district boundaries, in order to capture the full extent of Hyderabad's more dispersed and radial urban sprawl. Urban features within each buffer zone were analysed to identify growth gradients and prioritize regions for infrastructure development and heritage conservation. This buffer-based growth analysis offers actionable insights for informed governance, urban planning, and cultural heritage protection.

4. Results & Discussions

4.1 Georeferencing and Map Correlation Validation

The correlation between the historical maps and the remote sensing layer was validated for Varanasi and Hyderabad using Google Earth Pro. This involved marking five iconic locations in each study area, corresponding to snapshots shown in Figure 4 for Varanasi. For Varanasi, three maps were used: an 1822 map from the 19th century, a 1911 map from the 20th century, and the Google Earth layer. Five iconic spots were selected and annotated from 1 to 5: 1 – Kashi Temple, 2 – Beniya Park, 3 – Company Garden, 4 – Varana River, and 5 – Railway Line. This process ensured a comprehensive and accurate correlation across different time periods, enhancing the reliability of the study's findings.

1

(a) (b) (c)

Figure 4. Correlation of Land Features in Varanasi Over 2 Centuries; (a) 1822 Map, (b) 1911 Map, (c) Google Layer

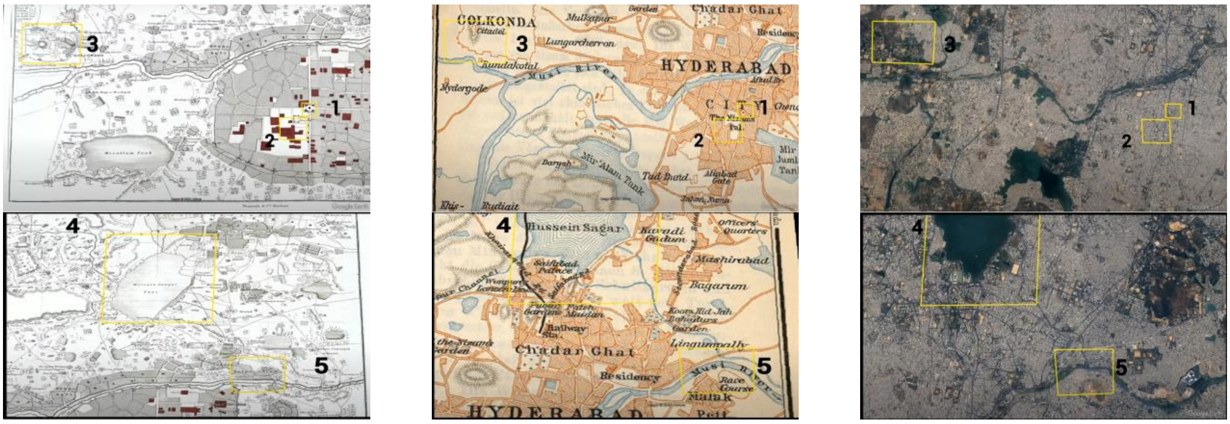
2

Figure 5 illustrates the Hyderabad correlation between historical paper maps and the current remote sensing layer, marking five iconic locations: 1 – Charminar, 2 – Chowmahalla Palace, 3 – Golconda Fort, 4 – Hussain Sagar Lake, and 5 – Musi River. These landmarks were then used to verify the correspondence of the maps for the years 1854 and 1914, and the overlay by Google Earth. The analysis revealed a perfect correlation and thus verified the accuracy of the maps in urban layer extraction and facilitating subsequent analysis.

4.2 Built-Up Area Growth Analysis

Significant spatial dynamics in the growth of Varanasi's urban footprint over various historical eras are revealed by the analysis. Figure 6 shows the built-up area measurements obtained from vector layers that depict Varanasi's urban boundaries for the years 1822, 1911, 1975, 1995, and 2025. Two centuries of change are depicted in Figure 7, which compares the trends in urban growth during these times. The data emphasizes the city's notable spatial and structural evolution over time, highlighting a notable increase in urbanization.

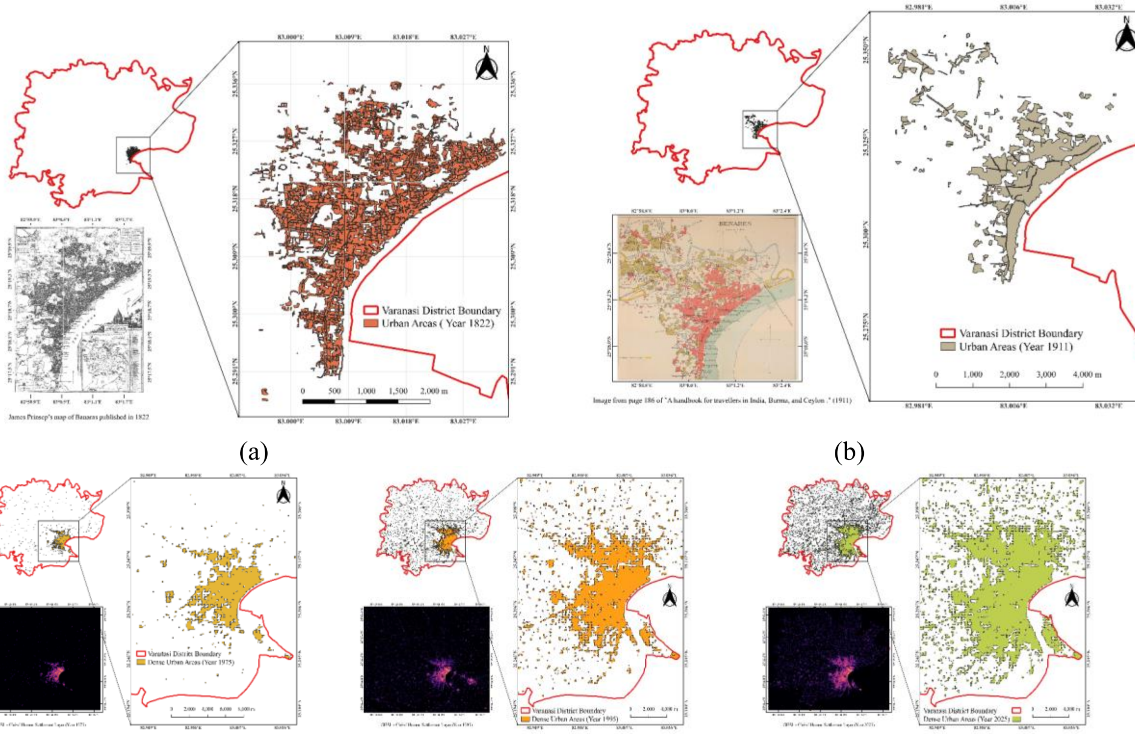
Varanasi's built-up area increased at a moderate rate of 53.24%, from 4.02 sq. km in 1822 to 6.15 sq. km in 1911. This stage mirrored the British colonial era, when the urban core was progressively shaped by early infrastructure advancements, administrative reorganizations, and demographic changes.



(a) (b) (c)

Figure 5. Correlation of Land Features in Hyderabad Over 2 Centuries; (a) 1854 Map, (b) 1914 Map, (c) Google Layer

1



(a) (b)

(c) (d) (e)

Figure 6. Delineated Urban Extents Across Different Years in Varanasi: (a) 1822, (b) 1911, (c) 1975, (d) 1995, (e) 2025

1

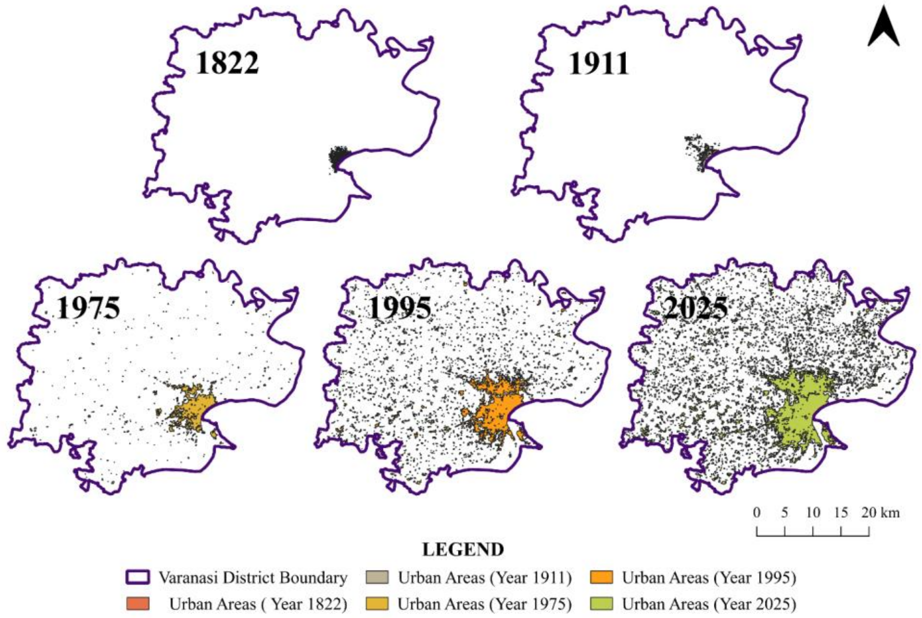


Figure 7. Comparison of Built-Up Area Expansion in Varanasi Over Time

2

Between 1911 and 1975, Varanasi's built-up area expanded significantly from 6.15 sq. km to 43.26 sq. km, a striking growth rate of 603.66%. This period was marked by the establishment of Banaras Hindu University (1916), one of Asia's largest residential universities, which acted as a key institutional catalyst. Additionally, the development of rail and road infrastructure, civic amenities, and administrative integration post-independence contributed to Varanasi's emergence as a cultural and educational hub. From 1975 to 1995, urban expansion accelerated further, reaching 123.61 sq. km with a growth rate of 185.89%, driven by urban sprawl, heritage tourism development, and service sector growth, particularly in trade, education, and healthcare. During this period, Varanasi's strategic location along the Ganges and increasing religious tourism amplified demand for urban infrastructure and real estate development. This area growth is illustrated graphically in Figure 8.

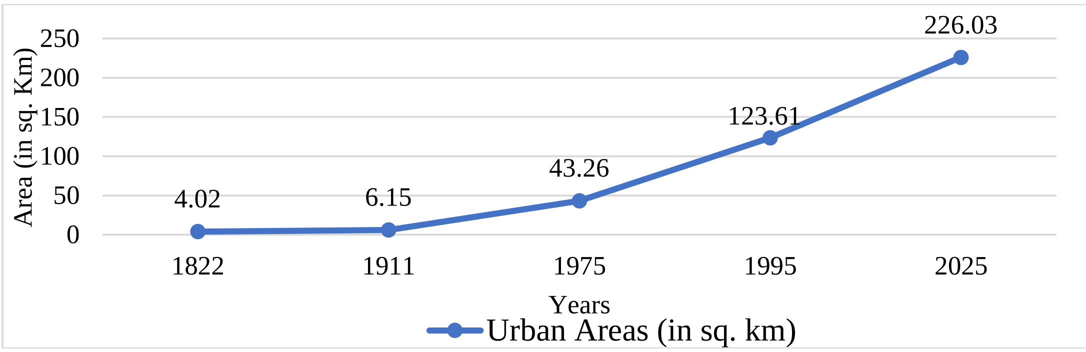
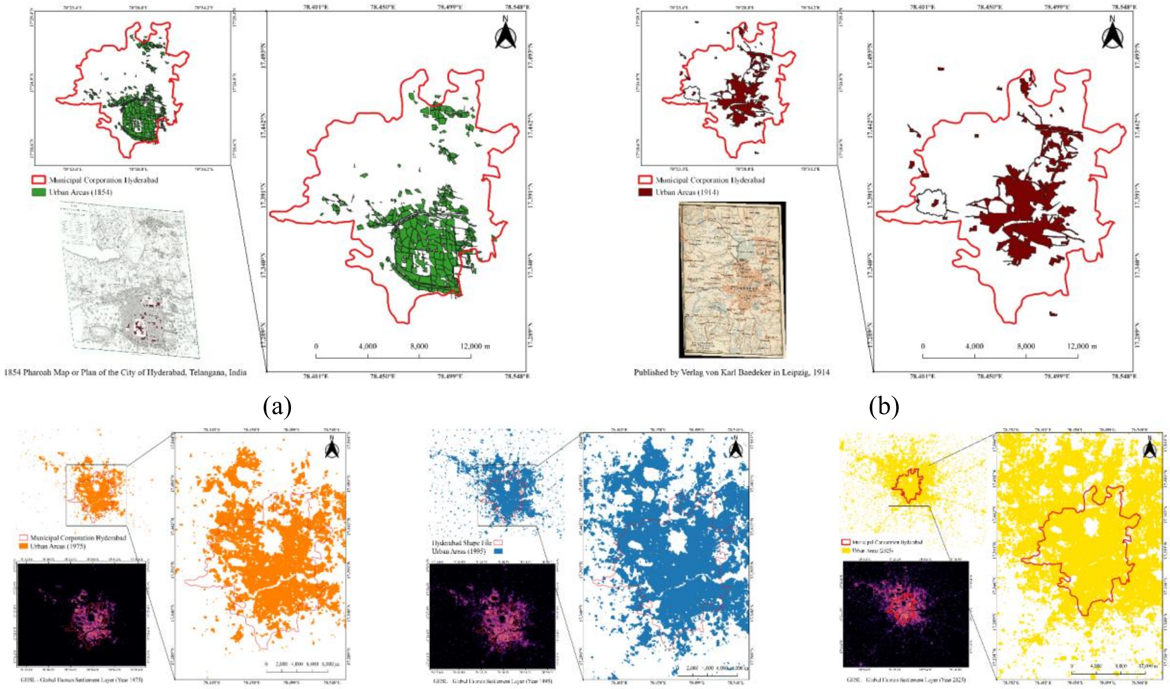


Figure 8. Built-Up Area Growth in Varanasi Over Time

The urban expansion of Hyderabad, as illustrated in Figures 9, 10, and 11, reveals distinct phases of growth driven by a combination of environmental, institutional, and technological factors. Between 1854 and 1914, the city exhibited a negligible decline in built-up area (-1.80%), largely attributed to stagnated development under princely rule and the devastating Musi River Flood of 1908 (Sultana and Sultana, 2021), which disrupted infrastructure and settlement patterns. From 1914 to 1975, Hyderabad experienced a sharp urban expansion (457.10%), catalysed by post-integration reforms, the establishment of major institutions like Osmania University, and the growth of public sector industries and administrative centres. The formation of Hyderabad Urban Development Authority (HUDA 1975) marked a new era of structured urban planning, and between 1975 and 1995, the city's footprint grew by 88.98%, reflecting infrastructural investments and economic diversification into pharmaceuticals, defence, and education. The period from 1995 to 2025 saw exponential growth (~156.70%), driven by the rise of the IT and software industry, the development of HITEC City, and the expansion of transport networks, including the Outer Ring Road (ORR), Hyderabad Metro, and MMTS. This phase reflects Hyderabad's evolution into a global technology and service hub, characterized by polycentric urban growth, expansion of suburban nodes, and dynamic shifts in land use patterns to accommodate commercial, residential, and industrial demands.



(a) (b)

(c) (d) (e)

Figure 9. Delineated Urban Extents Across Different Years in Hyderabad: (a) 1854, (b) 1914, (c) 1975, (d) 1995, (e) 2025

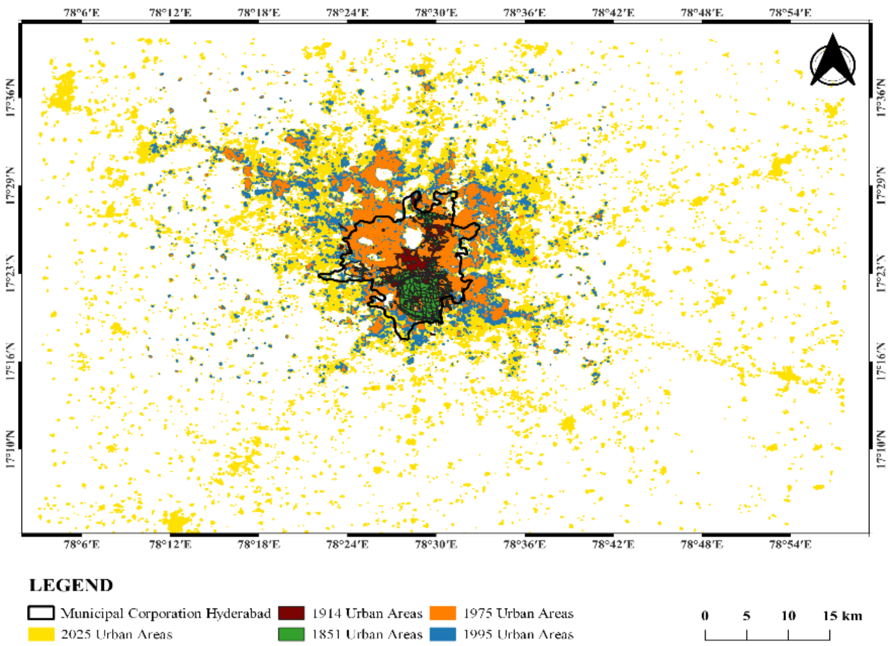


Figure 10. Comparison of Built-Up Area Expansion in Hyderabad Over Time

1

The comparative analysis of urban expansion in Varanasi and Hyderabad reveals two divergent yet instructive trajectories shaped by their unique historical legacies, institutional frameworks, and policy environments. Varanasi's spatial growth reflects a layered and organic transformation from a sacred religious city into a multidimensional urban hub, driven by education-led development (notably the establishment of Banaras Hindu University), the resilience of trade and cottage industries such as weaving and crafts, and the post-liberalization thrust toward modernization through programs like the Smart Cities Mission. The growth was further amplified through better-connected transport networks and ongoing rural-urban migration. On the other hand, the urban development in Hyderabad proceeded along a more systematic and state-directed trajectory, growing from a princely capital to an institutional centre, and later metamorphosing to a global technology-oriented metropolis. Its physical reorganization revolved around major institutional nodes (e.g., Osmania University, public sector units), aided by urban planning organizations such as HUDA and GHMC, and spurred on by infrastructure-driven developments such as HITEC City. The years after the 1990s marked Hyderabad's rapid ascendancy as a leader in the IT and service industry domains, and the urban landscape expanded through policy-facilitated investments and upgrades in strategic connection. While Varanasi exemplifies a continuity of historical and cultural urbanism, Hyderabad stands as a model of contemporary, state-supported smart urbanism, highlighting how different development paradigms can shape distinct urban morphologies in Indian historic cities.

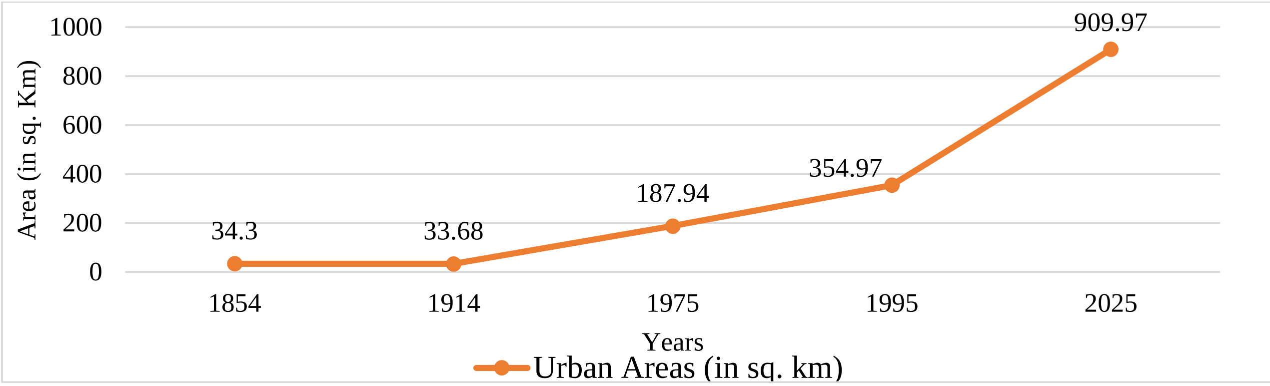
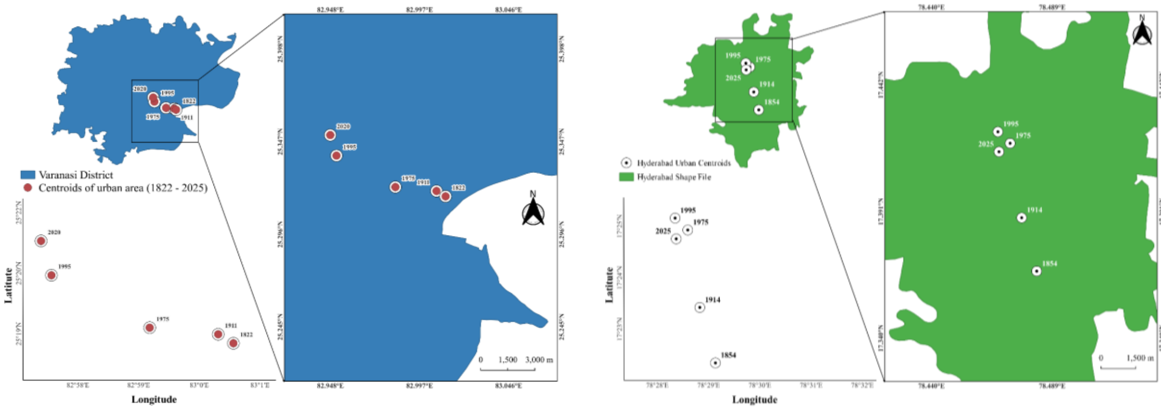


Figure 11. Built-Up Area Growth in Hyderabad Over Time

4.3 Shift in Historic City Centroid

The city centroid shift analysis, derived from the urban area data of different years, reveals distinct patterns in Varanasi and Hyderabad over a span of 200 years. In Varanasi, the centroid has consistently shifted towards the northwest. From 1822 to 2025, there is a noticeable northward and westward trend in the centroid movement. It suggests there is urban growth in all directions, predominantly stemming from increased population, investment in facilities, and perhaps the growth of major cities. Figure 12(a) shows the sequential centroids for 1822, 1911, 1975, 1995, and 2025, all of which have a north-western shift. Hyderabad, on the other hand, seems to have a more intricate structure to the shifts of the centroids. Up until 1995, the centroids exhibited a northward movement with a slight bias towards the west. In contrast, by 2025, there is a notable shift of the centroid towards the southeast relative to its position in 1995. This alteration is indicative of Hyderabad's significant urban expansion, which has increasingly become more dispersed and less oriented over time. The movement of the centroid suggests that urban growth is taking place throughout the city rather than being confined to a particular direction, thereby implying extensive development and the assimilation of formerly peripheral areas into the urban core. Figure 12(b) illustrates these shifts in centroids for Hyderabad, clearly depicting their trajectories and offering valuable insights into the dynamics of urban growth.



(a) (b)

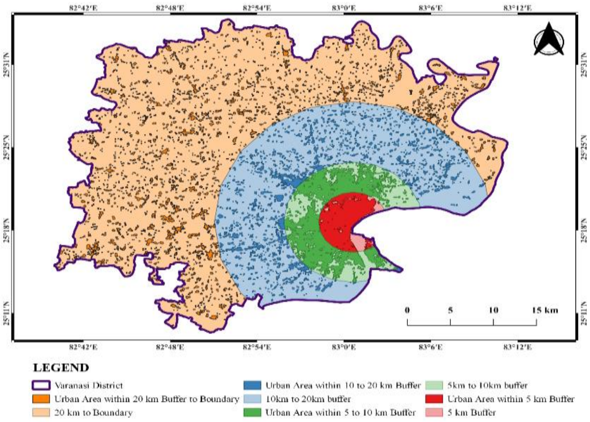
Figure 12. Historic Cities Centroid Shift Map; (a) Varanasi from 1822 to 2025, (b) Hyderabad from 1854 to 2025

Analysis of the shift in centroids plays a vital role in governance and urban planning since it enables urban development orientation trends to be identified. The understanding enables the support for decision-making on the development of infrastructure, distribution of resources, and sustainable urban management. The north-westward shift in the Varanasi case identifies regions in need of improved urban infrastructure and services. Hyderabad's varied development pattern calls for thorough urban planning to guarantee that all expanding areas receive enough support. A crucial tool for planners, centroid shift in urban settings enables them to examine both the historical and anticipated growth of cities. The creation of strategic plans for urban expansion is then made possible by this information, allowing cities to effectively and sustainably accommodate future growth. Additionally, planners can better anticipate the needs of expanding populations, plan for sustainable development, and maintain the historic and distinctive features of older cities.

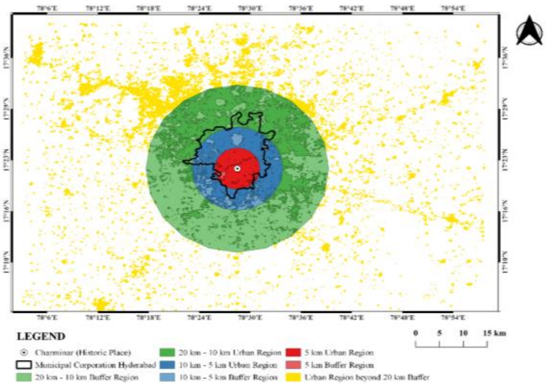
4.4 Built-Up Area Growth Analysis Around Selected Historic Site

To analyze urbanization around study sites, 5 km, 10 km, and 20 km buffer zones were set around Kashi Temple at Varanasi and Charminar at Hyderabad. The purpose of the buffer zones, which are coloured differently in Figures 13(a) and 13(b), is to support analysis and encourage clarity so that an analysis of an urban area can be conducted. To examine urban growth in such densely populated areas, areas inside each buffer zone were carefully clipped. Frameworks for strategic planning are heavily influenced by the dynamics of urbanization in the buffer zones. In order to guarantee that the required urban policies are incorporated to promote sustainable and balanced urban growth, they are helpful in predicting urban sprawl in the upcoming years and in directing urban planning frameworks.

The examination of urban development in proximity to the Kashi Temple in Varanasi shows notable patterns and trends over time.



(a)



(b)

Figure 13. Buffer Around Historic Hotspot: (a) For Varanasi Around Kashi Temple, (b) For Hyderabad Around Charminar

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Initially, in 1822, urban expansion was restricted to a radius of 5 km surrounding the temple, signifying minimal growth. By the year 1911, the spread of urbanization began to reach the 5 to 10 km range; however, no urban environments were detected beyond the 10 km boundary. This period represented the commencement of a consistent expansion. A pronounced increase in urban growth transpired between 1911 and 1975, with urban areas swiftly disseminating beyond the 5 km threshold and encroaching into the 10 to 20 km and even the 20 km to boundary regions. This acceleration underscores a phase of significant urban development, propelled by an array of socio-economic influences. Growth within the 5 km radius persisted throughout this timeframe, but at a reduced pace in comparison to the outer buffers, presumably due to the saturation of available land.

Between 1975 and 1995, there was a notable change in growth dynamics. The rate of urban development within the 0 to 5 km buffer considerably diminished, implying that this zone had reached its limits for further urbanization. Conversely, robust urban growth was observed in the 5 to 10 km and 10 to 20 km buffers, signifying a shift in emphasis towards the development of the periphery surrounding the original urban center. Supporting this observation are the facts between the years 1995 and 2025, which indicate that despite negligible growth within the 0 to 5 km buffers, almost all of the buffers beyond these boundaries continued to expand almost with no restraint. The noticeable growth within the 5 to 10 km and 10 to 20 km buffers makes it clear that the government has a responsibility and a focus to fulfil when it comes to extending and improving the areas of infrastructure and associated services within these high-growth regions. Improving the facilities and infrastructure within these areas will also foster urban growth in a sustainable manner and improve the overall living standards of the people. These findings are detailed in Table 3, which quantifies the urban area growth around the Kashi Temple across different buffer zones over the years. The data is also graphically represented in Figure 14(a), providing a clear visual depiction of the urban expansion trends.

Table 3. Built-Up Area Growth Around Kashi Temple Buffer

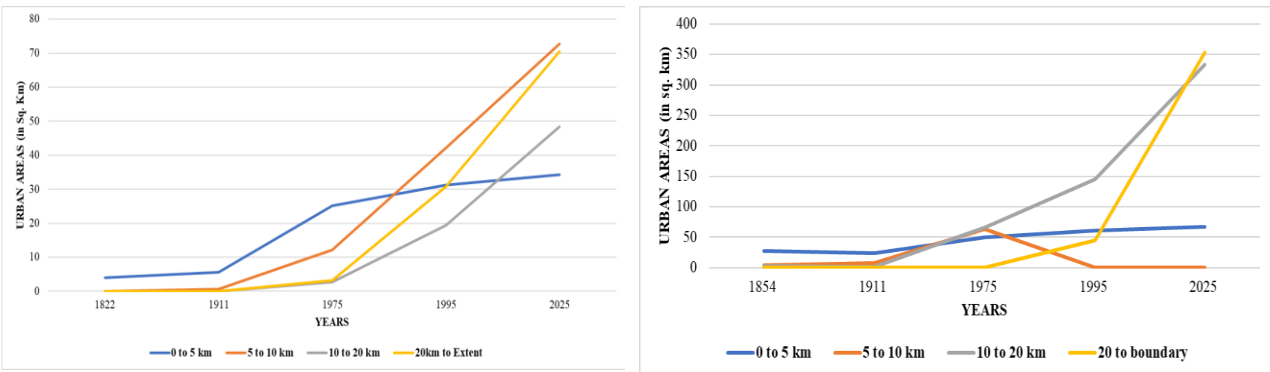
Year	Built-Up Areas around the buffer Varanasi (in sq. km)			
	0 to 5 km	5 to 10 km	10 to 20 km	20 km to Boundary
1822	4.02	0	0	0
1911	5.59	0.56	0	0
1975	25.15	12.12	2.72	3.26
1995	31.3	42.09	19.39	30.77
2025	34.26	72.72	48.42	70.53

The urban area around the Charminar in Hyderabad was analysed using buffer zones of 5 km, 10 km, and 20 km, revealing a distinct pattern of urban expansion compared to Varanasi. The urban landscape in Hyderabad appears to have been well-established even in the 19th century. In 1822, the area within a 5 km radius of Charminar encompassed 28.24 sq. km of urban land, with an additional 6.05 sq. km of urban area within the 5 to 20 km range. However, there was no urban extent beyond the 20 km buffer at that time. A notable decrease in the urban area within the 5 km buffer occurred by 1911, shrinking from 28.24 sq. km to 24.53 sq. km. This reduction is largely attributed to the catastrophic Musi River flood of 1908, which devastated Hyderabad, causing extensive loss of life and property. Despite this setback, urban growth continued in the 5 to 10 km buffer during the same period. Between 1911 and 1975, Hyderabad experienced significant urbanization, likely driven by industrialization. This period saw substantial development within the 5 to 20 km buffer zones, with urban areas extending beyond the 20 km mark, increasing to 9.62 sq. km from previously non-existent urban regions. The trend of rapid urban growth persisted from 1975 to 1995, with a notable expansion in areas beyond 20 km, which grew from 9.62 sq. km to 44.6 sq. km. During this period, substantial urban development was also observed in the 5 to 20 km buffers.

From 1995 to 2025, the urban growth within the 5 km buffer appears to have reached a saturation point, with only a modest increase compared to previous years. However, significant growth continued in the 10 to 20 km and beyond 20 km buffers. The urban area beyond the 20 km buffer saw a dramatic increase from 44.6 sq. km to 352.74 sq. km, indicating extensive suburbanization and outward expansion of the city. This comprehensive analysis underscores the dynamic and multifaceted nature of urban growth around historic sites in Hyderabad. The findings, detailed in Table 4 and graphically represented in Figure 14(b), provide valuable insights for urban planners and policymakers, highlighting areas that require focused development efforts and infrastructure improvements.

Table 4. Built-Up Area Growth Around Charminar Buffer

Year	Built-Up Area around the buffer Hyderabad (in sq. km)			
	0 to 5 km	5 to 10 km	10 to 20 km	20 km to Extent
1854	28.24	3.66	2.39	0
1911	24.53	7.59	1.55	0
1975	49.51	63.1	65.68	9.62
1995	61.17	104.21	144.97	44.6
2025	67.33	156.94	332.94	352.74



(a) (b)

Figure 14. Built-Up Area Growth Analysis Around Generated Buffer of Historic Cities: (a) Varanasi, (b) Hyderabad

This detailed analysis provides crucial insights for prioritizing governmental development efforts and optimizing resource allocation. Comprehending the urbanization dynamics in the context of famous historical monuments helps urban planners to approach infrastructural requirements methodically and sustain urban development. The perspective underscores the necessity for well-informed decision-making to sustain the protection of the cultural and historical heritage while managing urban expansion efficiently in the future. The perspective emphasizes the need for intentional planning and development initiatives as well as the dynamic character of urban development.

5. Conclusions

The significance of such approaches for comprehending long-term urban growth patterns is highlighted by this thorough examination of urban growth in Varanasi and Hyderabad, which integrates historical maps and remote sensing data. The study offers important insights for sustainable urban planning practices by exposing notable spatial dynamics and measurable changes in urban areas over the previous 200 years.

High-accuracy correlation between satellite imagery and 200-year-old maps was obtained in Varanasi and Hyderabad, offering a solid basis for additional research. Different growth patterns were revealed by extracting and quantifying urban areas using a special multiresolution segmentation technique. In Varanasi, the urban area expanded from 4.02 sq. km in 1822 to 226.03 sq. km in 2025, with significant growth rates of approximately 53.24% from 1822 to 1911, 603.66% from 1911 to 1975, 185.89% from 1975 to 1995, and 82.75% from 1995 to 2025. Additionally, a consistent northwest shift of the city centroid was observed. Analysis of buffer zones around Kashi Temple indicated rapid urbanization within a 5 to 10 km radius and beyond 20 km. Similarly, in Hyderabad, the urban area grew from 34.30 sq. km in 1854 to 909.97 sq. km in 2025, with an average annual growth rate of about 3.04%. The city's centroid shifted northwards until 1995, then moved southeast from 1995 to 2025, indicating rapid urban growth in that direction. Urbanization was faster outside a 20 km radius than it was inside, according to buffer analysis. These results demonstrate how both cities' urban growth is dynamic and emphasize how crucial it is to combine remote sensing data with historical maps in order to conduct a thorough urban analysis. This method offers important new information for advancing sustainable urban planning and development.

Future research could include more comprehensive evaluations by adding more variables like geographic conditions, population data, road networks, and terrain slope. Future urban growth forecasting may be more accurate with the creation of predictive models that use high-resolution imagery and long-term datasets. By expanding the parameters of future research studies, urban planners and policy makers are able to develop a more robust framework for sustainable urban development and ensure that historical cities not only prosper but also retain beneficial cultural heritage.

Declaration

Authors declare that the content of this manuscript has not been generated by AI tools. AI tools such as ChatGPT were used only to assist in paraphrasing the original content to improve the clarity and coherence of the writing. All paraphrased content has been thoroughly verified and reviewed by the authors to ensure originality.

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