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"Quantifying Delhi's Sprawl Signature: A Geospatial analysis of Peri-Urban Morphogenesis (1980-2024)"

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Abstract

Cities have been spreading apart due to the recent decades' fast urbanization and population expansion. This study examines the spatiotemporal dynamics of the urbanization process in Delhi, the capital city of India, which is separated into nine districts, utilizing remote sensing and spatial metrics (Jain, Dimri, & Niyogi, 2016). Based on unprocessed satellite imagery, the urban patterns, and procedures within the city's nine administrative districts have been identified considering. Calculations have been made for area, population, patch, edge, and form metrics as well as Shannon's entropy and Pearson's chi statistics. The city is home to three different kinds of urban patterns: 1) The districts that are most extensively distributed are West, North, East, and North East; 2) North West, South, and South West are moderately dispersed; and 3) Central and New Delhi are the least widely distributed. For the districts and time periods, relative entropy which adjusts Shannon's entropy values from 0 to 1—is computed. Its values from 1977 to 1993, 1993 to 2006, and 2006 to 2014 are, respectively, 0.80, 0.92, and 0.50, showing a significant degree of urban sprawl (Jain, Dimri, & Niyogi, 2016). In addition, this study examines and makes an attempt to quantify how urban sprawl has changed land use and land cover over a five-decade period (1972–2014) in India's central national capital region (CNCR).

In order to ascertain the patterns of urban growth and changes in land use and land cover in Delhi between 1989 and 2014, satellite-based LULC maps were created and examined. Afterwards, in order to calibrate the model and forecast the future extent of built-up areas, the primary elements leading to urban growth were analyzed. To get the best outcomes, much consideration was paid to model calibration. Our study illustrates the dynamics of change in the urban environment of Delhi, India. The pattern of structural change is most prominently

characterized by the establishment of new towns and the distribution and density of population between the spread and the core. However, it is debatable whether or not it is useful to designate villages as census towns for the purpose of include them in the urban agglomeration because it hides the underlying character of urbanization, which is demonstrated by the shifting patterns within the urban spread.

Keywords: *Shannon, Entropy, Urban environment, Urbanization, Spatiotemporal dynamics, LULC, Spatial metrics, Remote sensing, Satellites, etc.*

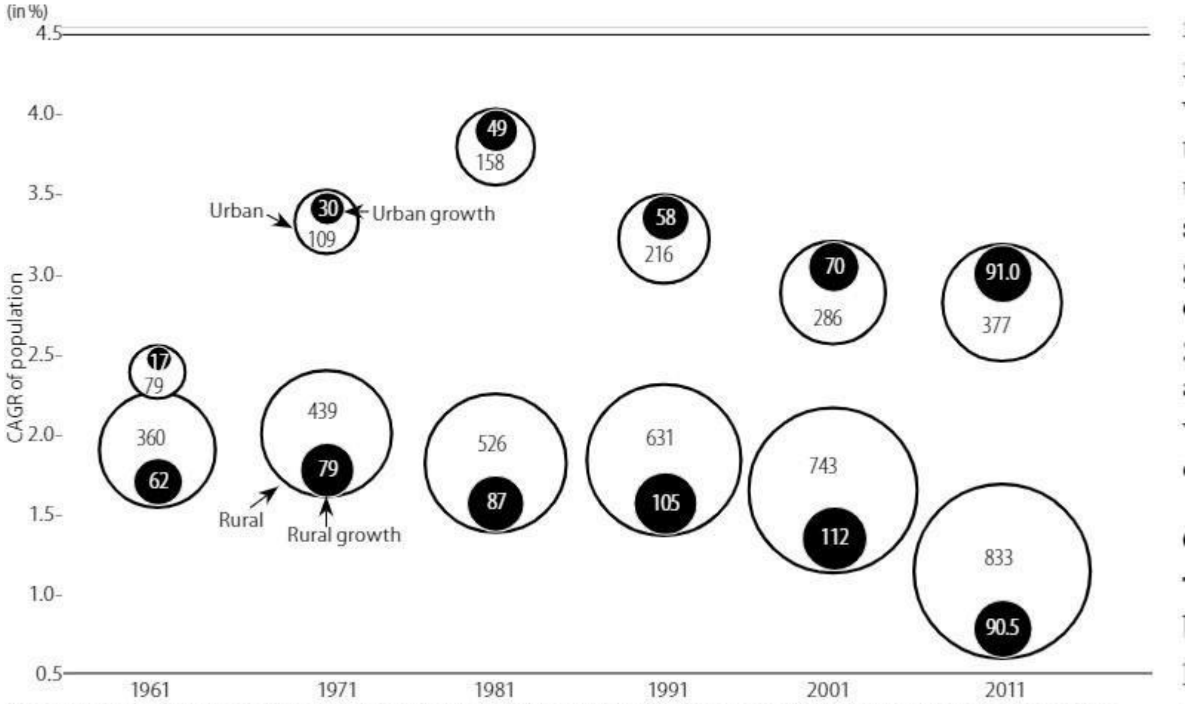
1. Introduction

According to the 2011 Census of India, there were 53 urban agglomerations in India with a population of more than one million in 2011, up from 35 in 2001. Three megacities—Delhi, Mumbai, and Kolkata—are distinguished among these urban agglomerations as having a population of more than 10 million. With populations of between five and ten million, Chennai, Bangalore, Hyderabad, Ahmedabad, and Pune are now considered to be incipient megacities. However, due to their exceptionally rapid rates of growth, they are expected to eventually become megacities (Jain, Dimri, & Niyogi, 2016).

Studying the urban dynamics of megacities is crucial since emerging megacities will probably have to deal with the consequences of increasing urbanization in the future (Taubenböck et al. 2009). Delhi's National Capital Territory (NCT) is located between the coordinates of 28.888N, 77.358E and 28.418N, 76.848E, including an area of 1483 km^. Surrounded by the districts of Ghaziabad, Gautam Budhha Nagar, Bhagpat, Sonepat, Jhajjar, Faridabad, and Gurgaon, it is located within the administrative boundaries of the National Capital Region (NCR) (Figure 1). Delhi currently has eleven districts as opposed to nine. This analysis adheres to the 2011 administrative configuration since the official census data from 1961 to 2011 that is currently accessible has only been projected for the earlier 9 districts.

In Delhi sustainable development, environmental management, and social fairness are seriously hampered by urban sprawl, a phenomenon defined by the unchecked spread of metropolitan regions into peri-urban and rural areas (Ewing, Pendall, & Chen, 2002). Delhi, India, a megacity that has drastically changed its peri-urban areas over the past few decades, is a prime example of rapid urbanization and the sprawl that follows. This study aims to measure the sprawl signature of Delhi by conducting a thorough geospatial analysis of the peri-urban morphogenesis between 1980 and 2024. To better understand the trends, causes, and effects of sprawl in and around Delhi, this study will examine the geographical and temporal dynamics of urban growth.

The study's foundation is a 44-year time series of raw satellite image data that was gathered. The goal of the study is to look into the many urban dynamics that are defined within the city. An extensive research project that aims to comprehend potential micro and macro environmental changes brought on by urbanization has as its first step examining these surface processes (Jain, Dimri, & Niyogi, 2016).



The outer bubble shows the total population (in million) and the inner bubble shows the increase of population (in million) with respect to the previous census. CAGR is the compound annual growth rate.
Source: Census of India 2011.

Fig 1.1: Graphical Illustration of Urban and Rural Population of India (1961-2011).

The 2011 Census's urbanization statistics have sparked a variety of responses. For the first time, the absolute rise in the urban population (91 million) is somewhat higher than predicted(Kundu 2011; Bhagat 2011) and greater than that of the rural population (Figure 1.1, p. 7). Inthis census, the urban growth rate increased as well, having decreased during the previous 20years.

1.1Background

There are two sorts of urban city forms: compact and sprawling. Mixed land-use patternswith high residential and employment densities, contiguous development, multimodal transportation, low open space ratios, and possibly higher energy efficiency in comparison to a sprawling city due to the close connectivity in the urban centre are some of the key features of a compact city (Neuman 2005). An expansive metropolis has a highly specialized pattern of land use, low residential density, limitless potential for growth in all directions, and an increased dependence on private mobility. There is disagreement over which of the two urbanshapes is naturally sustainable (Gordon and Richardson 1997; Burgess 2000).

Fig 1.2 Maps showing NCR and nine administrative districts of Delhi as per census2011.

The term "urban sprawl" generally refers to the unplanned or inadequately planned, uncontrolled, and uncoordinated growth of lower density urban land uses into areas that areforested and agricultural. It is distinguished by auto dependent, limitless outward development in the shapes of ribbon, radial, and leapfrog growth. The term "sprawl" has negative connotations and is frequently used disparagingly. Given that sprawl is an unsustainable kind of urbanization, it differs from urban growth (Sinha, 2017).

Increased energy consumption, lost agricultural land, higher vehicle emissions, and a host of other social problems, such as the marginalization of rural communities, have all been linked to sprawl (Seto, Güneralp, & Hutyra, 2012). Furthermore, Delhi's distinct socioeconomic and policy environment—which is characterized by quick industrialization, population expansion, and changing land use regulations—provides a rich backdrop for examining the subtleties of urban sprawl (Bhatta, Saraswati, & Bandyopadhyay, 2010).

Review of Literature

According to Galster et al. (2001), it is important to distinguish between the pattern and process of sprawl and its causes or effects. The phenomenon of urban sprawl gained prominence in the latter part of the 20th century. Urban population growth, government policies, the expansion of the highway system, the widespread use of automobiles, economic prosperity, and the democratization of society are considered to be the main causes of sprawl,according to the majority of researchers (Kaiser and Weiss, 1971; Pendall, 1999; Harvey and Clark, 1971; Ewing, 1994; Morill, 1991; Harvey and Clarke, 1965; Burchfield et al., 2006;Squires, 2002).

Numerous studies have discovered that the primary factors contributing to urban sprawl in Indian cities are fast migration and urbanization (Sudhira et al, 2004; Malik et al., 2013; Tyagi,2015). In his research on urban sprawl in the Gautam Buddha Nagar district, Sinha (2017) discovered that the main factors driving people to migrate to urban settlements and contributing to urban sprawl are economic backwardness and a lack of job prospects in small towns and rural areas (Annez et al., 2010).

The proximity to Delhi, the availability of employment and income prospects, and the reduced rental prices were the other major factors in the migration to Noida. According to Sinha and Shekhar (2017), push factors account for a greater proportion of outmigration. They discovered that although though the majority of migrants wind up in low-paying positions and are frequently refused access to even the most basic facilities, they nevertheless choose to travel to big cities in the hopes of a better future.

The examination of urban sprawl has been transformed by the development of geospatial technologies. Urban expansion mapping and quantification have benefited greatly from the use of remote sensing and GIS (Sudhira, Ramachandra, & Jagadish, 2004). In particular, the dynamics of urban sprawl have been shown by the widespread use of Landsat satellite data to monitor changes in land use over time (Bhatta, Saraswati, & Bandyopadhyay, 2010). Quantitative measurements of sprawl can be obtained by separating built-up areas from natural landscapes using techniques like supervised classification and NDVI (Normalized Difference Vegetation Index) analysis (Liu, He, Zhou, & Wu, 2014).

(Singh et al. 2017) have conducted recent studies that highlight the acceleration of Delhi's spread after 2000, blaming it on population pressure and economic reforms. The morphogenetic processes sculpting Delhi's urban edge are highlighted by the transformation of peri-urban areas into urban agglomerations (Dadras et al., 2015).

Methodology

The study mostly draws on material from secondary sources, such as urban sprawl studies. This study also evaluates the socio-environmental effects of urban development, tracks the evolution of Delhi's urban footprint, and characterizes its sprawl using cutting-edgegeospatial technologies, such as remote sensing and GIS (Ahluwalia et al., 2011). Thismethodology advances our knowledge of urban morphogenesis in emerging megacities and facilitates the development of well-informed urban planning and policy initiatives targeted at reducing the negative consequences of sprawl (Sudhira, Ramachandra, & Jagadish, 2004).

For the years 1977, 1993, 2006, and 2014, cloud-free images of the study region were obtained using Landsat and Indian Remote Sensing (IRS) satellites (Table 1). Supplementary information was gathered from the Delhi Master Plan, the 1:50 000 scale toposheet of the Survey of India (SOI), and the Census of India decadal population database. ArcGIS 9.3 and ERDAS Imagine 9.1 were used to process digital photos and construct the GIS database.District and state borders were established. Images were brought to the Universal Transverse Mercator System (UTM) zone 43 north projection, or UTM WGS84 43N projection, and the World Geodetic System (WGS84) reference datum.

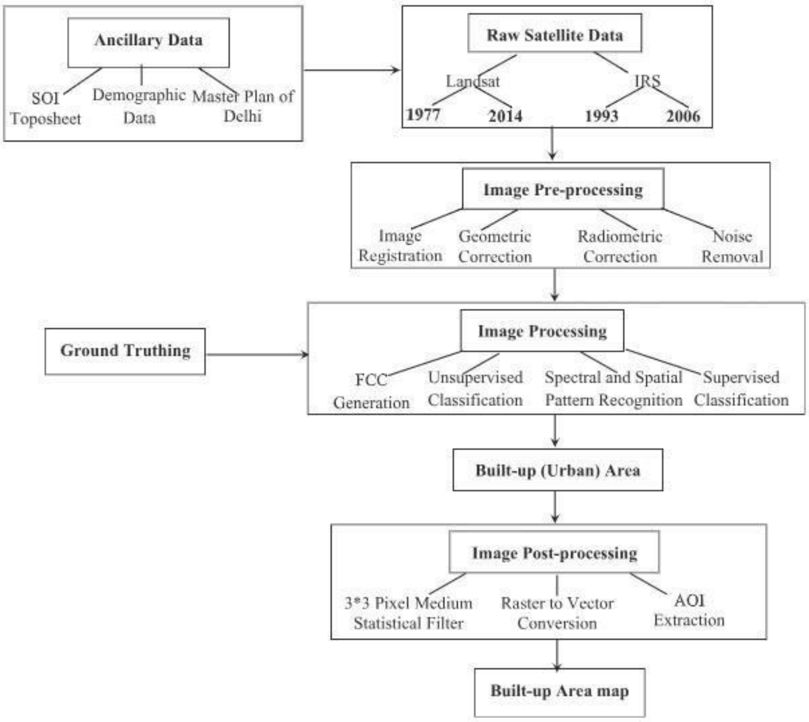
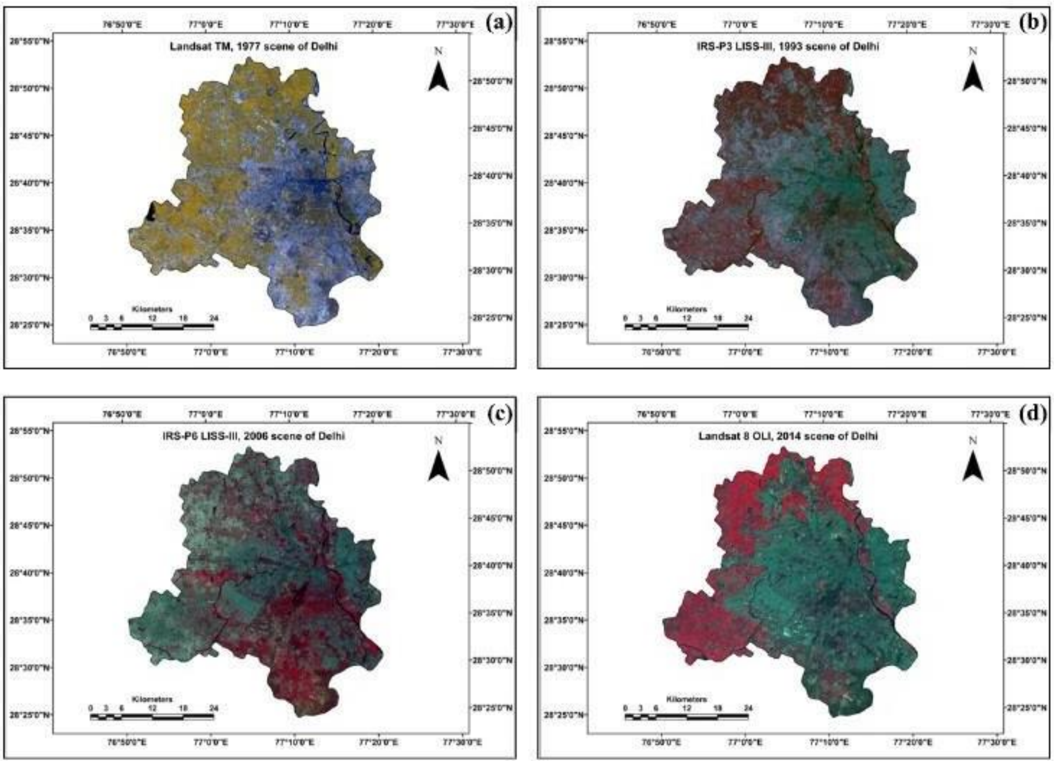


Figure 2: Flowchart showing the technique used to create built-up area maps using satellitedata.

Pre-, during, and post-processing approaches for images were used in the interpretation ofsatellite images. The flowchart of the methods used to create built-up area maps for the research years is displayed in (Figure 2.).
The first steps in image preprocessing involved processing the raw image data for geometric rectification of any innate distortions, radiometric calibration of the data, and removal of anynoise (Curren, 1985, pp. 219-221).

The false color composite (FCC) images were created during image processing by routing bands in the near-infrared (NIR), red, and green via the corresponding red, green, and blue cannons.
See (Figure 3) for these FCCs. Deep waterways appear black, while metropolitan areas appear cyan in the FCCs. Red areas should be understood as flora, and white as waste or barren terrain. The density and material utilization of the urban region influence its color tones. Every image was brought to the UTM WGS84 43N projection,



which is the same platform. The cubic convolution approach was used to resample pictures with a spatial resolution of 60 m to 30 m (Homer et al. 2004).

In **Figure 3.** The Delhi False Colour Composite FCCs for the years 1977, 1993, 2006, and2014 are shown. All the FCCs were created using a layer stack of the bands red, green, andinfrared.

The precision of the nonresampled 30-m image is lost in this downscale resampling, but the pixel size is reduced (Dixon and Earls 2009). The decision was made not to upscaling to a common coarser resolution of 60 m since doing so would have reduced the classification accuracy of the remaining images. Following ten iterations of primary unsupervised classification on the images, a supervised classification strategy was implemented. Following

ten iterations of primary unsupervised classification on the images, a supervised classification strategy was implemented. To distinguish, a USGS level I categorization was applied. Following ten iterations of primary unsupervised classification on the images, a supervised classification strategy was implemented.

A USGS level I categorization was used to separate nonurban (non-built-up) terrain fromurban or built-up territory. Urban or built-up land is classified as level I by the USGS,differentiating it from other land-use classes including agricultural land, forest land, water,etc (Anderson et al.,1976). Level II categorization, on the other hand, provides a thorough listof level I classifications. The level II classification divides the imagery's residential, commercial, industrial, and other areas into several classes for the urban (built-up) area class. The classification was restricted to the level I scheme because the satellite images obtainedfrom Landsat and IRS had a moderate geographic resolution and special utilization of urban(built-up) regions was not required (Anderson et al. 1976). By applying spatial and spectralpattern recognition, which makes use of characteristics including tone, texture, shape, andpixel group arrangement in the image, urban area identification was accomplished. The built-up area class was extracted using the hybrid classification approach mentioned above, and theoutput of the classification was verified using techniques for ground-surveying. Although ittakes longer, this type of hybrid classification method yields much more accurate and refinedclass outputs than either supervised or unsupervised classification alone.

Following classification, the data was subjected to picture postprocessing and a 3 multiplied into 3 medium statistical filter. The urban (built-up) area was vector-polygonised. The area ofinterest (AOI), which is the state or district boundary, was clipped from the map in order to derive the final built-up area maps for the four years. After (Currit, 2005), an accuracy evaluation was conducted again to verify the overall categorization accuracy rate. 50 reference test pixels that matched the built-up area class were selected using stratified random sample strategy used for the annual FCC. The test pixels were made sure to be evenly spaced throughout the images.

RESULTS

Delhi's Sprawl Dynamics Analysis (1977-2014) through Remote Sensing and Spatial

Metrics.

Delhi has experienced significant changes in land use and cover (LULC) during the last 40 years, with urbanization serving as the main cause of these changes (Jain et al. 2016). The country's independence, its status as the country's capital, the wave of immigrants, and the country's gradual transition from an agrarian to a service-based economy have all contributed to the rapid development of infrastructure. Consequently, the creation of jobs in the service industry draws additional immigrants to the city (Jain et al. 2016). Thus, a pattern of employment creation resulting in population growth leads to the construction of infrastructure (housing, offices, road connectivity, etc.). In Delhi, there is variation in the dynamics of urban expansion at the district level. Historically, the construction of Delhi's earliest urban centers, Old Delhi (located in the Central District), Shahdara (located in the East District), and Mehrauli (located in the South District), in an incredibly compact manner, was motivated more by fortification and protective purposes than by a lack of available building space. High population density was noted since residents of the urban neighbourhood tended to live near to one another. However, the Lutyen zone in the New Delhi District was established by the British, and the existing policies have been successful in preventing any significant sprawl in that area (Jain et al. 2016). The remaining urban areas grew over time—some planned, others unplanned—to meet the needs of both population pressures and infrastructure development. The goal of the current study is to determine whether the urban growth indicators also reflect the influence of various planning mindsets at the district level. If so, it can probably play a significant role in addressing the negative environmental effects of urbanization.

Satellite	Sensor	Path/Row	Acquisition Date	Data Types and Band
Landsat	OLI	146/40	9 Feb 2014	Digital (1,2,3,4,5,6,7)
IRS-P6	LISS-III	096/051	2 Jan 2006	Digital (2,3,4,5)
IRS-P3	LISS III	029/047	5 Nov 1993	Digital (2,3,4,5)
Landsat	MSS	157/040	8 March 1977	Digital (4,5,6,7)

Table 1. Shows the location of the scene and data bands together with the data sourceand specifics of the satellite's onboard sensors.

Area Metrics

The area metrics measure the composition of the terrain. In this context, the term "landscape area" refers to the state's administrative region as well as each district as determined by census data (Uttarwar et al., 1988). Urban or built-up land is described as "areas of intensive use with much of the land covered by structures" by (Anderson et al.,1976, p. 10). Towns, villages, strip developments beside freeways, complexes, and establishments that might be cut off from the central metropolitan region are all included. Pixels are employed in conjunction with the image's color, tone, and texture to distinguish between built-up and non-built-up areas. Comparing an FCC's impermeable (concretized) area to other materials such as mud, grass, water, etc. reveals a different spectrum reflectance pattern.

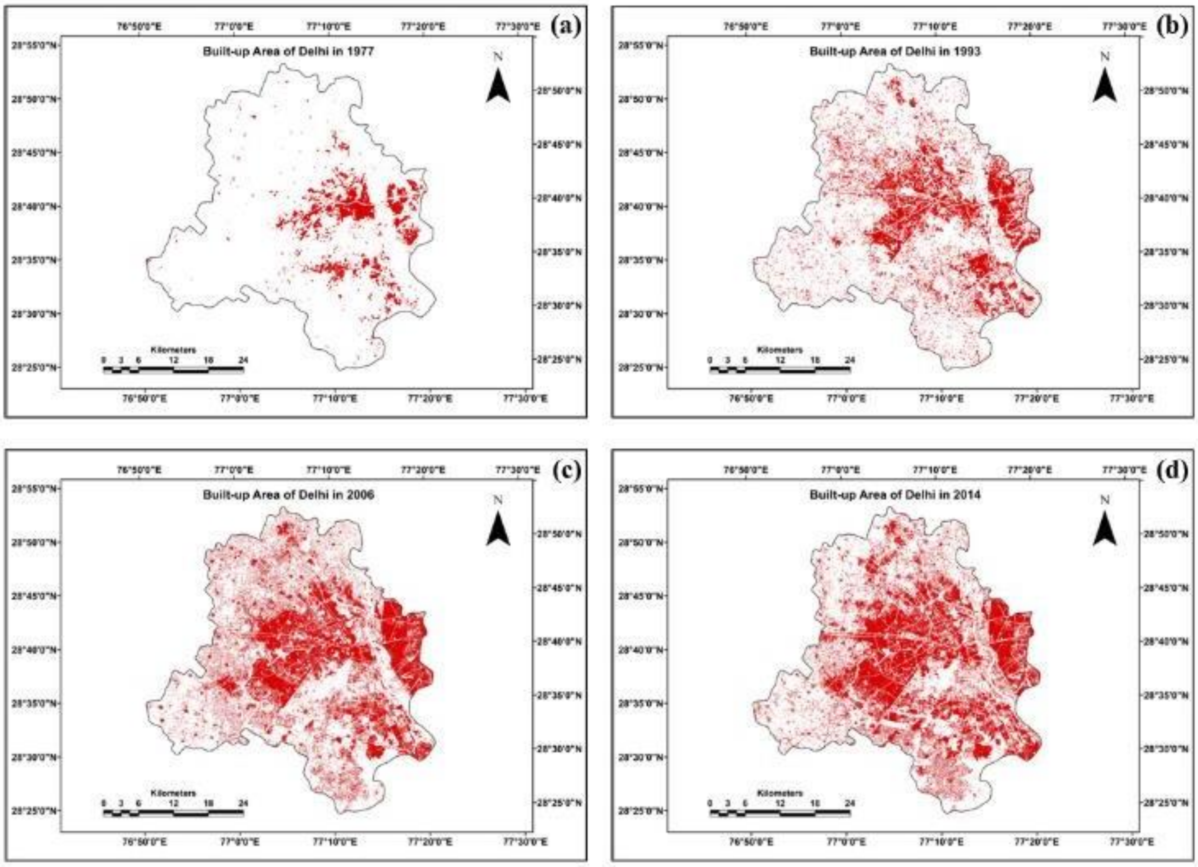
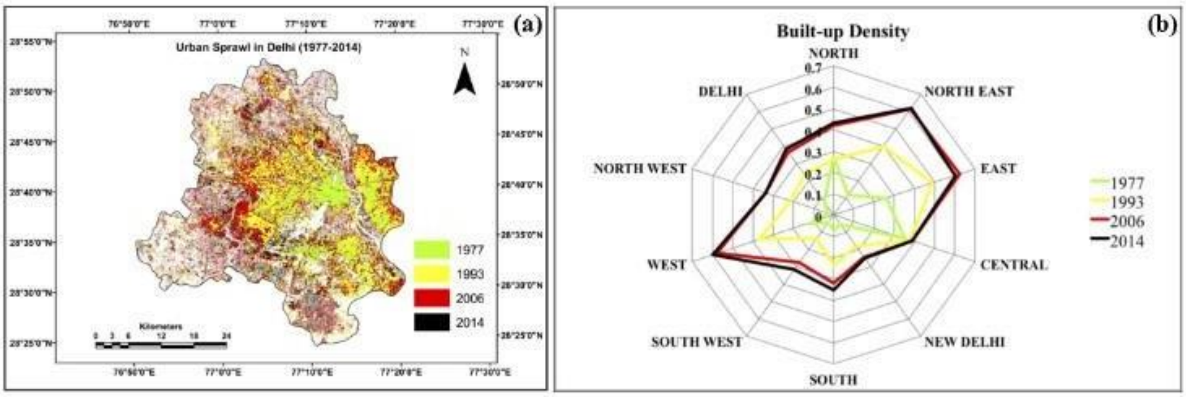


Figure 4. Built-up (urban) 1977, 1993, 2006 und 2014. Red colour denotes the separate-yearbuilt-up area.

The built-up area identified from satellite imagery is commonly referred to as the urban areaover a landscape (Zha et al. 2003). The study's definition of "built-up area" includes residential, commercial, institutional, and industrial districts; paved roads are not included.

(Figure 4) shows the mapped built-up areas for 1977, 1993, 2006, and 2014. These urban patches' exact placement throughout any given period of time is entirely determined by human activity. As more construction is done, old patches enlarge over time, and new patchesmay appear in unexpected places. It clarifies a certain aspect of urban sprawl and compactness. The data derived from the supervised and unsupervised categorization of raw satellite imagery shows an uneven distribution of urban areas among Delhi's districts. The districts with the largest absolute built-up (urban) area are North West, South West, and South. Given that no two districts are the same size, built-up density is a more appropriate indicator of urban expanse.

Figure 5: A built-up area overlay map and a spider chart representing built-up density are usedto illustrate Delhi's



urban spread during a 38-year period.

The pace at which the built-up area increases over time can be used to calculate urban growth. The ratio of the overall landscape area at any given period to the urbanized (built-up) area is known as built-up density (Drabkin, 1977). It merely presents the urban area's density numerically, regardless of where urban patches are located inside the administrative boundaries. Delhi's urban sprawl is visually shown by an overlay map (Figure 5a) of the built-up area throughout time. The built-up density spider graphic (Figure 5b) provides an estimate of the districts with the highest rate of urban growth. The built-up density increased in every district between 1977 and 1993, with the exception of the North district. This can be linked to the district's consistent population for this period of time (Census of India 2011), recurrent flooding (Delhi Disaster Management Authority 2015), and eviction and demolition

drives of unauthorised dwellings. Every district had an increase in built-up density between 1977 and 1993, with the North district being the exception. The Delhi Disaster Management Authority (2015) links this to recurring flooding, the district's steady population during this time period, and the eviction and demolition of unauthorised dwellings. North Delhi has a pretty significant growth in built-up area between 1993 and 2006. After the Right Marginal Embankment was built and extended along the Wazirabad–Palla section, the settlement of Burari was established and the flood problem was lessened (Jain 2009). Following 1993, there was a fairly consistent urban density in the Central district, and a similar pattern was observed in the New Delhi area. Between 1993 and 2006, there was a noticeable rise in the built-up density in Delhi and the other districts and the city itself.

With the exception of a notable increase in the South West area from 2006 to 2014—which can be attributed to the development of Dwarka, a sub-city, and many other smaller settlements the urban density did not change significantly between the years. As of 2014, the built-up area class included up to 60% of the administrative land in the districts of East, North East, and West. It is proof of the high urban saturation that certain neighbourhoods in the city are going through.

Conversely, New Delhi is the least densely built-up district in terms of built-up area, with only roughly 25% of the administrative area being built up.

Population Metrics

In (Figure 6) (Census of India 2011) illustrates the exponential rise in Delhi's resident population over the last century. The district-wise population for the years 1977, 1993, 2006, and 2014 is displayed in Figure 6b. This data was obtained through the use of interpolation methods that rely on decadal population change rates. Based on statistics from the 2001–11 census and the assumption of a constant growth rate, the population for 2014 was calculated.

The population for 2014 was computed using the 2001–11 census data, which assumed a steady growth rate. Based on estimates, Delhi's total population in 2014 was more than 17 million. Six districts remain, except for Central, New Delhi, and North, have reached the one million milestone. By comparing the number of people living in the area to the landscape area, population density is computed (Delhi Development Authority, 1962). Urban population density should, in theory, only consider the proportion of the urban population to the total urban area as defined by the administrative authorities (Denis,

Mukhopadhyay, & Zérah, 2012). The total rural population of the state has stayed relatively stable over time, whereas there has been a noticeable increase in the urban population (Census of India 2011). However, in Delhi's situation, the data from the nine districts' rural- urban population census are not available prior to 2001.

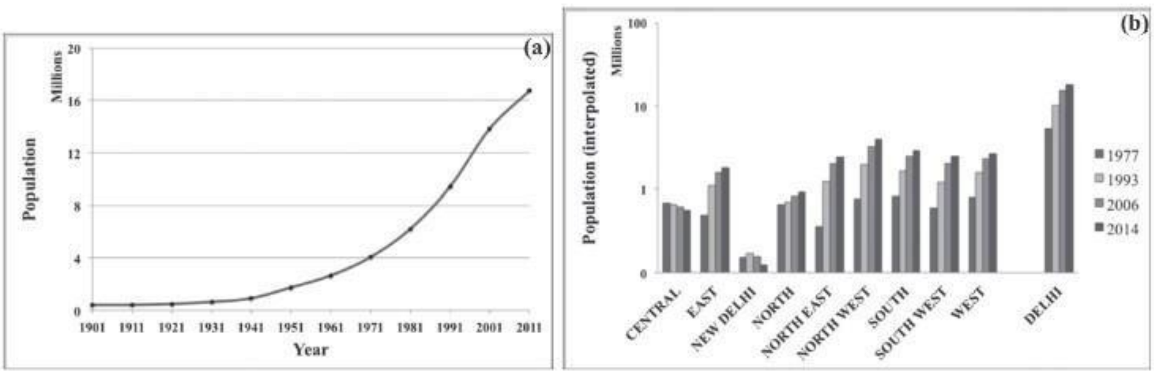


Figure 6.1: (a) shows Delhi's population growth from 1901 to 2011 (source: Census ofIndia 2011); (b) shows the district-by-district interpolated population for the years 1977, 1993, 2006, and 2014.

The pattern of urban population density is like the overall population density in certain aspects (Denis, Mukhopadhyay, & Zérah, 2012). As a result, the urban population density in the current study was calculated by dividing the total population by the built-up areas that were taken from the satellite data. North East (40,341 people per square kilometer), East (28,019 people per square kilometer), and Central (22,419 people per square kilometer) are the districts with the largest urban population densities.

The North East, East, and West districts have experienced an exceptionally quick growth in density between the first time (1977–1993) and the last (2006–14). It is noteworthy that since 1977, the Central district's urban population density has been steadily declining. People have been compelled to relocate to different areas of Delhi over the past ten years due to the dismantling of the Yamuna Pushta slum cluster and widespread commercialization, which alters land-use planning (Government of National Capital Territory of Delhi 2013). The New Delhi district exhibits a similar pattern, with a spike in population density in 1993 being followed by a fall in subsequent decades.It is noteworthy that since 1977, the Central district's urban population density has been steadily declining. People have been compelled torelocate to different areas of Delhi over the past ten years due to the dismantling of the Yamuna Pushta slum cluster and widespread commercialization, which alters land-use

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Urban Agglomeration	Year	Population			% of Total UA Population	
		Core*	Spread	Total	Core*	Spread
Delhi	1991	7,602,394	816,690	8,419,084	90.3	9.7
	2001	10,236,674	2,554,784	12,791,458	80.0	20.0
	Change	2,634,280.0	1,738,094.0	4,372,374.0	-10.3	10.3
	% Change	34.7	212.8	51.9	-11.4	105.9

**Core = New Delhi Municipal council, Delhi Municipal Corporation and Delhi Cantonment.*

Source: See Table 1

in subsequent decades.

Fig 6.2: Population Distribution of the Delhi Urban Agglomeration: Core andPeriphery, 1991–2001 (*Source: Mookherjee 2004*).

Agglo-meration	1991			2001			% Change 1991-2001		
	P	A	D	P	A	D	P	A	D
Core	7,602,394	46,831	162.8	10,236,674	52,366	195.5	34.65	11.81	20.4
Spread	816,690	10,586	77.1	2,554,784	23,749	107.6	212.8	124	39.4

P – population; A – area; D – Density

Source: Calculated by authors from census data

Fig 6.3: Population Density by Core and Spread (Periphery) of the Delhi UrbanAgglomeration, 1991–2001 (*Source: Mookherjee 2004*).

Findings and Discussions

Expansion of sprawl from Delhi to Noida.

In 2016, a survey was conducted in Uttar Pradesh's Noida city. Understanding the factors thatcontribute to urban sprawl was one of the survey's goals. With a total size of 20,316 hectares, Noida is completely contained within the Gautam Buddha Nagar district, which shares a western boundary with Delhi (American Society of Photogrammetry, 1983). In the Yamuna

basin, the city is located between Hindan and the Yamuna River. The area is a virtually level,gently sloping alluvial plain that stretches from northeast to southwest.

The National Capital Region (NCR) plan served as the basis for the development of Noida,with the goal of reducing Delhi's traffic by limiting in-migration.
Therefore, alternative planned residential and industrial sites were made available to people at a significantly cheaper cost than in Delhi to redirect population that was headed for Delhito Noida (Indian Institute for Human Settlements, 2011).

Due to its planned city growth, less expensive land, and proximity to Delhi, Noida has become one of the fastest growing cities in the world. Since 1991, the population has doubledevery ten years, and this trend is expected to continue until 2031. The population of Noida increased to 3,05,058 in 2001 from 1,46,514 in 1991. As per the Noida Master Plan 2031, the population is anticipated to increase to 25 lakhs by 2031 from 6,37,272 in 2011.The main causes of sprawl in the city have been identified in the primary survey conducted in Uttar Pradesh's Noida city. These include the area's increasing urbanization, differences in employment and income, Delhi's close-proximity, the availability of inexpensive land, reasonably priced houses, and more.

The reasons of sprawl differ significantly between the developed and developing worlds, as can be shown by a

comparison of urban growth patterns in these two regions. Consequently, different approaches are required to address the issue of urban sprawl. Given the general paucity of research in this area on developing-world cities, additional work is needed to fully comprehend the reasons behind sprawl in these urban areas (Sinha, 2018).
According to the results of the questionnaire survey, the primary factor behind families moving from Delhi to Noida was the latter's cheaper land value. Because Delhi's land values are so high, these families are unable to afford a home there. They succeeded in buying a home in Noida. Therefore, the primary factor influencing the majority of the families leaving Delhi was having their home. The fact that their workplace was in Noida was another crucial factor.

Effects on Thermal Comfort and Urban Heat Islands.

A study conducted on Delhi's urbanization over the past 50 years revealed that heat island intensities had increased by up to 4-6 °C. The city's average near-surface temperatures have risen by 1.02 °C as a result of urbanization (Datta, 2009). The urbanized areas had an

increase in extremely uncomfortable hours, with an average of 10 hours per day to 13 hours per day. By 2030, the Delhi urban agglomeration—India's capital city—is expected to hold the title of largest city in the world. Growing urbanization has resulted in nighttime canopy layer heat island (CLHI) of over 4 °C in 500 km2 of the CNCR area, and the emergence of new, smaller areas with CLHI of 5–6 °C that did not exist half a century ago. The five- decadal period from 1972 to 2014 is expected to have seen a 1.02 °C increase in spatially averaged ambient temperatures in Delhi.Throughout this multi-decadal period, there has been an increase in thermally unpleasant hours, from an average of 10 to 13 hours per day, due to urban sprawl (Indian Institute for Human Settlements, 2011). It is stressed that urban LULC changes can have a major effect at the macro-climate scale when this impact is collectively considered over the entire globe with numerous such urban agglomerations (Indian Institute for Human Settlements, 2011).

The characterization of canopy layer urban heat islands, their effects on cooling energy use, indoor and outdoor ambient comfort, urban air quality, and the analysis and development of various mitigation technologies have advanced significantly over the last three decades (Akbari and Kolokotsa, 2016; Mirzaei, 2015).

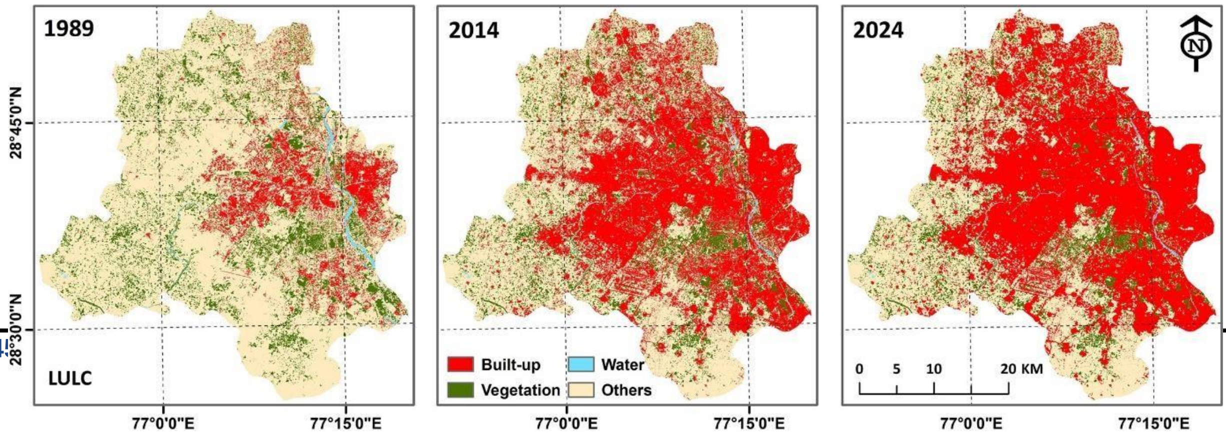

Figure 7. Delhi's land use changed significantly because of the fast urban growth (net increase 457 km2 & 448 km2) shown by the satellite-based and simulated LULC between 1989 and 2014. The other class was significantly impacted by the fast urban growth (changeof 27.3%), and greenery came in second.

Conclusion

The study examines the factors that contribute to urban sprawl, an unsustainable pattern of development. Urban population increase, regional differences in development, economic growth, transportation, government regulations, affordable housing (Barret & Curtis, 1982). According to (Taubenböck et al.,2012), the spatial dynamics of urban sprawl from 1975 to 2010 show that developed country cities like London and New York. only see a marginal spread, while developing country cities (like Kinshasa, Brazzaville, Manila, Cairo, Mumbai, etc.) experience the fastest growth (Government of India, 2011). Megacities in India, like Delhi, have high values for the built-up density, urban area, and landscape shape index (Taubenböck et al. 2009). The current study's city-level findings are in line with earlier research (Chatterji, 2007).

Numerous studies have been conducted on LULC alterations and their overall effects (Denis, Mukhopadhyay, & Zérah, 2012). However, in the context of the global urbanization process, there is a dearth of knowledge and judgment of the degree to which long-term changes in urbanization could affect temperature, heat island effect, thermal comfort, etc (Jensen & Toll, 1982). The current study primarily evaluates the effects of changes in land use and cover (LULC), notably the growth of urban sprawl, on thermal comfort and urban heat island (UHI) intensities over a period of approximately five decades (F.Y. Cheng *et al)*.

According to a district-level analysis, Delhi is home to three different types of urban patterns:extremely, medium, and least spread (Jain (2013). The districts of Central and New Delhi have the least amount of sprawl, while the districts of West, North, East, and South have the most. The districts of North West, South, and South West have medium levels of sprawl.

Overall, the state of Delhi exhibits a pattern resembling that of medium-sized, disperseddistricts.

People are dispersing from the centre of the city, where there is little room for urban growth(Bhagat, 2011). The population growth rates over a given decade provide evidence for this.

According to Clark's (1951) generalization, every large city, except for the central business core, has interior districts that are heavily populated, with the population density gradually decreasing as one moves out into the suburbs. In conjunction, population density tends to migrate and increase in the outside districts as it moves out of the densest central districts over time. In this way, the population of the city tends to disperse. Regarding the actual situation on the ground in Delhi, both generalizations are accurate (Dutt, 1999).

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