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Quantifying Spatial-Temporal Patterns of Urban Expansion in Lucknow City, Uttar Pradesh, India

ORIGINAL ARTICLE


Authors

Vijay Kumar Singh Rathore
Assistant Professor, Department of Geography
K. S. Saket P. G. College
Ayodhya, Uttar Pradesh, India

and

Dr. Anjani Kumar Singh
Professor, Department of Geography
K. S. Saket P. G. College
Ayodhya, Uttar Pradesh, India

Abstract

It is crucial to have a hindsight evaluation of the magnitude and pace of urban expansion for effective growth management in metropolitan areas. The objective of this paper is to quantify the spatial– temporal patterns of urban expansion in the Lucknow City, Uttar Pradesh, India. The analysis was carried out using the Remote Sensing & Geographical Information System Technique in which Landsat satellite images of the years 1980, 2000, and 2020 were used and classified into 5 Land-use & Land-cover classes (Agricultural land, Built-up, Waterbody, Wasteland and Tree cover) using supervised maximum likelihood algorithm to obtain the built up expansion for each respective years. Further, the city's municipal area was divided into 8 concentric multiple ring buffers, each with a width of 2 km. To estimate the amount and intensity of expansion over the 40-year study period from 1980 to 2020, 3 indices such as Annual urban expansion rate (AUER), Urban expansion intensity index (UEII) and Urban expansion differential index (UEDI) are computed for each buffer. Results show that middle buffers 4, 5, and 6 have the highest annual urban expansion rate (AUER) during the study period as compared to other buffers. Buffers 3, 4 and 5 show the highest value of the Urban Expansion Intensity Index (UEII) during 1980-2020 in contrast to other buffers. Buffer 5, having the highest value of the Urban expansion differential index (UEDI) (10.31) among all other buffers, has been the fastest growing region of the Lucknow municipal area during the study period. The study also revealed that from 1980 to 2020, according to the values of UEDI, buffers 4, 5, 6 and 7 are the fast-growing areas, while buffers 1, 2, 3 and 8 are the slow-growing areas of Lucknow. Moreover, the metropolitan-core buffers (buffers 1 & 2), which serves as the focal point of urban development and the historical origins of expansion, show the least built-up expansion over the 40 years due to limited available land. During the study period, urban expansion has spread into the middle and peripheral buffer areas, with the highest intensity and fastest rate of expansion occurring in the buffers located around the core regions. A comprehensive regional growth management strategy grounded in effective strategic partnerships among the respective administrative districts to curb unsustainable urban expansion is recommended.

Key Words

Multiring buffer analysis, Landsat, Maximum Likelihood Supervised Classification, Built-up, Urban Metrics.

Introduction

In general, urbanization refers to the growth of settlements in terms of population, physical area, and economic activity over time. According to the agglomeration theory, urbanization is driven by the concentration of population and economic activity, which historically led to the emergence and growth of cities and metropolitan regions. Urbanization creates external economies of scale that improve productivity and growth, making existing cities attractive for further population and activity. In addition to demographic changes, urbanization also affects the physical form and structure of settlements by expanding existing built-up areas into greenfield land or surrounding rural settlements, as noted by unhabitat in 2010. The rapid and unconstrained urban expansion is a noticeable manifestation of the ongoing process of urbanization in Indian cities. The expansion of urban areas in India is driven by the demographic factors of natural population growth and the migration of people from rural to urban areas.

To classify urban expansion, three related processes including infilling, expanding, and outlying have been identified by Wilson et al. (2003). Infilling is a more compact form of physical development, but in many developing countries, there has been rapid peri-urbanization leading to unconsolidated lateral expansion and sprawl. This has resulted in existing built-up areas engulfing smaller towns on their outskirts, as seen in various studies (Webster 2002; Kombe 2005; Doan and Oduro 2012). The uncontrolled expansion of urban centers into their peripheries is a contemporary form of urbanization driven by the need to accommodate population growth and space demands of socio-economic activities, often at the expense of greenfield land, as pointed out in several studies (Acheampong and Anokye 2013; Appiah et al. 2014; Owusu-Ansah and O'Connor 2006).

Decades of rapid urbanization have led to significant challenges in India, including climate change, environmental degradation, and resource depletion. Such challenges pose threats to public health, essential ecosystem services, and food security. To manage urban growth and avoid unsustainable expansion and its negative consequences, it is essential to understand the spatiotemporal dynamics of urban land-use and the driving forces behind them. This paper uses Landsat remote sensing imagery from 1980, 2000, and 2020, as well as GIS techniques and spatial metrics to assess the patterns of urban expansion within the 2 km buffer of Lucknow Municipal Area. Lucknow, a rapidly urbanizing metropolitan region in Uttar Pradesh, India, has been designated for this study.

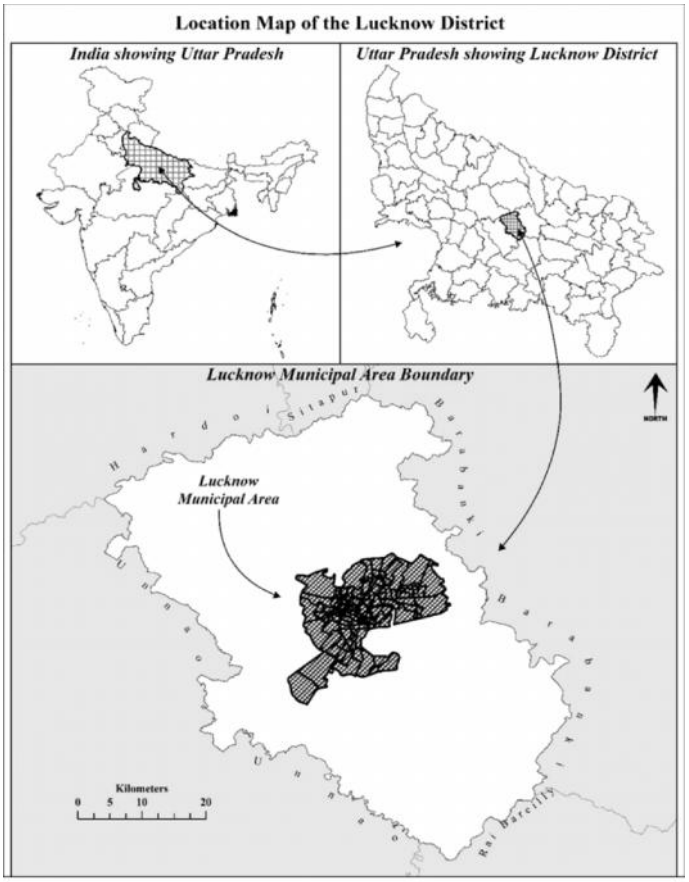
The extent of the urban expansion or urban sprawl can be appropriately analysed through the multiple ring buffer analysis and zonal analysis. In both the analysis methods, the study area is divided into many zones. In the case of concentric multiple buffer analysis, the study area is divided into many concentric rings of a definite width. After analysing the expansion of urban areas based on these concentric rings interesting results can be found. In the case of Lucknow Municipal Region, this type of study will provide very useful results. On looking at the urban area of Lucknow it is found that the growth of the city was in every direction so here multiple ring buffer analysis will be very useful to identify the zone-wise sprawling character of the city area. In this multiple ring buffer analysis, many indices are used to characterise the urban sprawl character of Lucknow city such as Land consumption ratio (LCR), Land absorption coefficient (LAC), Urban expansion rate (UER), Annual urban expansion rate (AUER), Urban expansion intensity index (UEII) and Urban expansion differential index (UEDI). These indices have been successfully used by many researchers worldwide. Kamlesh et. al. (2021) has applied these indices in concentric multiple-ring buffer analysis as well as zonal analysis in the study of Jhansi city of Uttar Pradesh. Acheampong et. al. (2017) has computed three complementary growth indexes namely; Average Annual Urban Expansion Rate, Urban Expansion Intensity Index and Urban Expansion

Differentiation Index to estimate the amount and intensity of expansion over the 28-year period in Greater Kumasi Sub-Region (GKSR)—a functional region comprising eight administrative districts in Ghana, West Africa.

Study Area

Lucknow, a city in Uttar Pradesh, is the most populous state in India as per the Census of 2011. It is a city with rich historical and cultural significance and is the fifth-largest city in terms of population in Uttar Pradesh with a population of 4,589,838 according to the Census of 2011. The population density of the city is 1816 persons per sq. km. Lucknow is centrally located in Uttar Pradesh and is situated on the fertile Gangetic plain. The city is divided into two parts by the Gomti River, a tributary of the Ganga River. These two parts are Trans-Gomti and Sis-Gomti. The latitudinal and longitudinal extent of Lucknow district is from 26° 30' N to 27° 09' N and from 80° 33' E to 81°13' E respectively. The district covers an area of 2528 square kilometres, bordered by Hardoi and Sitapur in the north, Barabanki in the East, Raebareli in the south and Unnao in the west. The north-south and east-west extents of Lucknow district are approximately 65 kilometres and 51 kilometres respectively. The average elevation of the district from the mean sea level is 123 meters. Lucknow is a significant political, commercial, and economic center of Uttar Pradesh, well-connected to the surrounding major cities through highways and expressways. In recent years, tourism, economic activities, and infrastructure development have grown significantly, attracting migrants from neighbouring towns and villages in pursuit of higher education, businesses, and services. The study area is shown in the figure 1.

Figure 1: Map showing the study area.



Methodology

The methodology section of the present study is divided into 3 sections: data used, multi ring buffer analysis and spatial metrics. Details of each is provides as follows:

Data Used

The current research employs Remote Sensing and GIS methodology by utilizing Landsat satellite imagery with multi-spectral moderate resolution to gain a comprehensive understanding of the study area. The Landsat program, which has been collecting land cover data since 1972, is the longest-running remote sensing satellite programme in the world. These satellite images are extensively used for various purposes such as agricultural, geological, forestry, regional and urban planning, natural resource mapping, education, research, and global land cover change analysis.

Free LANDSAT satellite data was downloaded from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/) to achieve the goals of this study. In order to achieve the objectives of the research, satellite images with a 10-year interval were utilized. The images correspond to the years 1980, 2000, and 2020. All of the images are free of clouds to ensure the maximum exposure of features and were taken during the winter season (December to February), namely Ravi, for maximum similarity of the surface condition. Table 1 provides a detailed description of the image characteristics. Survey of India Toposheets were also used. High-resolution images from Google Earth were used for accuracy assessment. Digital image processing software like ENVI and ERDAS IMAGIN, as well as Geographic Information System (GIS) software like ARC GIS, were used to process and classify the satellite images.

Table 1: Detailed description of Landsat Remote Sensing Satellite Data used in the study.

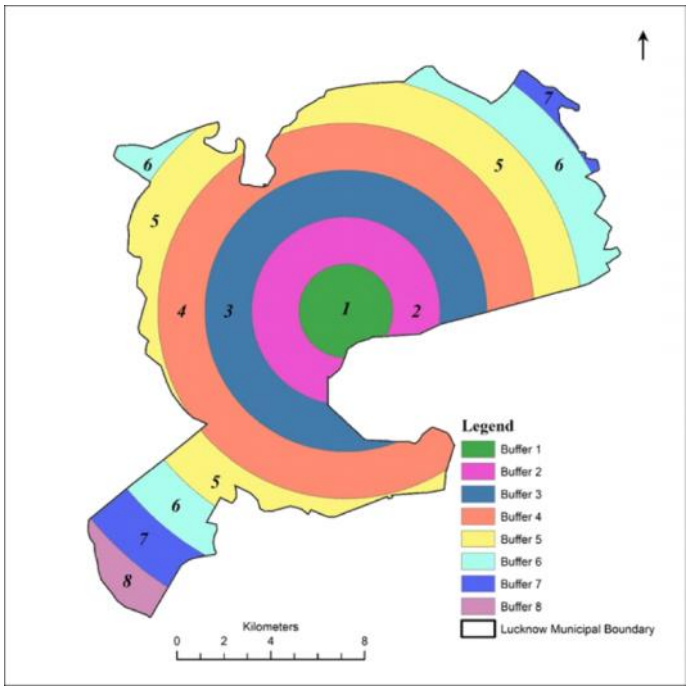
Landsat Mission	Sensor	Acquisition Date	Path / Row	Spatial Resolution	Radiometric Resolution	Projection & Datum	Source
Landsat 3	MSS	09/02/1980	154/041 154/042 155/041	60 meters	8 bit	UTM Zone 44N WGS1984	USGS Earth explorer
Landsat 7	ETM+	29/02/2000	144/041 144/042	30 meters	8 bit	UTM Zone 44N WGS1984	USGS Earth explorer
Landsat 8	OLI / TIRS	12/02/2020	144/041	30 meters	16 bit	UTM Zone 44N WGS1984	USGS Earth explorer

The satellite images were subjected to atmospheric correction and then classified into five distinct land use and land cover categories, including agricultural land, forest cover, water bodies, built-up areas, and waste land. The classification process was carried out using supervised image classification techniques. The built-up class was extracted from each classified image, with a particular emphasis on a 2 km buffer surrounding the municipal boundaries of Lucknow.

Multi Ring Buffer Analysis

To analyse and examine urban expansion multiple ring buffer analysis is an important method. In this method, concentric multiple ring buffers are created in the study area. For this multiple ring buffer analysis, Lucknow municipal boundary is chosen as the study area. The buffers were overlayed on the classified images of 1980, 1990, 2000, 2010 and 2020. Through this overlay zonal statistics are calculated and the area under each buffer is year wise tabulated. Here in this study, 8 concentric ring buffers (CRB) of 2 km width from the centre of the city (Hazratganj Chauraha) to the outskirts of the city were created (figure 2). The name of each buffer ring is given as Buffer 1 (0-2 km), Buffer 2 (2-4 km), Buffer 3 (4-8 km), Buffer 4 (8-10 km), Buffer 5 (10-12 km), Buffer 6 (12-14 km), Buffer 7 (14-16 km) and Buffer 8 (16-18 km).

Figure 2: Map showing buffers (2 km width) in Lucknow Nagar Nigam.



Spatial Metrices

To quantify urbanisation and to understand the nature of urban expansion following 6 spatial metrics were calculated.

Land Consumption Ratio (LCR)

It is a very simple index. It is the ratio between the areal extent in hectare of Land use and Land cover class (here built-up class) to the population of that area. According to Singh et al. (2015), it measures compactness and shows the progressive spatial expansion of the urban area. It is calculated from the formula:

$$LCR = \frac{A}{P}$$

Here, A is the built-up areal extent of the city (Ha) and P is population.

Land Absorption Coefficient (LAC)

It is a ratio-based index. It is a ratio between the difference in the areal extent of the built-up class of the current year to the previous year by the difference in the population of the current year to the previous year. It measures the population pressure on built-up class. According to Singh et.al. (2015) LAC suggests that how change in consumption in urban land by each unit of increase in population. It is computed from the following formula:

$$LAC = \frac{A_2 - A_1}{P_2 - P_1}$$

Where, A_1 and A_2 are the areal extents in ha of current and previous years, and P_1 and P_2 population of the current and previous years respectively.

Urban Expansion Rate (UER)

The rate of urban expansion is a very important index as it talks about the speed of change between two periods rather than the absolute values of the changes. The UER index quantifies the change in a built-up area as a percentage of total urban growth in each interval.

$$UER = \frac{B_{2i} - B_{1i}}{B_{1i}} * \left(\frac{1}{T}\right) * 100$$

Where, B_{2i} and B_{1i} are the built-up area at time t+1 and t respectively, and T is a time interval between t+1 and t (in years).

Annual Urban Expansion Rate (AUER)

According to Acheampong et al. (2017), the annual urban expansion rate provides detailed information about the built-up expansion in an urban area. It is calculated from the equation as follows:

$$AUERi = \left[\left(\frac{ULA_i^{t2}}{ULA_i^{t1}}\right)^{\frac{1}{t2-t1}} - 1\right] * 100$$

Where AUERi is the Annual Urban Expansion Rate of unit i, and ULA_i^{t2} andULA_i^{t1} are the area of built-up land at time t2 (ending year) and t1 (base year).

Urban Expansion Intensity Index (UEII)

According to Hu et al. (2007) and Li et al. (2010), the urban expansion intensity index is the average growth area standardized by the total area of a spatial unit and shows the future direction and potential of urban expansion. Ren et al. (2013) categorised UEII into many classes as follows: very high-speed expansion (> 1.92), high-speed expansion (1.05–1.92), medium-speed expansion (0.5–1.05), slow expansion (0.28–0.59), and very slow expansion (<0.28). The formula to calculate UEII is given as:

$$UEIIi = \left(\frac{ULA_i^{t2} - ULA_i^{t1}}{TLAi * \Delta t}\right) * 100$$

where$UEIIi$ is the Urban Expansion Intensity Index of unit i; $\left|ULA_i^{t2}\right|$ and are the area of built-up land at time t2 and t1 respectively; is the total land area within the study area i and Δt is the study time period.

Urban Expansion Differential Index (UEDI)

Urban Expansion Differential Index is a ratio between the urban expansion rate of a spatial unit to the urban expansion rate of the total study area. Its formula is as follows:

$$UEDI = \frac{\left(\frac{\left|ULA_i^{t2} - ULA_i^{t1}\right|}{ULA_i^{t1}}\right)}{\left(\frac{\left|ULA^{t2} - ULA^{t1}\right|}{ULA^{t1}}\right)}$$

Where UEDI indicates the urban expansion differentiation index of unit i; and indicate the area of urban land of unit i at time t2 and t1, respectively; and and indicate the total area of urban land in the study area at time t2 and t1, respectively.

UEDI compares the urban expansion of a constituent unit to the overall study area. According to Akubia and Bruns (2019), Three possible categories of UEDI are as: (1) constituent spatial unit having UEDI >1, in this case, it will be categorised as a fast-growing area compared to other sub-regions, (2) when UEDI <1, then spatial unit will be categorised as a slow-growing area, and (3) when UEDI = 1, it will categorise a sub-area as a moderate growing concerning the other sub-regions (Kushwaha et al., 2021).

Results and Discussion

Values of LCR and LAC are given in the tables 2 and 3 and are graphically represented in figures 3 and 4. Both of the indices depend upon the population of the study area. The value of LCR slightly increases from 1980 to 1990, it is because the ratio of increase in population was almost the same as the ratio of the increase of built-up area in both years. From 1990 to 2000 the value of LCR decreases because the population growth was higher than the built-up area growth. From 2000 the value of LCR increases continuously. In 2000, 2010 and 2020 its values are 0.0047, 0.0050 and 0.0055. The increasing value of LCR shows that the built-up area has been expanding more than the population growth during this period from 2000 to 2020. Due to this expansion, the urban area shows the characteristics of urban sprawl.

Table 2: Table showing area under built up class, population of LMC and land consumption ratio in 1980, 1990, 2000, 2010 and 2020

Year	Area of Built-up classin hectare in LMC	Population of LMC	Land Consumption Ratio(LCR)
1980	04804.41 Ha	0947990	0.0050
1990	08309.88 Ha	1619116	0.0051
2000	10451.52 Ha	2185927	0.0047
2010	14102.28 Ha	2817105	0.0050
2020	18340.49 Ha	3286420	0.0055

Table 3: Table showing land absorption coefficient during 1980 - 1990, 1990 - 2000, 2000 - 2010 and 2010 – 2020

Period	Land Absorption Coefficient (LAC)
1980 - 1990	0.0052
1990 - 2000	0.0037
2000 - 2010	0.0057
2010 - 2020	0.0090

Figure 3: Line Graph showing the values of LAC in different years

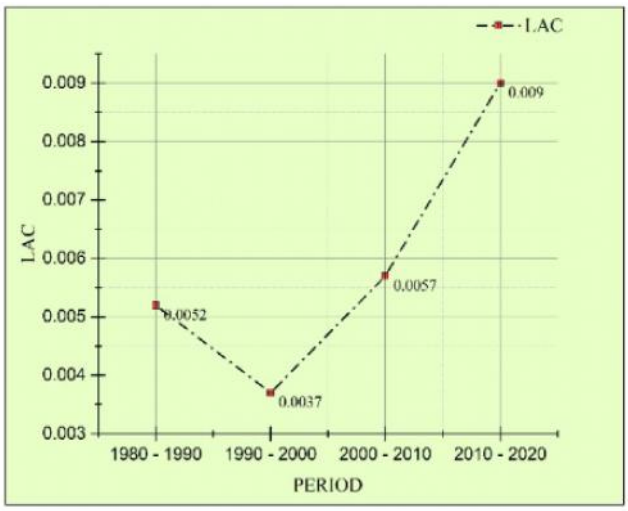
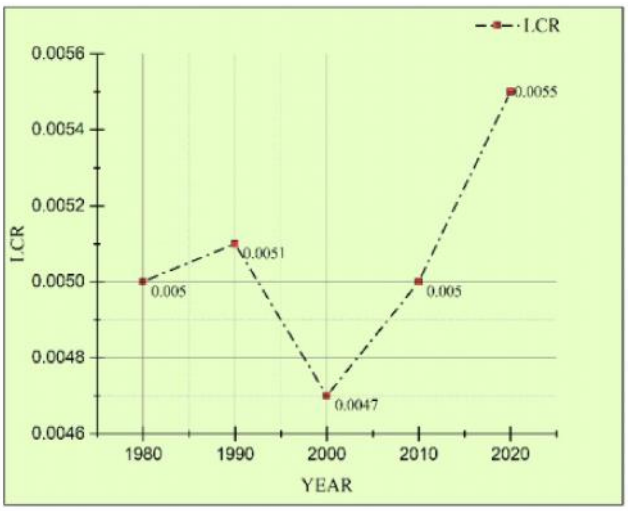


Figure 4: Line Graph showing the values of LCR in different years



The value of LAC is 0.0052 from 1980 to 1990 but in the period 1990 – 2000, its value decreases to 0.0037. From the period of 1990 – 2000 to 2010 – 2020 the value of LAC continuously increases. In the period of 2000 – 2010 and 2010 – 2020 values of LAC are 0.0057 and 0.0090 respectively. LAC measure how the built-up area increases as the population increases. Doan et al. (2012) and Kushwaha et al. (2021) found that the decreasing trend of LAC always indicates internal city growth which is a compact type of growth in an urban area. When LAC decreases the internal city growth is more prevalent than the external expansion of the built-up area as sprawl. During the period of 1990 – 2000, the lower value of LAC suggests that during this period compactness of the city increased. New built-up areas were developed in the previously open spaces in the inner part of Lucknow city. Due to the increase in the compactness of the city the development and management of the city in the form of transportation, green space, solid waste management, sewerage, water, energy, etc. affected. That's why people moved towards the outer areas of the city for residential purposes in search of better living conditions. Due to this outward movement, the value of LAC increases continuously. Its value of 0.0090 is very high in 2010 – 2020 which shows much urban sprawl in this period. Both the metrics LCR and LAC show that the population rise had triggered the built-up sprawl in a region.

8 concentric ring buffers having 2 km width were created and numbered from 1 to 8 from the centre to outer areas as shown in figure 2. The area corresponding to each buffer is given in the table 4. The area of buffer number 4 is maximum, succeeded by buffers 5, 3, 6, 2, 1, 7 and 8. For the years 1980, 2000 and 2020 the area of the built-up class according to the buffer is provided in table 4 and represented through the maps of 8 buffers in LMC in the figures 5 and 6.

Table 4: Table showing the buffer area and buffer wise area of built-up class in hectare in 1980, 2000 and 2020

Buffer Number	Buffer Area	Area of Built-up class in ha (1980)	Area of Built-up class in ha (2000)	Area of Built-up class in ha (2020)
1	1174.28	836.28	1058.40	1058.60
2	2896.83	1650.09	2090.61	2200.05
3	4838.73	1406.16	3090.15	4108.95
4	7182.27	481.68	2479.05	5536.35
5	5477.81	123.12	1065.87	3699.99
6	2936.43	201.24	496.89	1351.89
7	1085.32	75.60	125.01	291.96
8	553.641	30.24	45.54	92.70
Total area	26145.31	4804.41	10451.52	18340.49

Figure 5: Maps showing the changes in built up area in buffers 1, 2, 3 and 4 during 1980, 2000 and 2020.

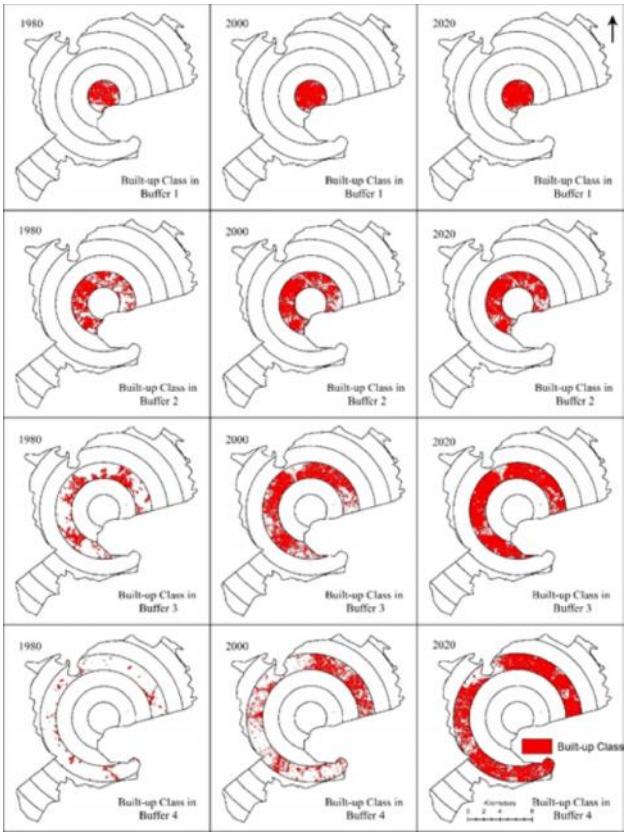
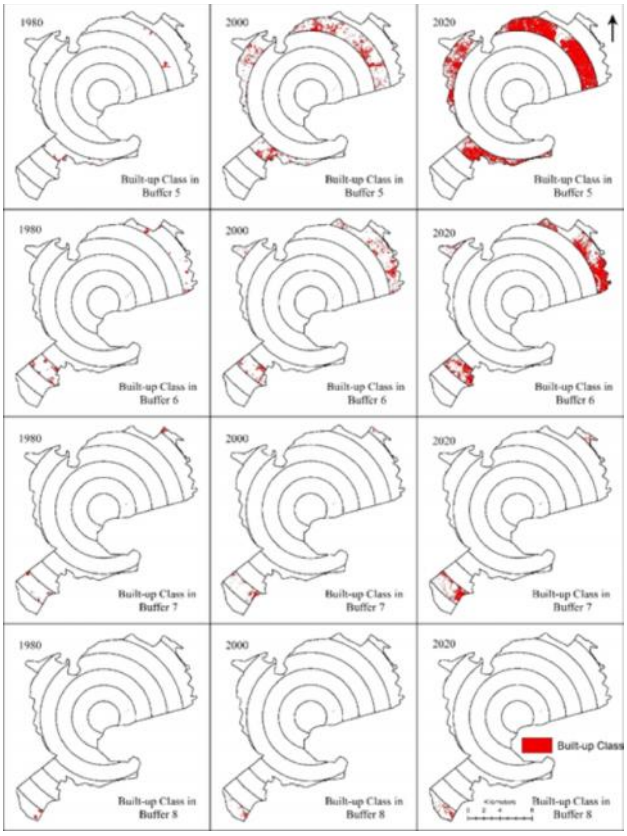


Figure 6: Maps showing the changes in built up area in buffers 5, 6, 7 and 8 during 1980, 2000 and 2020.



Buffer wise expansion in the built-up area and annual expansion in the built-up area of LMC for the periods 1980 – 2000, 2000 – 2020 and 1980 – 2020 are given in table 5 and graphically presented in the figures 7 and 8. The highest expansion in the built-up area during 1980 - 2000 is seen in buffer 4. While highest expansion in the built-up area during 2000 - 2020 is seen in buffer 5. During the 40 years of the period from 1980 to 2020 highest expansion in built-up is seen in buffer 4 succeeded by buffers 5 and 3 (figure 5 & 6). In buffer 1 during the period 2000 – 2020 minimum expansion of only 0.2 hectares was seen. Buffer 1 is found in the centre of the city around the Hazratganj chauraha. During the period 1980 - 2000 a growth of 222.12 ha was there in buffer 1. Buffer 1 is known for its market and offices so no land was left for further growth that's why it shows minimum growth during 2000- 2020.

Maximum annual expansion in built-up during 1980 - 2000 was seen in buffer 4 followed by buffers 3 and 5 while the minimum expansion was observed in buffers 8 and 7. During 2000 – 2020 maximum annual expansion was seen again in buffer 4 followed by buffers 5, 3 and 6 while the minimum expansion was observed in buffers 1, 8 and 7. During 1980 – 2020 maximum annual expansion was seen in buffer 4 followed by buffers 5, 3 and 6 while the minimum expansion was observed in buffers 8, 7 and 1. Major dominated growth is seen in buffers 4, 5 and 3 during all time. These middle buffer areas are the fastest-developing area of Lucknow city.

Table 5: Table showing the buffer wise expansion in a built-up area and annual expansion in a built-up area in LMC during 1980 - 2000, 2000 - 2020 and 1980 - 2020.

Buffer Number	Expansion in built-up area (1980-2000)	Expansion in built-up area (2000-2020)	Expansion in built-up area (1980-2020)	Annual Expansion in built-up area (1980-2000)	Annual Expansion in built-up area (2000-2020)	Annual Expansion in built-up area (1980-2020)
1	222.12	0.20	222.32	11.110	0.01	5.56
2	440.52	109.44	549.96	22.030	5.472	13.75
3	1683.99	1018.80	2702.79	84.200	50.94	67.57
4	1997.37	3057.30	5054.67	99.870	152.86	126.37
5	942.75	2634.12	3576.87	47.140	131.71	89.43
6	295.65	855.00	1150.65	14.790	42.75	28.77
7	49.41	166.95	216.36	2.480	8.35	5.41
8	15.30	47.16	62.46	0.765	2.36	1.57

Figure 7: Bar graph showing the buffer wise expansion in built-up areas in hectare in 1980 – 2000, 2000 – 2020 and 1980 - 2020

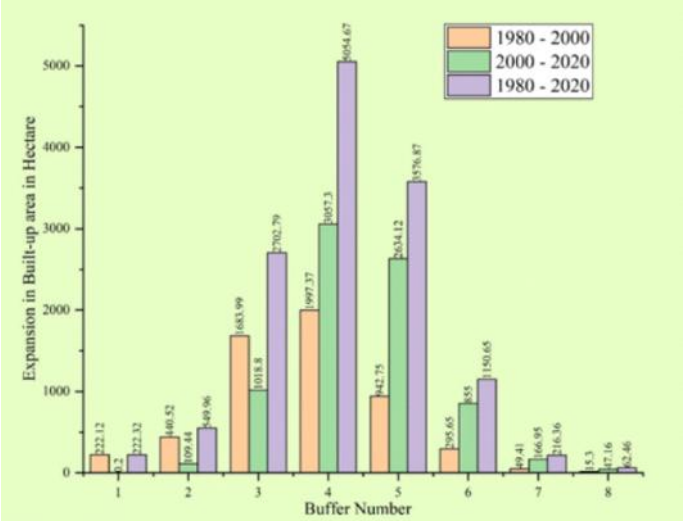
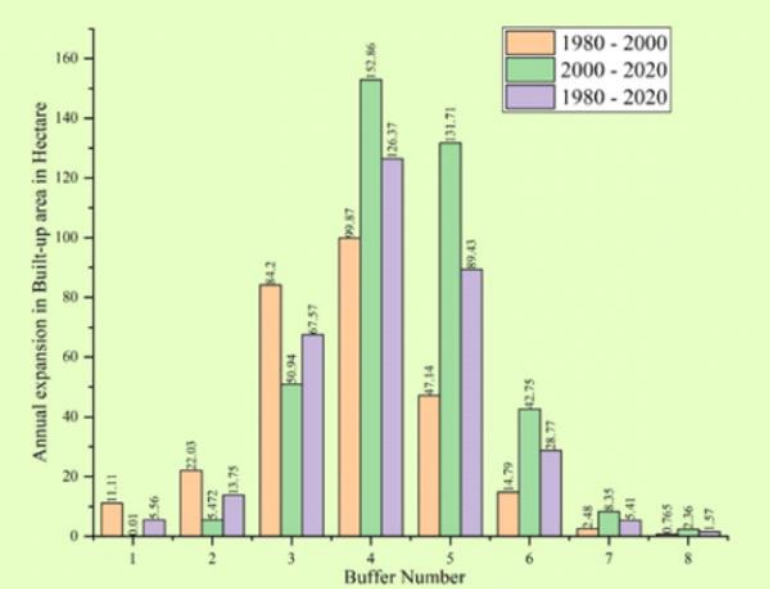


Figure 8: Bar graph showing the buffer wise annual expansion in built-up areas in hectare in 1980 – 2000, 2000 – 2020 and 1980 – 2020



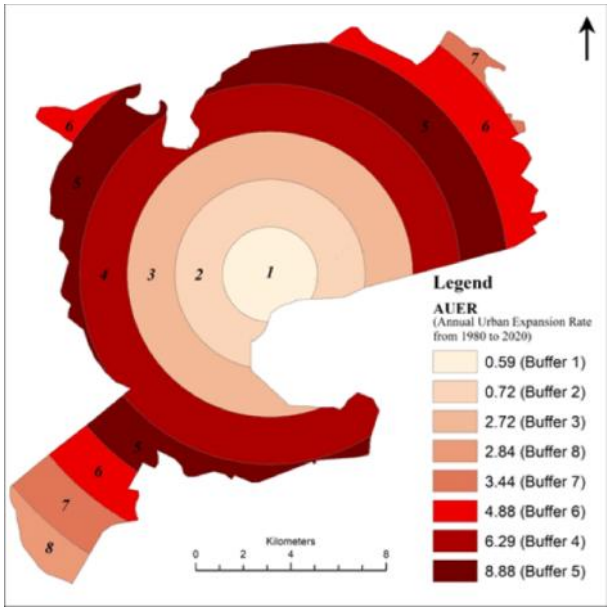
The Urban Expansion Rate (UER) data, shown in table 6, has been computed and it is observed that buffer 5 has the highest percentage of expansion rate for the periods of 1980–2000 (38.29%) and 2000 - 2020 (12.36%). During the 40 years of study period i.e., from 1980 to 2020 buffer 5, with a UER of 72.63%, is the fastest growing region of the LMC. The analysis shows that buffer 1 has the all-time minimum UER with 1.33 in 1980 – 2000 and 0.0009 in 2000 – 2020. For the period of 1980 – 2020 UER for buffer 1 is only 0.66%.

Annual urban expansion rate scores (AUER) are shown in the table 6. In buffers 1 and 2 AUER values are very low for 1980 - 2000 and 2000 - 2020 because these areas are in the centre of the city and are already highly urbanised. The highest score of AUER for 1980 – 2000 and 2000 – 2020 is for buffer 5. During the period of 40 years from 1980 to 2020 buffer 5, 4 and 6 shows the highest value of AUER while buffer 1 and 2 shows the minimum value. Figure 9 presents the map of buffers of LMC showing AUER values. It is evident from the map that regions included in the buffers 4, 5 and 6 are fast growing as compared to inner areas.

Table 6: Table showing the buffer wise urban expansion rate and annual urban expansion rate during 1980 - 2000, 2000 - 2020 and 1980 - 2020

Buffer Number	UER 1980-2000	UER 2000-2020	UER 1980-2020	AUER 1980-2000	AUER 2000-2020	AUER 1980-2020
1	1.33	0.0009	0.66	1.18	0.001	0.59
2	1.33	0.2600	0.83	1.19	0.260	0.72
3	5.99	1.6500	4.81	4.02	1.430	2.72
4	20.73	6.1700	26.23	8.54	4.100	6.29
5	38.29	12.3600	72.63	11.40	6.420	8.88
6	7.35	8.6000	14.29	4.62	5.130	4.88
7	3.27	6.6800	7.15	2.55	4.330	3.44
8	2.53	5.1800	5.16	2.07	3.620	2.84

Figure 9: Map showing buffer wise annual urban expansion rate from 1980 - 2020



Scores of Urban Expansion Intensity Index (UEII) and Urban Expansion Differential Index (UEDI) are provided in the table 7 are represented in the figures 10 and 11.

Very high-speed expansion (>1.92) was not seen in the period of 1980 – 2000. High-speed expansion (1.05–1.92) was seen in buffers 3 and 4 for the period of 1980 – 2000. Medium speed expansion (0.5–1.05) is seen in buffers 1, 2, 6 and 5 and very slow expansion (<0.28) in 1980 – 2000 was seen in buffers 7 and 8. Similarly, for the period of 2000 – 2020 buffer 4 and 5 show very high-speed expansion, buffer 3 and 6 shows high-speed expansion, buffer 7 shows medium-speed expansion, buffer 8 shows slow expansion (0.28–0.59), and buffer 2 and 1 shows very slow expansion. For the 40 years period from 1980 to 2020, neither buffer shows very high-speed expansion, buffer 3, 4 and 5 shows high-speed expansion, buffer 6 and 7 shows medium speed expansion while buffer 1 and 2 shows slow expansion and finally buffer 8 show very slow expansion.

UEDI values for the period 1980 - 2000 shows that buffer 3, 4, 5 and 6 were the fast-growing areas (UEDI > 1) while buffer 1, 2, 7 and 8 were slow-growing areas (UEDI < 1). UEDI values for the period 2000 - 2020 shows that buffer 4, 5, 6, 7 and 8 were the fast-growing areas while buffer 1, 2 and 3 were the slow-growing areas. From 1980 to 2020 according to the values of UEDI buffers 4, 5, 6 and 7 are the fast-growing areas while buffers 1, 2, 3 and 8 are the slow-growing areas.

Table 7: Table showing the buffer wise urban expansion intensity index and urban expansion differential index during 1980 - 2000, 2000 - 2020 and 1980 - 2020

Buffer Number	UEII 1980-2000	UEII 2000-2020	UEII 1980-2020	UEDI 1980-2000	UEDI 2000-2020	UEDI 1980-2020
1	0.95	0.0009	0.47	0.23	0.0003	0.09
2	0.76	0.19	0.47	0.23	0.07	0.12
3	1.74	1.05	1.40	1.02	0.44	0.68
4	1.39	2.13	1.76	3.53	1.63	3.72
5	0.86	2.40	1.63	6.51	3.27	10.31
6	0.50	1.46	0.98	1.25	2.28	2.03
7	0.23	0.77	0.50	0.56	1.77	1.02
8	0.14	0.43	0.28	0.43	1.37	0.73

Figure 10: Map showing buffer wise urban expansion intensity index from 1980 – 2020

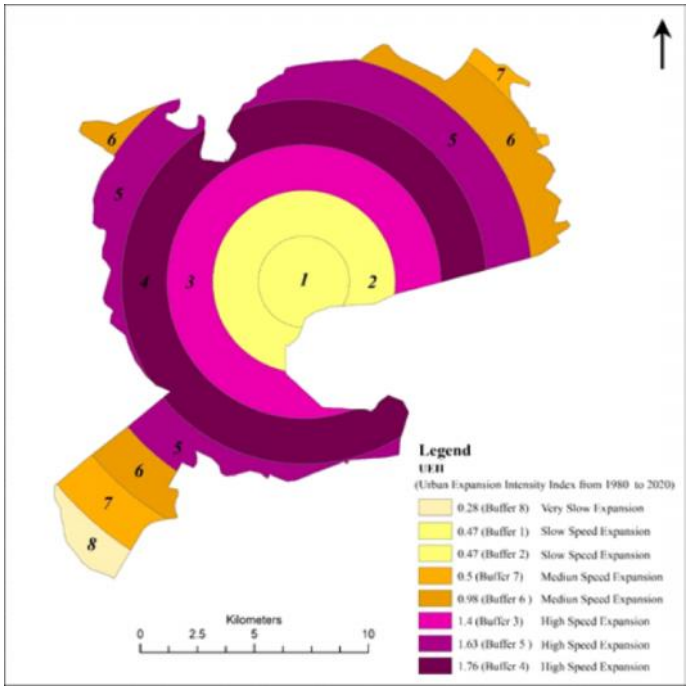
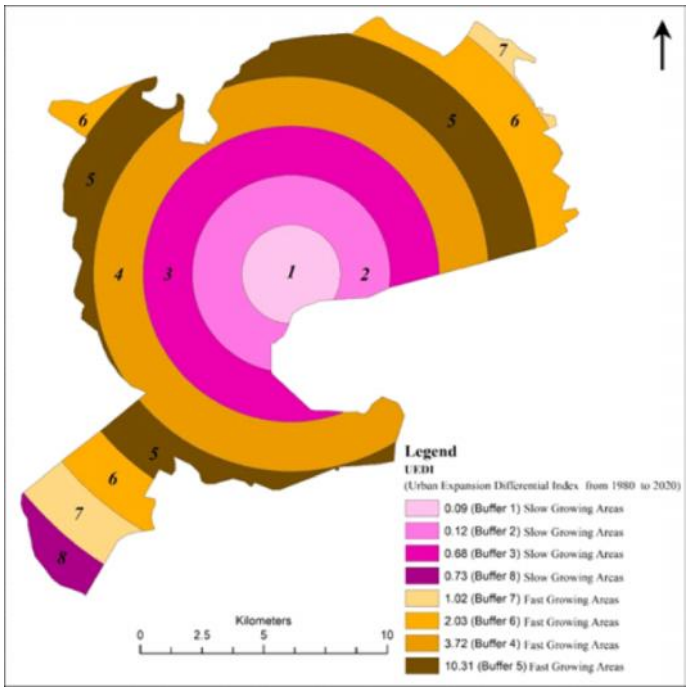


Figure 11: Map showing buffer wise urban expansion differential index from 1980 - 2020



Conclusion

The focus of this study is on utilizing Landsat data and urban metrics to measure the extent and annual rate of urbanization. To understand the magnitude of urbanization, Landsat satellite data from 1980, 2000, and 2020 were utilized to quantify the change in urban expansion over the decades in Lucknow, India. The satellite images were classified using the maximum likelihood classifier and urban growth metrics were computed to measure the extent of built-up areas by intensity, rate, and amount. The results of a multi-ring buffer analysis, which analyzed the changes in urbanization from the city center to the periphery in increments of 2 kilometers, indicate that the pressure of urban expansion is higher on the periphery (urban-rural fringe). The findings will be useful in developing a practical strategy for the region by providing information about the urban footprints.

The values of LCR increase from 1980 to 2020 indicating that the built up area increases more in comparison to population during these 40 years of study period. In the same way values of LAC also incresase from 1980 to 2020, which evidenced the outer or external expansion in the built up land. Highest expansion in the built up area and highest annual expansion in built up area during the period 1980- 2020 is found in the buffers 4 and 5 while lowest values of both the metrics are found in the outer most buffer number 8. The data of Urban Expansion Rate indicates that during the 40 years of study period i.e., from 1980 to 2020 buffer 5, with a Urban Expansion Rate of 72.63%, is the fastest growing region of the LMC. Buffer 5 and 4 shows the maximum values of Annual Urban Expansion Rate during 1980 to 2020. Scores of Urban Expansion Intensity Index (UEII) suggeste the highest expansion in the buffers 3, 4 and 5. From 1980 to 2020 according to the values of Urban Expansion Differential Index buffers 4, 5, 6 and 7 are the fast-growing areas while buffers 1, 2, 3 and 8 are the slow-growing areas. Hence it can be said that the outer regions of LMC shows the pronounced growth in the built up areas which indicated the urban expansion.

The term "urban footprints" refers to the physical expansion of urban areas, which results in an increasing demand for land for built-up areas, often at the expense of agricultural land. In addition, socio-economic factors such as access to education, employment opportunities, and improved infrastructure can drive urbanization. Migration from surrounding areas to a specific location can also contribute to the urbanization process.

This study serves as a case study to assess the vulnerability of socio-environmental resources to the encroachment of urbanization in the absence of adequate planning and management tools. It highlights the potential negative impacts of uncontrolled urban expansion on natural resources, such as land and water, as well as on the socio-economic well-being of local communities. The findings of this study can be used to develop effective strategies to manage urban expansion and promote sustainable development in similar urbanizing areas.

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