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Quantifying the characteristics and types of urban growth of Varanasi city using multi-temporal remotely sensed data and geospatial techniques

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Abstract

In the present study, multi-temporal remotely sensed Landsat data from 1972, 1980, 1990, 2000, 2010 and 2020 were used to assess the spatio-temporal dynamics and types of urban growth of Varanasi city in the mid-Gangetic plain.. In this study, the directional and distance-based analysis of hot zones of urban growth and distribution patterns of newly urbanized areas in different periods was carried out with the help of GIS. The results of this study showed that there had been a significant increase in the natural growth of the Varanasi city. Within the study area, the maximum growth of built-up land occurred in the form of edge expansion. After this, the second largest growth has occurred as outlying growth. The city is expanding rapidly in NW and SW directions and at a moderate pace in N and S direction. Therefore, to achieve strong urban sustainability in the development of the small cities in mid-Ganga plain, the planning and conservation policy should be implemented promptly so that the targeted goal of developments can be achieved successfully.

Keywords: *Urban expansion types, remote sensing, GIS, Varanasi City.*

Introduction

Today, urbanization is accompanied by the rapid growth of the urban population, leading to the haphazard and unplanned natural growth of cities into their peri-urban areas. Swift industrialization and urbanization have fueled regional economic development in North India, which have affected the surrounding rural areas and have effected changes in rural-urban as well as industry-agriculture relations (Shah, 1988; Chakravorty *et al*., 2000; Ghosh and De 2005; Saikia, 2011). Population growth in urban areas demands more and more natural resources over time, including land for housing and industrial, commercial and transportation infrastructure resulting in concentration of population in city's outskirts to meet their residential and commercial needs. The tendency to move from city centres to peri-urban areas often promotes the natural and uncontrolled growth of the cities. Therefore, along with identifying and analyzing the spatio-temporal patterns of urban expansion, it imperative to analyze the types of the natural expansion of cities and their characteristics so that effective and sustainable infrastructural planning can be done in cities and their peri-urban areas.

Remote sensing and geographic information systems (GIS) applications are now increasingly used in mapping and

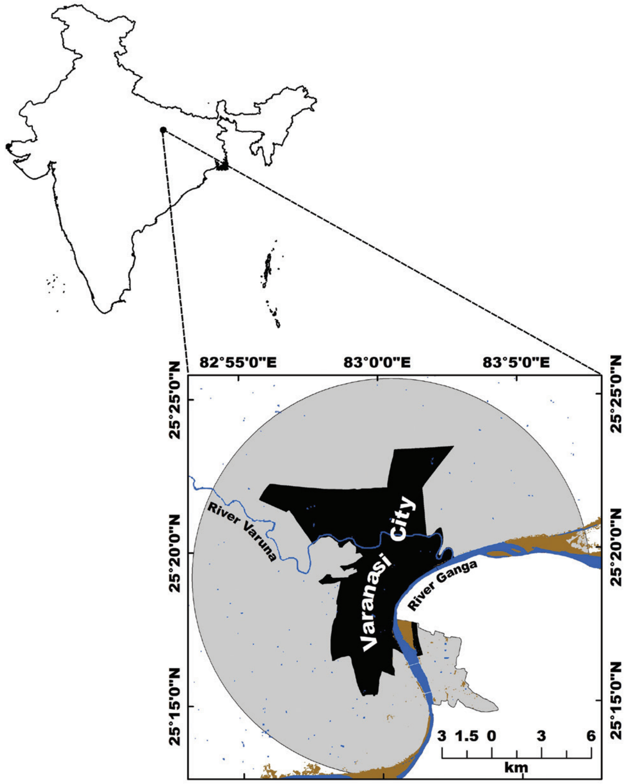

Fig. 1: Location of study area

monitoring the dynamics of urban growth and generating related spatio-temporal data. In this paper, an efficient and cost-effective approach has been used to monitor and analyse spatial properties of the urban growth of Varanasi city by combining remote sensing and GIS. The analysis of historical urban growth in Indian cities using remote sensing and GIS reveals the natural dynamics, processes and types of urban growth with greater accuracy (Blei *et al.*, 2018; Dhanaraj and Angadi, 2021), which is very useful for city planners and managers to manage complex urban development in small cities in India effectively.

There are mainly three types of urban growth which have been identified and delineated by different scholars using GIS. These are: infill growth, edge expansion, and outlying growth or spontaneous growth (Xu *et al.*, 2007; Bhatta, 2009; Liu *et al.*, 2010; Shi *et al.*, 2012; Sun *et al.*, 2013; Jiao *et al.*, 2015). The first of these, infill growth, describes new construction within an existing established urban area (or built-up land). Edge expansion is developing and expanding along existing urban areas' edges (or built-up land). The outlying or the spontaneous growth is the last type of urban growth in which the development of new urban areas (or built-up land) separately develops away from existing old urban areas and occurs independently. It has been seen that before the rise of space-borne technologies, the types mentioned above were mainly studied on a qualitative basis. In recent years however, the development of GIS, remote sensing and other related technologies has helped quantitative studies of urban growth into the mainstream (He *et al.*, 2018), enabling a combination of qualitative and quantitative approaches in the study of urban growth.

In this paper, Landsat images of the past 48 years (1972 to 2020) were used with remote sensing and GIS to explore the natural extent and types of urban growth of the Varanasi city (India) and to analyze its spatial and temporal variability.

Study area

Urbanization has increased many urban problems in Varanasi city. Among these, the decreasing availability of residential and commercial land over time is a major problem, due to which the city is rapidly expanding in the peri-urban areas, uncontrolled and unmanaged (Final Draft Report of Varanasi Master Plan 2031). Therefore, Varanasi city has been selected for the present study for patch-level identification of city expansion and spatiotemporal analysis of its types. It is an ancient religious town (25° 15' North to 25° 22' North and 82° 57' East to 83° 01' East) situated on the western bank of river Ganges (Fig. 1). The Varanasi city is connected with different parts of the country via three national highways (NH-02, NH-29, NH-56), four state highways (SH-73, SH-74, SH-87, and SH-85), three railway lines (northern railway Varanasi branch, northeast railway, northern railway main branch), and an airport. A ring road connecting national highway 56 to 29 are located in the east-west direction at the city's northern boundary. Similarly, Vishwa Sundari bypass road passes through the southern and south-eastern border. The challenges of rapid urban expansion, population growth and traffic congestion are the major administrative issues of Varanasi city and its peri-urban areas today. The complexity of these issues is increasing over time due to increasing public pressure, in which unplanned urban expansion plays a major role. The total population of the Varanasi city is 1599260 (2011). The population growth rate of the

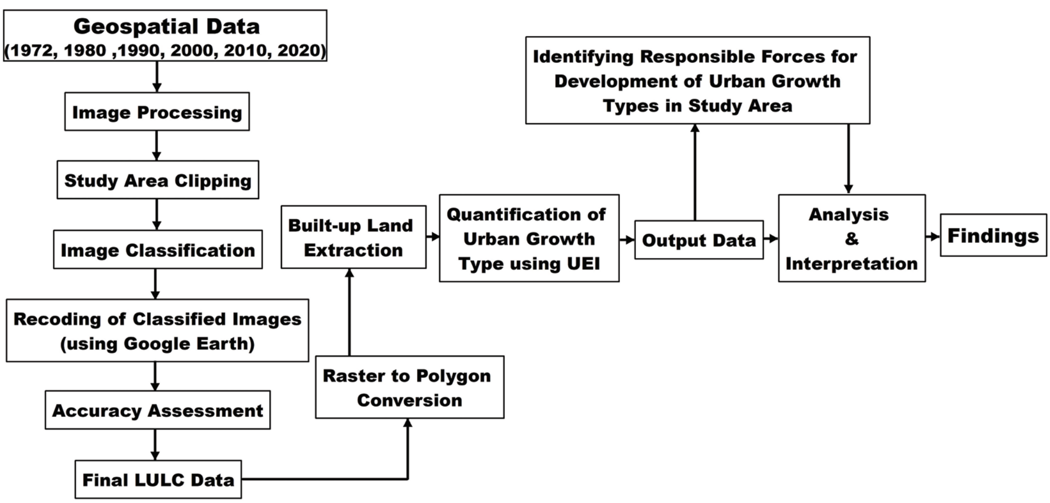

Fig. 2: Methodology

Varanasi city is 26.87 percent which is higher than both the Varanasi district (17.14 %) and Uttar Pradesh state (20.09 %).

Objective

The primary objective of this research is to quantify the characteristics and types of newly grown built-up land patches in Varanasi city and its peri-urban areas.

Methodology

The main purpose of the study is to analyse the characteristics and types of newly grown built-up lands at the patch level in order to make the study more accurate and reliable. The description of the methodology adopted is as follows (Fig. 2).

Landsat images have been processed in different stages of image processing in a GIS environment. The boundary of the identified study area has been fixed up to a buffer distance of 12 km from the city centre so that the generated data can give a logical and scientific basis for analysis. Such data are then classified by the supervised classification method into built-up and non-built-up lands. After classification, the final land use land cover (LULC) data has been obtained by recoding and accuracy assessment processes. After obtaining the final LULC, built-up land has been again classified into four classes viz high-density built-up land, moderate density built-up land, low-density built-up land, and dispersed built-up land, on the basis of pixel density to analyze the spatio-temporal changes in built-up land density. The built-land separation has been performed by converting the original LULC data from raster format (.tiff) to polygon format (.shp) to conduct spatio-temporal studies of the main built-land growth types e.g., infill growth, edge expansion, and outlying growth (Fig. 3). Afterwards, these types were analyzed on the basis of direction and distance from the city centre.

Liu *et al.* (2010) used remote sensing and a GIS based Landscape Expansion Index (LEI) to identify the type of urban growth, it is an index based on the relationship of old and newly developed built-lands. The urban growth types, as mentioned above, have been determined using the Urban Expansion Index (UEI). It is an analogous index that is particularly useful in characterizing the spatial

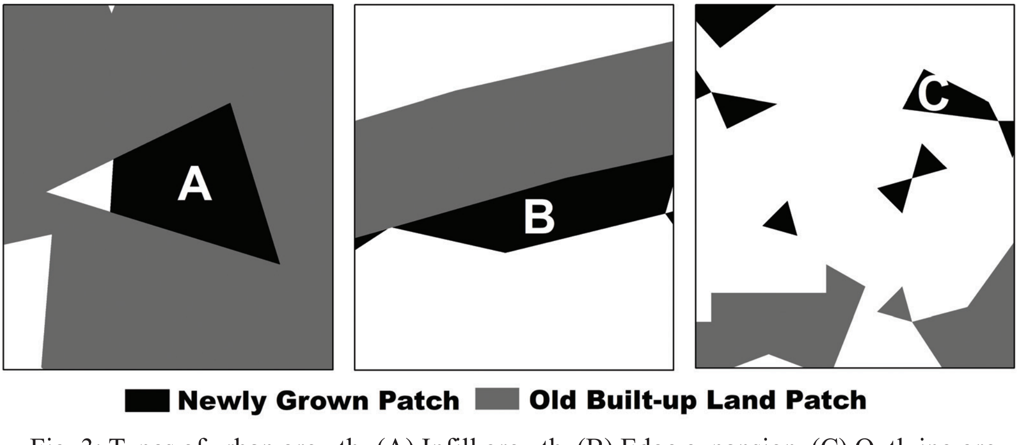

Fig. 3: Types of urban growth- (A) Infill growth, (B) Edge expansion, (C) Outlying growth

Table 1: Types and Values of Urban Growth

UEI Type	UEI Value
Infill Growth	0.50 or 50% < UEI =100 or 100%
Edge Expansion	0 < UEI < 0.50 or 50%
Outlying Growth	0

pattern of built-up land growth. This index identifies the types of newly grown built-up land around the old existing built-up land patches. A Buffer zone of specified distances around newly developed built-up land patches have been used to determine what percentage of the newly developed built-up land's buffer zone overlaps with the surrounding existing old built-up land patches. In this study, this overlapped percentage is the basis for determining the types of newly built-up land. The formula of UEI is:

$$UEI = [\frac{A_o}{A_o + A_v}] \times 100$$

Where UEI is the urban expansion index for newly developed built-up patch, A_o is the intersection area between the buffer zone and the occupied category, and A_v is the intersection area between the buffer zone and the vacant land category (Liu *et al.*, 2010). The value of this index can be anything between 0 and 100 (table 1). Scientific and logical determination of the urban growth types is done on the basis of these values. The relationship between the value of UEI and the type of built-up land growth is described in table 1. The detailed methodology is shown in figure 2.

Thus, the spatial pattern of urban growth types (infill growth, edge expansion and outlying growth) has been determined by computing the UEI for the overall study area. In addition, the UEI has also been computed and analyzed on the basis of direction and distance from the city centre.

Result and discussion

The present study shows that the built-up land area has increased rapidly in the study area while other LULC classes have decreased (table 2). Over the past 48 years, the growth rate of dispersed built-up land (36.95%) has been the highest (table 3). The dispersed built-up land increased from 68.40 ha to 846.50 ha during this period (Table 2). In contrast, the growth rate of low-density built-land (12.47%) was the lowest of all built-up land types (Table 3). In 1972–2020, the area of low-density built-up land increased from 516.24 hectares to 1322.18 hectares (Table 2). The LULC of the study are for different periods as shown in figure 4.

Similarly, high-density built-up land increased from 609.48 hectares to 3965.74 hectares, and medium-density built-up lands increased from 703.80 hectares to 3231.77 hectares with a growth rate of 26.38 and 20.99 per cent respectively, during 1972-2020 (Table 2 and 3). On the other hand, medium- and low-density built-up land had negative growth rates of -5.35 and -3.83 percent respectively, during 1980-1990. Similarly, the dispersed built-up land had a negative growth rate of -3.84 per cent in 2010-2020 (table 3).

Table 3 shows that the growth rate of other LULCs in the last 48 years was -3.06 per cent, and it declined from 34,199.93 hectares to 26662.81 hectares during this period (Table 2). In contrast to the built-up land growth rate, the other LULC had

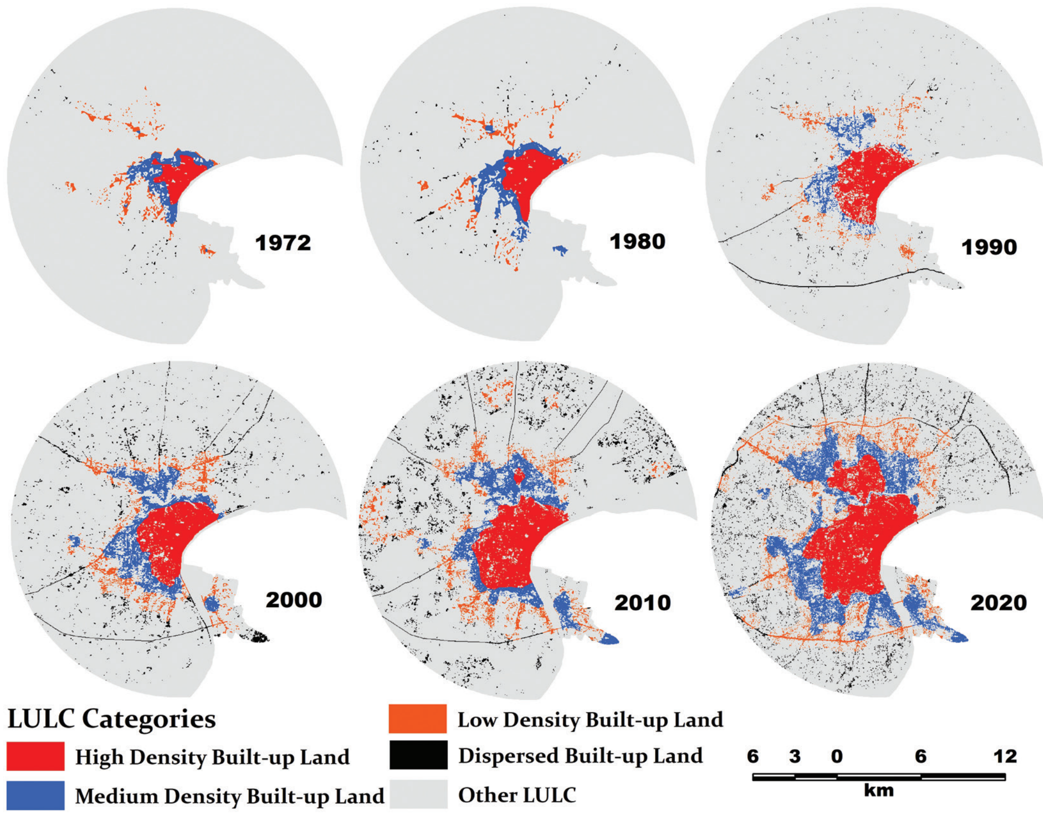

Fig. 4: LULC of the study area in different periods

Table 2: Area under LULC categories in different periods

LULC Class	Area (in ha)					
	1972	1980	1990	2000	2010	2020
High Density Built-up	609.48	1032.12	1529.82	1616.47	2376.99	3965.74
Medium Density Built-up	703.8	942.48	607.32	1318.48	1947.6	3231.77
Low Density Built-up	516.24	563.4	412.38	652.41	1231.56	1322.18
Dispersed Built-up	68.4	132	225.63	515.18	1157.76	846.5
Other LULC	34199.93	33450.55	33245.17	31978.57	29430.09	26662.81
Total	36097.85	36120.55	36020.32	36081.11	36144	36029.01

consistently registered negative growth rates. There has been a steady decline in the other LULC in the study area from 1972 to 2020. The lowest decrease among the other LULC was in 1980–1990 when it had a growth rate of (-0.08%). On the other hand, the largest decrease among other LULC was observed in 2010-2020; when it had a growth rate of -1.34 per cent (table 2 and 3).

Figure 5 shows the spatio-temporal pattern of urban growth types in different

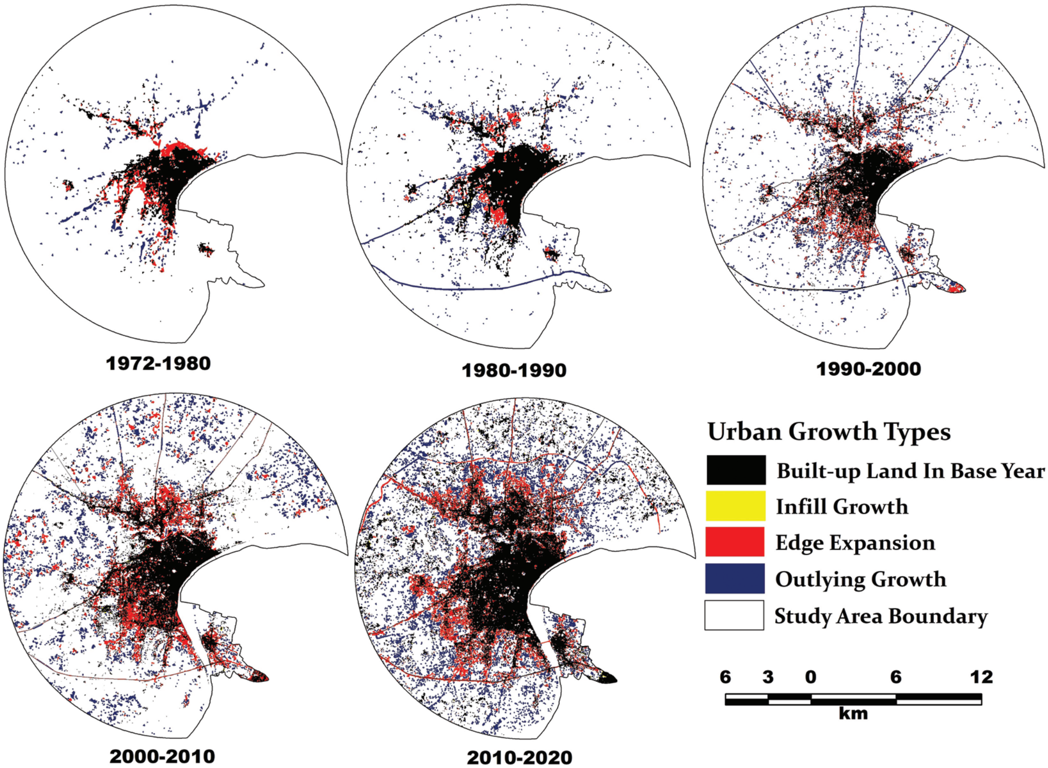

Fig. 5: Pattern of urban growth types in the Varanasi city and its peri-urban areas

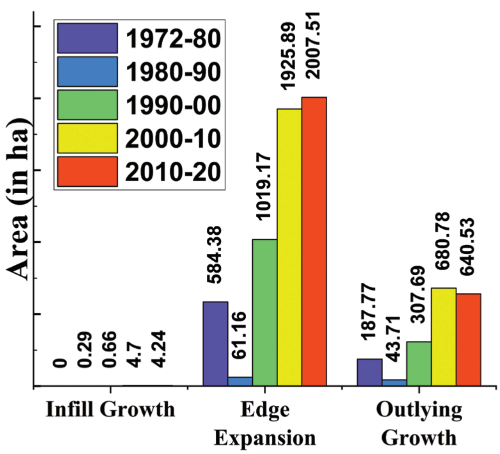

Fig. 6: Area under different urban growth types

periods. The analysis shows that the infill type of built-up land has been increasing steadily over the past decades from 1980. It did not increase in 1972–1980 but increased only marginally in 1980–1990, which was 0.28 percent (0.29 ha) of the total built-up area. The largest increase in infill type of built-land occurred in 2000–2010 (0.18%), covering 4.70 hectares of the entire built-up area (Fig. 6).

The built-up land under infill growth in small patches outside the city centre begins to expand starting from a buffer area of 3 km to a buffer area of 6 km in the 1980-1990. The built-up land under infill growth was absent before 1980–1990. The pattern of built-land development under infill growth in 1990–2000

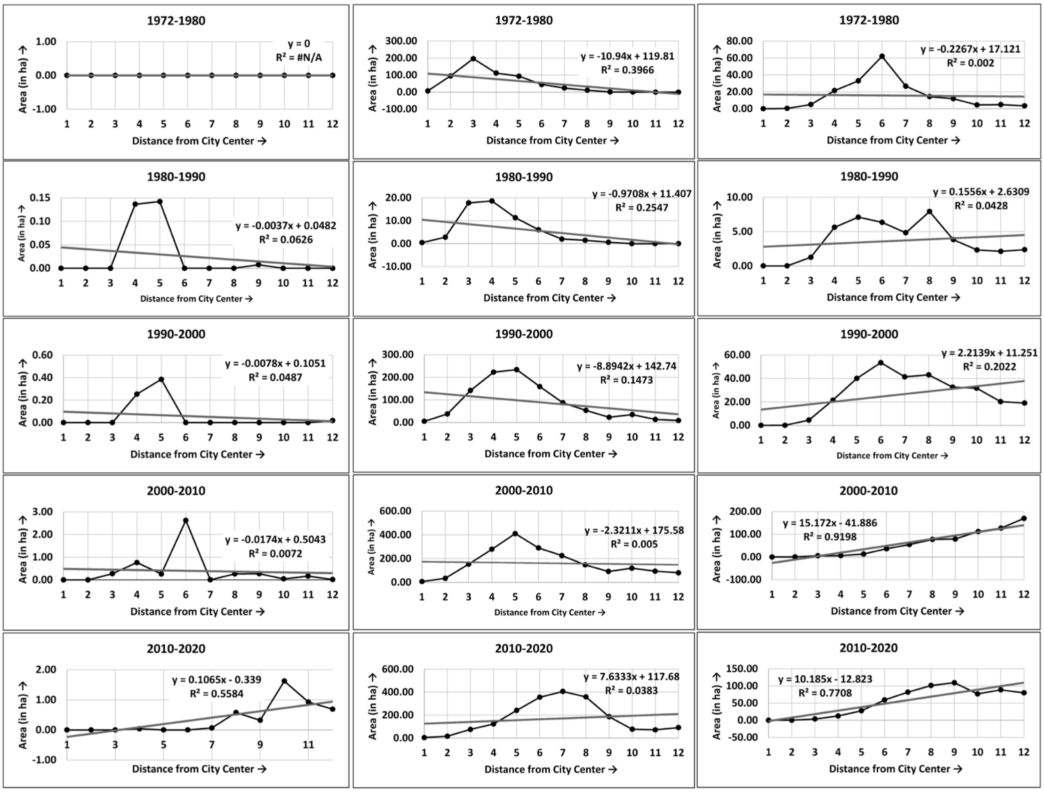

Fig. 7: Distance-based pattern of different urban growth types

Table 3: Growth rates of classified LULC categories in Varanasi city and its peri-urban areas

LULC Class	Area (in ha)					
	1972-80	1980-90	1990-00	2000-10	2010-20	1972-2020
High Density Built-up		5.04	0.69	4.94	6.61	26.38
Medium Density Built-up	3.72	-5.35	10.17	5	6.54	20.99
Low Density Built-up	1.1	-3.83	5.9	8.27	0.89	12.47
Dispersed Built-up	8.56	6.93	10.87	10.65	-3.84	36.95
Other LULC	-0.28	-0.08	-0.48	-1.03	-1.34	-3.06

was also similar to that of 1980–1990. In both these periods, the maximum growth of infill type built-up land was in the 5 km buffer zone. Later, in 2000-2010, the infill type built-up land has expanded to a 6 km buffer area which increased to 7 km in 2010-2020. Overall, figure 7 shows that infill type built-up land has developed over time in a sporadic manner in the spaces between older built-up lands patches located outside the city centre.

The directional pattern of infill type built-up land shows that the growth of infill type built-land is highest in the SW, W, and SE parts. Apart from these areas, N and NW are the other major areas where infill type built-up land growth has been prominent. At present, most of the infill type built-up land is growing rapidly in the N, W and NW regions apart from the SE part (Fig. 8).

Like infill type built-up lands, temporal analysis of edge expansion type built-up lands shows a much smaller increase in the area of edge expansion type built-up lands in 1980–1990 after 1972–1980. Where in 1972–1980, 584.38 hectares (75.69%) of the total built-up land was increased under the edge expansion, while in 1980–1990, only 61.16 hectares (58.16%) of the total built-up land was increased under this type of expansion. After 1990, the share of edge expansion type built-up land in total built-up land grew rapidly (Fig. 6).

The analysis based on distance per km outside the city centre shows that edge expansion type built-up land start from a buffer area of 1km and gradually decreased with increasing distance. In 1972–1980, the largest increase was seen in the buffer area of 3 km under edge expansion type built-up land. After that, it decreased with increasing distance from the city. In 1980–1990, it increased rapidly from a buffer area of 2 km and reached to peak in a buffer area of 4 km. Later, it decreased continuously with increasing distance. In 1990–2000, it began to increase from a buffer zone of 1 km, and in 5 km buffer, the edge expansion type built-land growth reached its peak, then creased with increasing distance. In 2000–2010 it follows the same pattern as 1990–2000. In 2010–2020, edge expansion type built-up area of land increases to 7 km buffer with increasing distance, after that it starts declining (Fig. 7).

The directional pattern of the edge expansion type built-up land growth shows that the highest edge expansions occurred in the W, SW, and S regions in 1972–1980. The major areas of the edge expansion type built-up land growth in the 1980s–1990s were SW, NW, W, and N. Similarly, in 1990–2000, the major areas of edge expansion were NE, S, and SE. The highest growth of the edge expansion type built-up land in 2000–2010 was in the SW and N regions. In 2010–2020, the NW and SW regions saw increases under the edge expansion type built-up land growth (Fig. 9).

The outlying growth type built-land pattern also remained the same as the edge expansion pattern. After 1972-1980, it also decreased in 1980-1990, then it started increasing after 1990 and increased continuously till 2020 (Fig. 6).

A distance-based analysis of outlying built-up land growth shows that there was a gradual increase in outlying type built-up land from the city-centre toward buffer area of 6 km in 1972–1980 and then decreased with increasing distance. In 1980–1990, it extended to a 5 km buffer area. After that it decreased to the next 2 km distance. Then it started increasing rapidly from the 7 km buffer area, and reached its peak at the 8 km buffer area after which it again decreased with increasing distance. In 1990–2000, there was a gradual increase in outlying type built-up land up to a 6 km buffer area. After that, it declined with slight fluctuations towards the periphery. In 2000-2010, this type of built-up land continued to increase outwards from the city-centre, and in 2010-2020, it increased continuously till buffer area of 9 km, and then

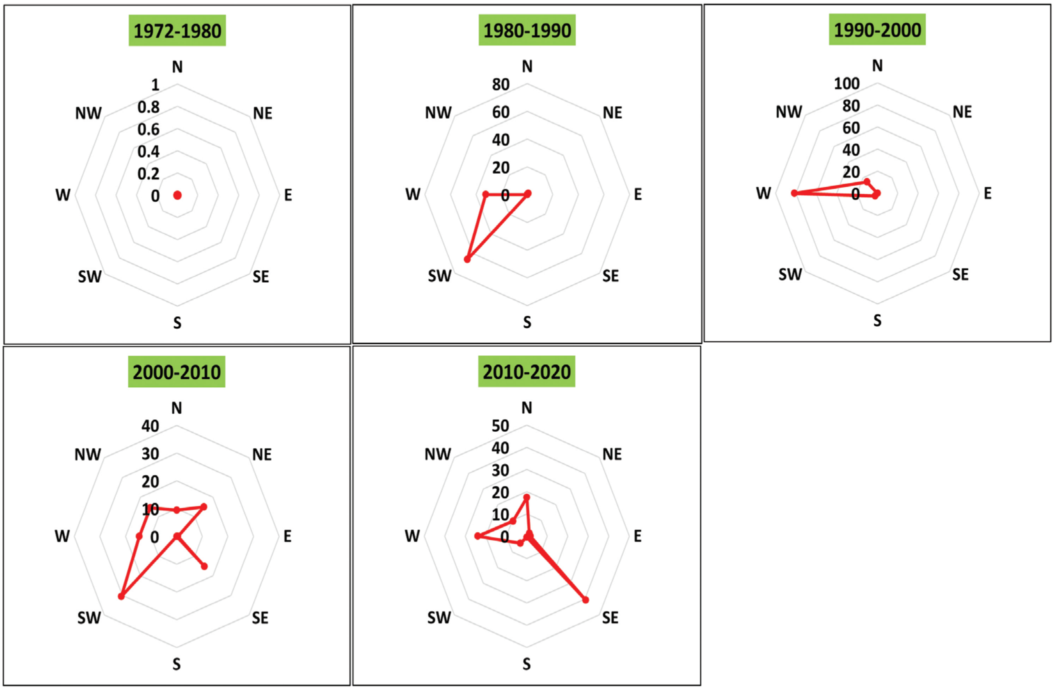

Fig. 8: Directional pattern of infill growth in different periods

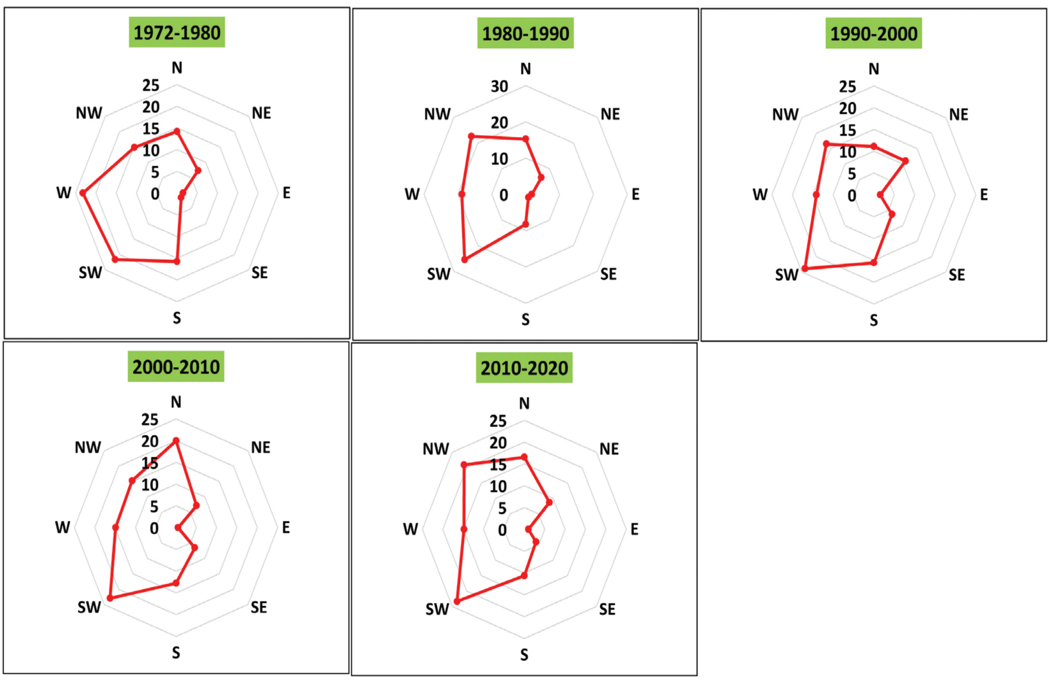

Fig. 9: Directional pattern of edge expansion in different periods

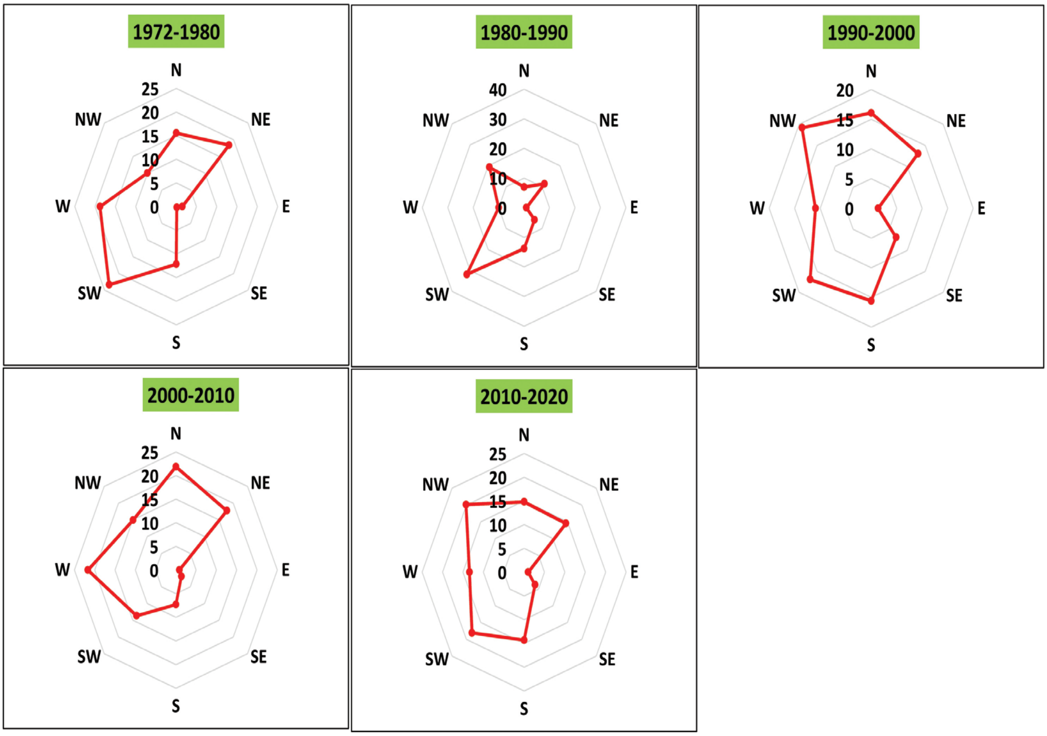

Fig. 10: Directional pattern of outlying growth in different periods

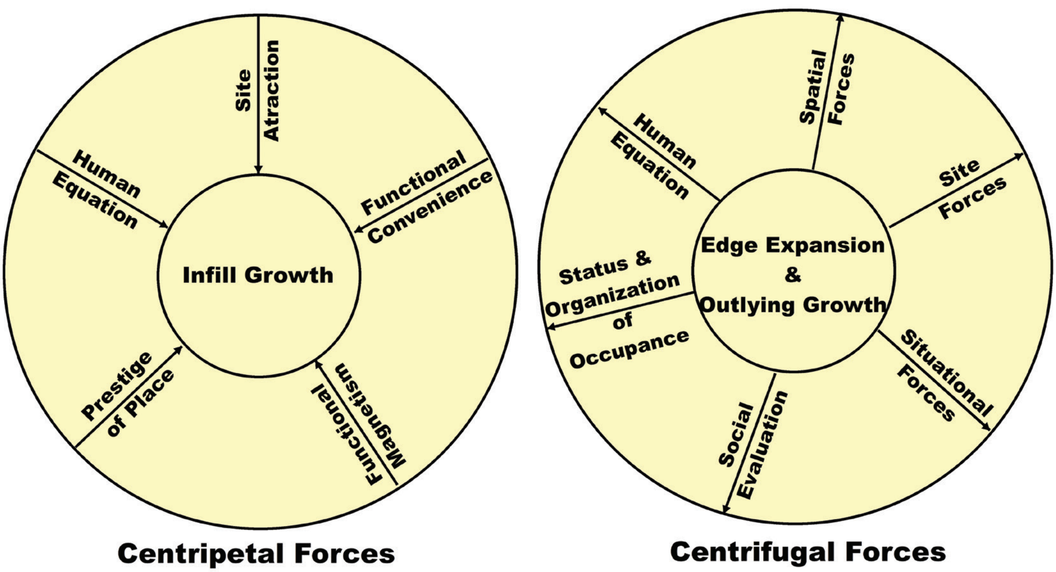

Fig. 11: Responsible forces for development of urban growth types in study area

began to decline with a rise and fall pattern (Fig. 7).

In 1972–1980, the SW, W, NE, and N parts were the major areas of outlying growth. NW and S were the other major areas during this period. It changed again later and in the 1980–1990, SW, NW, and S became the main areas of outlying growth. In the period 1990–2000, the growth pattern changed again, and the NW, SW, S, N, and NE areas became major areas of outlying growth. The N, W, NE, and NW parts became the main areas of outlying growth in 2000–2010, and in 2010–2020, most of the outlying growth occurred in the NW and SW regions (Fig. 10).

The main reason for the infill growth in the study area is the rapid absorption of the remaining urban space to meet the residential and commercial needs of the growing population in the city limits. Here, five main factors appear to have played an important role in promoting infill growth. These are site situation, functional convenience, place magnetism, place prestige, and human equation (Fig. 11). The religious landscape of Varanasi city has always attracted people towards it. Apart from this, it has been observed that the Varanasi city has been a major centre of small and medium scale industries, which acts as the functional magnetism for the surrounding regions. Therefore, apart from its religious and functional prestige, the human equation too has an important contribution among the main reasons behind the infill growth in Varanasi city.

On the other hand, the pattern of edge expansion and outlying growth in the study area shows that more people can shift towards the periphery to find their residential and commercial needs beyond the city limits as the density of built-up land in the city area has increased over time. This trend indicates the increasing influence of the forces of social evaluation here. High urban land value, urban taxes, and various types of urban inhibitions are prominent among these forces of social evaluation. All these together prompt people to settle in places free from high land values, taxes, and urban inhibitions outside the city limits of Varanasi. In an integrated manner, this study reveals that a complex system of spatial forces, site forces, and human equations play an important role in the edge expansion and outlying growth of the Varanasi city in its peri-urban areas (Fig. 11).

The maximum impact of the forces, as mentioned earlier, is working in the NW and SW parts of the study area, due to which the built-up land is rapidly expanding in these areas in the form of edge expansion and outlying growth. On the contrary, the effect of the forces mentioned above in the E, SE, and NE parts is opposite to that of the NW and SW parts, mainly due to the presence of river Ganges and its floodplains in these parts which limits the growth of built-up land in these areas in the form of infill growth, edge expansion and outlying growth. Because of this, the rate of edge expansion and outlying growth in these parts is lowest compared to the other parts of the study area.

Conclusion

Population growth, increase in per capita income, and development of efficient transportation has accelerated the spatial growth of cities in northern India. These cities are rapidly expanding in an unplanned manner due to a lack of effective policy intervention. The influx of newcomers and internal population growth has led to the rapid expansion of built-up land in Varanasi and its peri-urban areas. Due to natural expansion, the built-up land has increased in uncontrolled and unmanaged manner. Therefore, in this research paper, patch-level identification, and spatio-temporal analysis of various types (infill growth, edge expansion, and outlying growth) of uncontrollably growing built-up land in Varanasi city and its peri-urban areas have been presented. In the last 48 years, Varanasi city has been expanding into its peri-urban areas under the influence of factors such as population growth, economic development, improvement in transport facilities etc. Presently its growth direction is North-West and South-West. Over time, built-up land in these areas has increased in the form of edge expansion. Similarly, Trans-Varuna areas have witnessed rapid expansion of built-up lands in the form of edge expansion and outlying growth. These areas have emerged as commercial and residential areas. Similarly, the main reason for the growth of built-up land in the south, south-east and south-west parts is the low cost of land and proximity to the city. This study also observed that the maximum growth of built-up land in the study area had taken place in the form of edge expansion type. Therefore, in policy-making regarding the town planning, adequate attention should also be paid to the types and nature of urban growth in peri-urban areas so that the three main goals of urban planning - efficiency, equity, and sustainability can be achieved. There is also a need to examine local socio-economic factors influencing urbanization, re-urbanization, and urban growth in the peri-urban areas of the city.

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