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*Corresponding author(s)
email: kpsheladiya341996@gmail.com

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Application of Remote Sensing and Geographic Information System in Identification of Urban Growth Nodes: A Case of Surat City, India

Kaushikkumar P. Sheladiya[1]*, Chetan R. Patel[1]

1. *Urban Planning Section, Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, India-395007*

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Abstract

With the passage of time, the city's growth behavior will not change unless and until the government intervenes, and thus its identity will shift from monocentric to polycentric to meet the needs of citizens. As a result, this study is being conducted to identify emerging growth nodes within a selected area of Surat City, as well as their growth drivers over a 30-year period. Quantified built-up area within a patch size of 1km x 1km was used to compute patch density at five-year intervals from 1991 to 2021. In addition, the spatial changes that occurred within patches over the same time period were examined. Both analyses aid in determining the emerging growth nodes over a 30-year period. From 1991 to 2021, the city was driven by socioeconomic criteria such as land price, availability of good health and educational facilities, water and sewerage networks, fire stations, proximity factors such as proximity to major roads, bridges, bus stations, metro, railway stations, airport, environmental factors such as the development of riverfront and linear park, bio-diversity park, and government interventions in terms of Town Planning Schemes. This study thus aids urban planners and decision-makers in selecting which growth nodes to plan for new development and type of development, what to connect, and what to protect in the years to come.

1. Introduction

Future land use regulations will need a better knowledge of spatial urban dynamics throughout time in order to prevent the detrimental effects of urban sprawl, especially in rapidly urbanizing cities and regions that are predicted to see the highest urban growth by 2050 (Getu & Bhat 2021; Jiao, 2015, Jiao et al., 2021; United Nations 2018). Because urban expansion is a complicated and dynamic process that alters the physical and functional elements of a rural environment to create an urban region. Urban growth has been taking place throughout the initial stages of urban development since the region offers a variety of facilities and amenities in its central locations. People therefore choose to reside close to the inner fringe of the city's center, but this trend will have to change since it will come to an end once the inner and outer fringes of cities have become too congested due to population growth and an increase in land costs. They then seek to expand outside of the city in search of affordable property for residential and commercial development, which results in an expansion of the urban boundaries. This situation is known as urban sprawl (Hasnine & Rukhsana 2020).

This process of urbanization leads to changes in urban forms due to many reasons like proximity factors (Jun 2021; Shafizadeh-Moghadam et al. 2017; Thapa & Murayama 2020), socio-economic factors (Li et al. 2013; Lv et al. 2021; Zhou et al. 2020), policy interventions (Altuwaijri et al. 2019; Herold et al. 2005; Mandal, 2019; Mohammadian et al. 2017; J. Wang et al. 2018; Yadav & Ghosh 2019; Yin et al. 2018; Zhou et al. 2020),

environmental factors (Jokar et al. 2013; Shafizadeh-Moghadam et al. 2017; Yin et al. 2018) and topographical factors (Dendoncker et al. 2007; G. Li et al. 2018).

Town planners generally used zoning to differentiate land use as a method of guiding and controlling the growth of urban areas. In the early phase of development, this concept was applied in the planning of developed countries and now it is in developing countries (He et al. 2018; Sheladiya & Patel 2023a). Developing strategies for evaluating various urban development scenarios about potential implications for land use and the advancement of existing spatial plans and policies is of vital importance for urban and regional planners (Al-Ahmadi et al. 2009). Stakeholders, such as those involved in research, modeling, forecasting, and policymaking related to planning for sustainable urban growth, are also concerned about the effects of piecemeal planning in large cities (Sheladiya & Patel 2023b). However, the phase of urbanization and urban development around the world does not follow a uniform pattern. In developed countries, the concentration of population in medium-sized cities has risen dramatically. In India, most small and medium-sized cities are expected to be of regional significance by 2030. As a result, these cities will strengthen their socio-economic conditions and infrastructure and serve the larger hinterland.

Therefore, with passage of time, it is also important to identify the growth nodes that emerged over a time within city and peri urban areas due to various growth factors. In previous studies, mainly, researchers have applied different spatial techniques like urban extent metric, density metric, sub urbanization metric, contiguity and openness metric and compactness metric (Angel et al. 2007; Xu et al. 2020), patch metrics like relative richness (Japelaghi et al. 2019), edge density (Aguilera-Benavente et al. 2014; Japelaghi et al. 2019), patch areas (Aguilera et al. 2011; Japelaghi et al. 2019), patch compactness (Aguilera et al. 2011; Taubenböck et al. 2009). for spatial growth of urban areas. But the rate of urbanization in developing countries like India, also required to understand the emerging growth nodes due to implementation of different policies and schemes to avoid haphazard development within city areas and sub urban areas.

In the field of urban planning, Remote sensing (RS) and Geographic Information systems (GIS) are some of the most used to detect spatial and temporal changes (Deep 2014; Gharaibeh et al. 2020; Sahana et al. 2018; Tripathy & Kumar 2019). Hence, these techniques were used to fulfill the following objectives of this research study (1) To identify the urban growth factors behind the growth of Surat City (2) To quantify the rate of patch wise change within span of 5 years and (3) To check the nature of growth of Surat city.

This paper comprises into four sections. Section 2 is about methodology and data processing using geospatial and remote sensing techniques followed by section 3 decodes the spatial history of city by performing concentric sectoral analysis, patch density (PD) analysis and change in urban areas over a span within a grid of 1 sq.km. Finally, Section 4 and Section 5 includes discussions and conclusions on urban growth nodes and urban growth drivers found for Surat and Pune city from 1991 to 2021.

2. Data and Methods

2.1. Study Area Profile

Surat is well-known for its major diamond polishing industries as well as textile hub of Gujarat state of India. Surat is one of India's most populous cities (Directorate of Census Operations 2011). According to a report released by the National Institution of Transforming India (NITI) Aayog,2020 (Ministry of Housing and Urban Affairs 2021), it took first place in India's SMART city competition in 2021 and placed fifth in India's most livable cities. Furthermore, it is only one of the Indian cities with 0% liquid discharge. The Ministry of Housing and Urban Affairs recently named it the greatest city for public transportation. Its Gross Domestic Product (GDP) was primarily based on textiles until 2001, when it became one of the world's largest and greatest diamond polishing hubs, resulting in the migration of many people from other regions of Gujarat and India to Surat. It steered its natural resources like agricultural land and water bodies. Geographically, it is located in the southern portion of Gujarat state between latitudes 21°18' and 21°40' North and longitudes 72°42' and 72°59' East, with a coverage area of 326.52 square kilometres (Figure 1) (Directorate of Census

Operations 2011). Surat's total population was 44,66,826 people, with a population density of 13,680 people per square kilometre. The city boundaries was recently increased and now covers an area of 340 square kilometres. The city has expanded on both sides of the Tapti River.

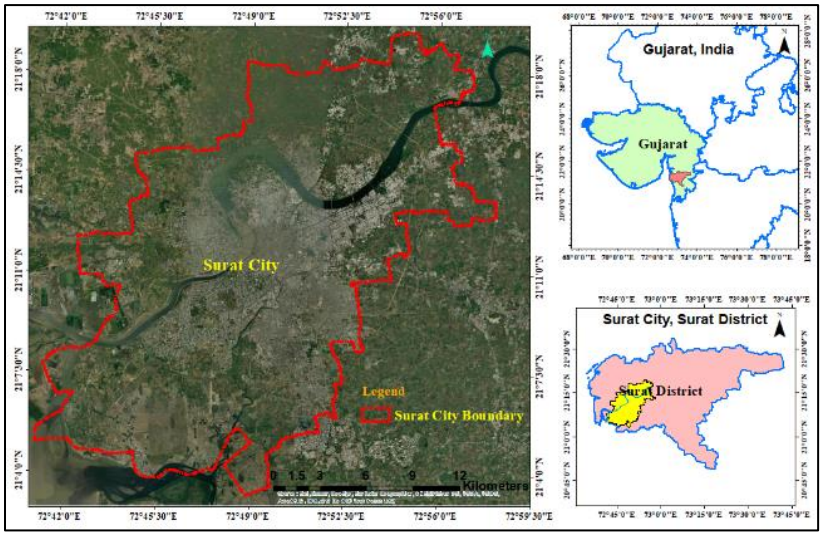

Figure 1. The Map of Surat City

2.2. Methodology and Data Sources

For the current investigation, Landsat satellite data were downloaded for the years 1991 to 2021 across a five-year period, and only those images acquired in January to May from USGS Earth Explorer were chosen to minimise image correction processing, as shown in Table 1. For the years 1991 to 2006, Landsat 5 satellite photos collected by the Thematic Mapping(TM) sensor were utilised, and the satellite images for the remaining years were selected from Landsat 8 images captured by the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) sensors. The resolution of each satellite image is 30 m x 30 m. Further, these images have been pre-processed before they can be used for landuse land cover change analysis.Detailed methodology of study is as shown in Figure 2 and discussed in the following sections.

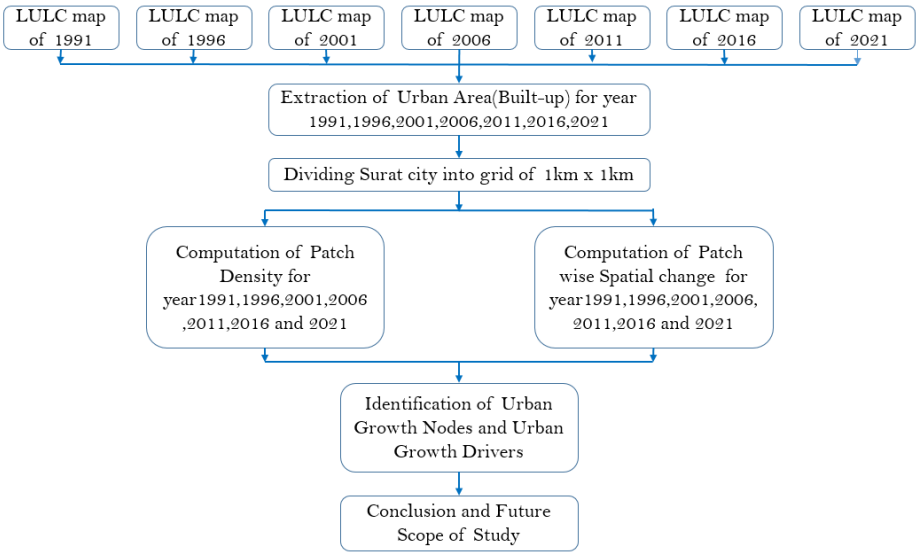

Figure 2. Flow chart of Identification of Growth Nodes and Growth Drivers

Table 1. Spatial Details of Satellite Data

Satellite Image	Year	Resolution	Sensor	Path/Row
Landsat 5	1991	30 m × 30 m	TM	148/05
Landsat 5	1996	30 m × 30 m	TM	148/05
Landsat 5	2001	30 m × 30 m	TM	148/05
Landsat 5	2006	30 m × 30 m	TM	148/05
Landsat 8	2011	30 m × 30 m	OLI/TIRS	148/05
Landsat 8	2016	30 m × 30 m	OLI/TIRS	148/05
Landsat 8	2021	30 m × 30 m	OLI/TIRS	148/05

2.2.1 Quantification of Urban (Built-up) Area

The widespread use of satellite data from various sensors to track spatio-temporal changes on the earth's surface is a result of recent advancements in remote sensing techniques (Roy & Roy 2014) . An important remote sensing application that involves the extraction of thematic information from satellite data is the classification of LULC change. It establishes the user-relevant spectral relationship between the various classes and the spectral signatures (Wulder et al. 2008). Numerous classification methods have been developed to categorize satellite data (Fonji & Taff 2014; Hassan et al. 2016; Islam et al. 2021; Maina et al. 2020). The maximum likelihood classification (MLC) algorithm places pixels into classes based on how likely they are to belong to those classes, reducing the possibility of incorrect classification (Sisodia et al. 2014). The MLC method and ArcMap 10.4.1 software is used in this study. A class's mean and covariance are referred to as the components of a normal distribution in multispectral feature space. Surat's land cover map is broken down into four categories: built-up, vegetation (agriculture & green space), open space, and water bodies for the years 1991, 1996, 2001, 2006, 2011, 2016 and 2021 and built-up is as shown in Figure 3. The producer accuracy, user accuracy, Kappa Index, and ground truth verification of LULC maps were calculated based on 120 randomly chosen ground control points from Google Earth. For further analysis, accuracy and index values higher than 0.8 are used. Table 2 only shows the built-overall up's accuracy and producer accuracy because the goal of the study is to identify patch density and spatial within patch. This made sure that LULC maps could be applied to more in-depth spatial analysis. A built-up area is an area that is used for residential, commercial, institutional, industrial, or transportation purposes in this context.

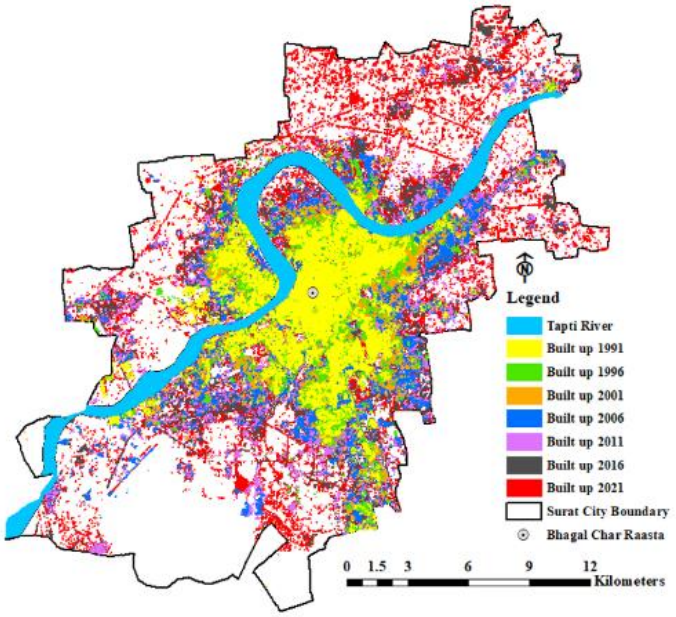

Figure 3. Urban growth of Surat city in 1991,1996,2001,2006,2011,2016 and 2021

Table 2. Producer Accuracy, User Accuracy and Kappa Index of Built-up area from year 1991 to 2021

Year	Producer Accuracy(Built-up)	User Accuracy(Built-up)	Kappa Index
1991	84.21%	80.00%	83.40%
1996	85.00%	81.00%	83.20%
2001	90.00%	90.00%	83.30%
2006	89.47%	85.00%	85.00%
2011	90.00%	90.00%	86.70%
2016	94.73%	90.00%	90.00%
2021	98.75%	95.00%	95.00%

2.2.2 Patch Density Technique

To understand the spatial behaviour of the city at the micro level, many researchers have used the patch density index method (Jiao 2015; W. Wang & Jiao 2020; Xu et al. 2020). To do this, a square grid of 1 km x 1 km is used to divide the city area. Then, according to the following Eq.1, the patch density for each block for the years 1991, 1996, 2001, 2006, 2011, 2016, and 2021 is extracted. Further analysis of the urban growth and the spatial behaviour of Surat and Pune City from 1991 to 2021 is done using these urban land density data.

$$Patch\ Density = \frac{Built\ up\ area\ within\ 1km\ x\ 1km}{Total\ area\ of\ Block} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (Eq.\ 1)$$

3. Results and Discussion

3.1. Analysis of Patch Density Index of Surat City

From the spatial analysis of urban growth as shown in Figure 3, Surat city is primarily expanding in the north east, north west, and south east directions, as opposed to the south west direction. As a result, for further study, the region of 239.93 square kilometres are evaluated, as indicated in Figure 4 for geographical analysis. The land was then divided into 1km × 1km square grids. The built-up area for each 1 sq.km block was clipped for the years 1991, 1996, 2001, 2006, 2011, 2016, and 2021, and the patch density was estimated using eq. (1), as shown in Fig. 5 to Fig.11.

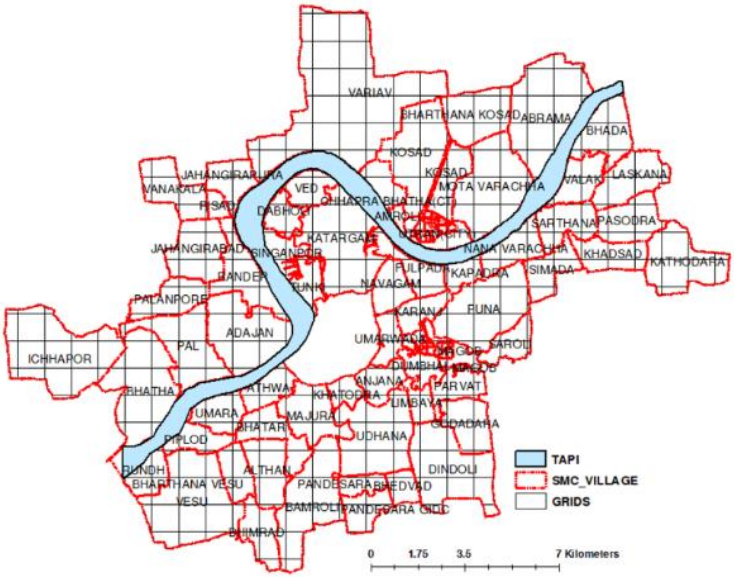

Figure 4. Spatial Grid of Surat City of 1km x 1km

The city is divided into 331 blocks, and its patch density is classified into five categories ranging from 0 to 1 for each year 1991 to 2021, as indicated in Table 3. Density less than 0.2 was found in 270 patches (81.57%) in 1991, but it will be reduced to 108 patches (32.63%) by 2021. While there were only 29 patches (8.76%) with a density between 0.2 and 0.4 in 1991, that number has climbed to 48 patches (14.50%) by 2021. While there were only 18 patches (5.44%) with density between 0.4 and 0.6 in 1991, that number has climbed to 43 patches (12.99%) by 2021. Similarly, there were only 11 patches (3.32%) with a density between 0.6 and 0.8 in 1991, but this climbed to 47 patches (14.20%) by 2021. It is surprising that there were just 03 patches (0.91%) with density between 0.8 and 1.0 in 1991, but this has climbed to 85 patches (25.68%) by 2021.

Table 3. Nos. of Urban Patches in year 1991 to 2021 of Surat City

PD	1991	1996	2001	2006	2011	2016	2021
<0.2	270 (81.57%)	257 (77.64%)	245 (74.02%)	214 (64.65%)	192 (58.01%)	167 (50.45%)	108 (32.63%)
0.2<PD<0.4	29 (8.76%)	29 (8.76%)	22 (6.65%)	33 (9.97%)	39 (11.78%)	42 (12.69%)	48 (14.50%)
0.4<PD<0.6	18 (5.44%	20 (6.04%)	22 (6.65%)	31 (9.37%)	26 (7.85%)	32 (9.67%)	43 (12.99%)
0.6<PD<0.8	11 (3.32%)	20 (6.04%)	28 (8.46%)	33 (9.97%)	39 (11.78%)	39 (11.78%)	47 (14.20%)
0.8<PD<0.1	3 (0.91%)	5 (1.51%)	14 (4.23%)	20 (6.04%)	35 (10.57%)	51 (15.41%)	85 (25.68%)

Adajan, Fulpada, Karanj, Khatodara, Limbayat, Udhna, Majura, Umarwada, Navagam, and Anjana villages would be urban growth centers in 1991 because these areas had patches with a maximum density of more than 50%. While Pandesara, Anjana, Kapadra, Pandesara GIDC, and Rander would be urban growth centres in 1996 because they have the smallest change in maximum patch density from 1991. Dindoli, Kosad, Magob, Parvat, Puna, Singanpore, and Tunki would be urban growth nodes because the minimum change in maximum patch density was greater than 0.30 in these villages. Between 2001 and 2006, the Nana Varachha and Mota Varachha areas became more people-centric because the changes in maximum patch density were 0.26 and 0.32, respectively. Ichhapore, Jahangirabad, Khatodara, Kosad, Mota Varachha, and Sarthana will be urban growth centers in 2011 because patches fall in these areas added at least 0.27 density in previous years patch density. Chhaprabhatha, Pal, Pasodara, and Rundh had added more than 25% patches to the areas, making them urban growth nodes by 2016. Vesu, Bharthana Kosad, Bharthana Vesu, Chhaprabhatha, Bhedavad, Saroli, Jahangirpura, and Variav were built up by more than 25% from 2016 to 2021 and will be people's preferred location by 2021. While maximum patch density increased by at least 80% in Dindoli, Althan, Bharthan Vesu, Chhaprabhatha, Gadodara, Magob, Mota Varachha, Palanpore, Parvat, and Puna.

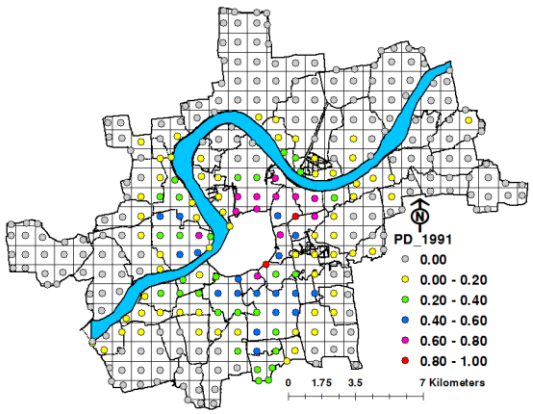

Figure 5. Patch Density of Surat City in 1991

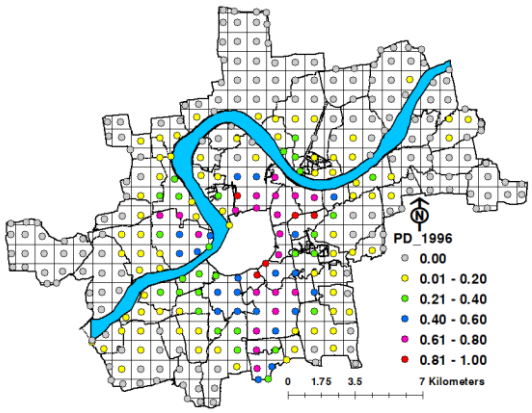

Figure 6. Patch Density of Surat City in 1996

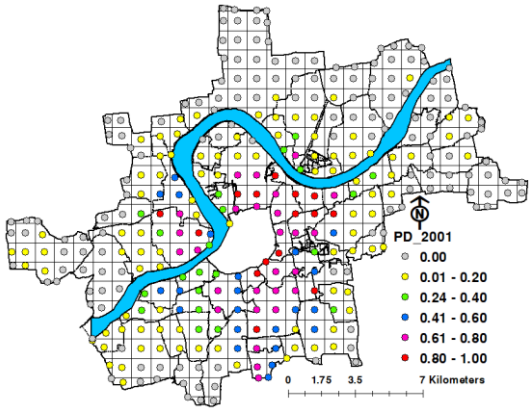

Figure 7. Patch Density of Surat City in 2001

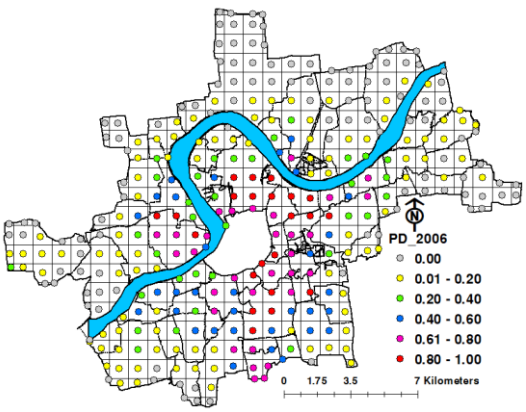

Figure 8. *Patch Density of Surat City in 2006*

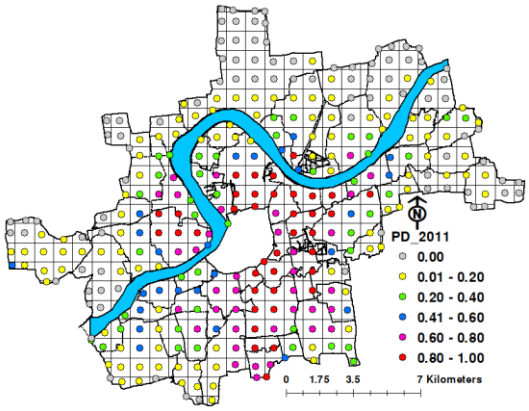

Figure 9. Patch Density of Surat City in 2011

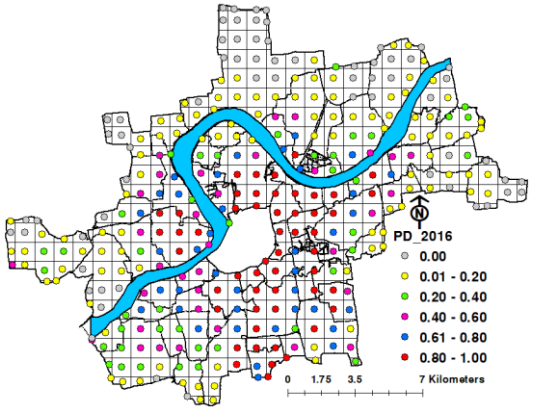

Figure 10. Patch Density of Surat City in 2016

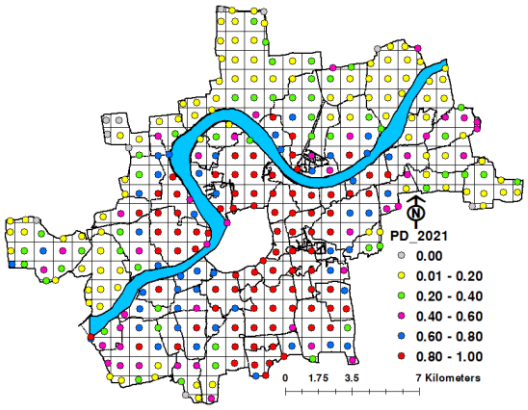

Figure 11. *Patch Density of Surat City in 2021*

3.2. Spatial Change in Patch Area from year 1991 to 2021

The spatial behavior of rapidly increasing urban areas is also examined by computing change in urban areas inside patches from 1991 to 2021 at five-year intervals. According to Figure 12 to Figure 17, the greatest change occurred in Anjana by adding 5.97 ha, followed by 5.81 ha in Pandesara, 5.47 ha in Pandesara GIDC, and 5.38 ha in Udhna. Maximum urbanization in these areas was achieved with the establishment of textile industry between 1991 and 1996. By year 2001, maximum urban change took place in Dindoli (6.09 ha), Bhatar (6.77 ha), Adajan (5.79 ha), Kosad (5.26 ha), Katargam (6.64 ha), Parvat (6.81 ha) and Puna (9.72 ha). By year 2006, maximum development took place in Puna area by adding 12.77 ha area followed by 9 ha in Dindoli

followed by 7.92 ha in Adajan area. Out of these, Adajan and Puna area are residential nodes while Dindoli acted as a Textile and Industrial nodes.

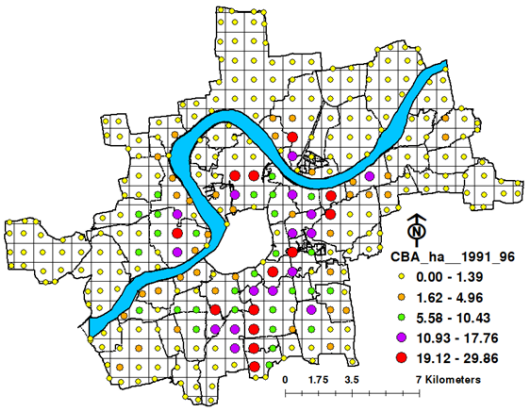

Figure 12. *Patch wise change in built up area from year 1991 to 1996*

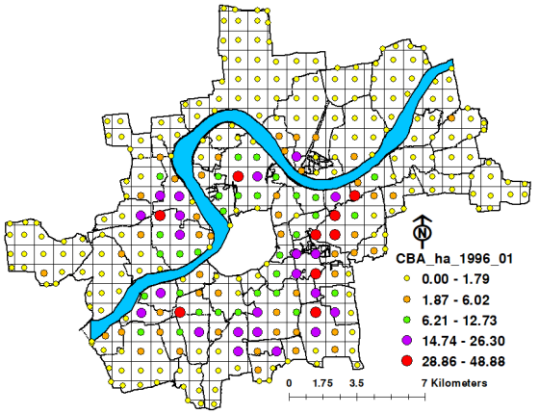

Figure 13. Patch wise change in built up area from year 1996 to 2001

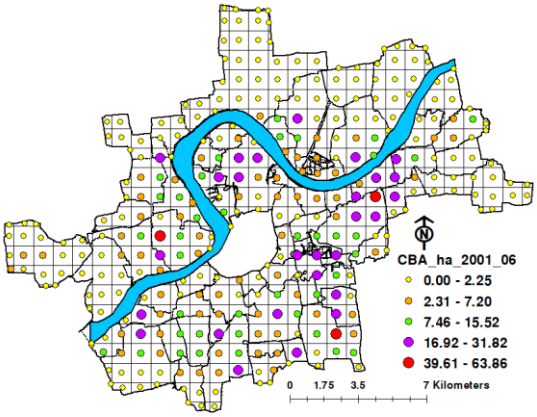

Figure 14. Patch wise change in built up area from year 2001 to 2006

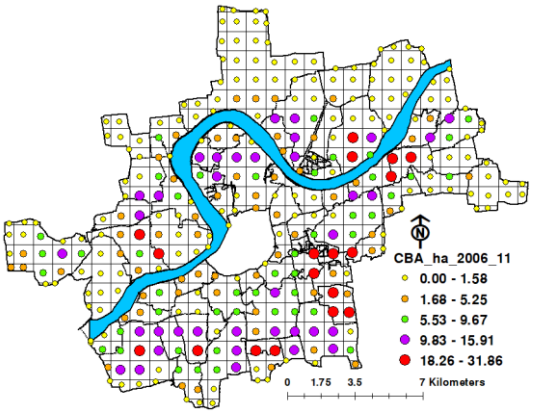

Figure 15. Patch wise change in built up area from year 2006 to 2011

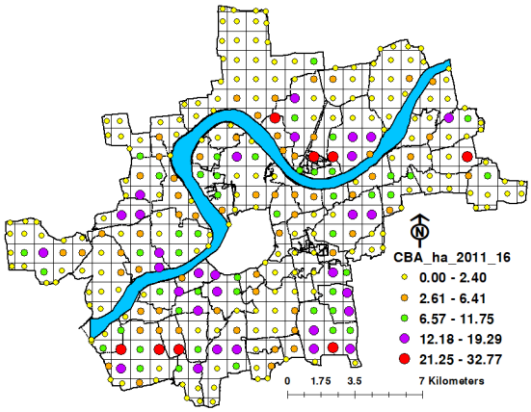

Figure 16. Patch wise change in built up area from year 2011 to 2016

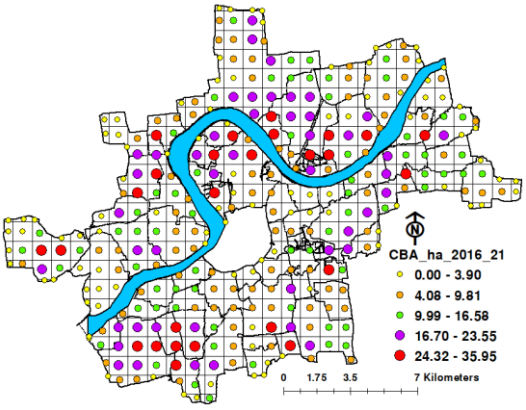

Figure 17. Patch wise change in built up area from year 2016 to 2021

From year 2006 to 2011, Mota Varachha has added 6.37 ha followed by 5.73 ha in Nana Varachha followed by 5.61 ha in Vesu. All these are residential and mixed land use nodes. Which indicates that the Surat

City was expanding in North East and North West directions compare to other sectors. By year 2016, new development was found in Bharthana Vesu by adding 5.94 ha area followed by 5.53 ha in Mota Varachha. By year 2021, new development was found in Parvat by adding 6.73 ha area followed by 6.68 ha in Mota Varachha followed by 6.48 ha in Ichhapore.

In 1991, all urban growth was concentrated within a 5 km radius of the city center before being dispersed. In terms of proximity factors, significant drivers were identified, including inner ring roads, major roads, bridges, bus stations, and railroad stations. Adajan, Rander, and Amroli's urban development only took place as a result of the presence of bridges that allowed for simple access to the city Centre. The land was priced at 1400 Rs/sq.m. from a socioeconomic standpoint, making it a center of commerce at the time. In Udhna, Pandesara, and Limbayat, Khatodara, industrial activity was concentrated. These areas were well-located in relation to major thoroughfares for the import and export of goods. While the main centres for employment in the diamond and textile industries were Katargam and Karanj. As part of the Town Planning Scheme (TPS), the government also made interventions in places like Katargam, Navagam, Fulpada, Karanj, Umarwada, Bhagal, Anjana, Dindoli, Majura, Khatodara, Umra, Athwa, Piplod, Adajan, and Rander. Before 1991, the plan to designate these areas as TPS was announced, and satellite images showed that urbanization was a result.

While the central area of the city became denser than in 1991, urban expansion in 1996 primarily took place in the north east, south east and northwest directions. The occurrence of urban growth in these directions was greatly influenced by TPS in terms of government interventions. People bought less expensive land for residential use as a result. In this way, the occurrence of urban growth in north east was primarily caused by both government interventions and socioeconomic factors. Due to proximity to major roads, the development of new textile industries in Udhna and Pandesara, as well as government interventions with a view to TPS in Bhestan, urban sprawl occurred in the eouth east directions. Urban growth in the directions of south west is a result of TPS declarations in the Bhatar, Majura, Althan, and Vesu regions as well as proximity and socioeconomic factors, such as the availability of cheaper land for commercial and residential purposes.

New urban areas were discovered in the years 2001 in north east, south east, south west and north west directions. Due to government interventions, including its designation as a TPS prior to 2001, proximity to important roads, and affordable land, Puna became a residential area in 2001. The textile industry had potential in Puna and Nana Varchha as well as Karanj, which was known for its diamond industry. Due to proximity, government interventions, and socioeconomic factors, Magob and Dumbhal experienced urban development in the south east directions. Additionally, Dindoli in south east, Pal in south west, Palnpore, Jahangirabad and Pisad in north west, all experienced urban growth. It was only possible due to easy access to amenities (such as medical and educational facilities), major roads, plans to create TPS, and socioeconomic standards.

The State Government increased their limit to 326.52 sq. km from 112.28 sq. km to include suburban development between 2001 and 2006 because by 2001, areas within the city and a distance of 7 km from the city centre were nearly 50% developed. Urban growth was observed in 2006 in Kosad, Utran, Sarthana, Simada (north east), Bamroli, Magdalla (south west), Dabholi, Ved and Jahangirpura(north west). The main factors influencing urban growth were proximity factors (important roads, railways, and bus stations), government TPS interventions, an environmental factor (Sarthana Nature Park), and socioeconomic factors.

SMC began offering public transportation in 2007 in the form of BRTS & SITILINK, which gave residents easy access to facilities. By 2011, government interventions were the main causes of the city's urban growth in the directions of Variav and Chhaprabhatha, Mota Varachha (north east), Parvat, Gadodara, Bhedvad(south east), and Dumas in south west. Additionally, the Pradhan Mantri Awas Yojna (PMAY) housing projects in Kosad and Utran are responsible for urban growth in the north east direction. In terms of environmental factors, Khajod's solid waste disposal site represented the absence of urban development in

south west direction. On peri-urban areas like Laskana, Khadsad, Ichhapore, Velanja, Kathore, Dumas, and Bhimpore, some new urban patches were also discovered.

New urban development appeared in the north east, south east and south west directions in 2016. The government intended to establish TPS in Gothan, Laskana, Pasodara in the north east, Sonari, Unn, and Vadod in the south east, and Bhatha in the south west direction. When deciding where to locate residential and commercial activities, Bus Rapid Transit System (BRTS) and Sitilink services, as well as an expansion of the road network, were very important factors. The development of linear parks in Pal and Adajan, as well as other areas of the city, had an impact on the environment. While textile and chemical industry establishments served as socioeconomic criteria.

In 2021, urban expansions were taking placed in all directions. In which, Variav, Segva Syadla, Gothan, Velanja,Umra,Kathor, Abrama, Bhada, Valak, Laskana, Khadsad, Kathodara, Pasodara in north east, Saroli ,Godadara,Dindoli, Sonari, Vadod, Unn in south east, Khajod, Jiav, Budia, Gabheni,Bhimrad, Bhimpore, Vesu, Sarsana, Dumas, Sultanabad, Vanta, Rundh, Bhatpore, Ichhapore, Bhatha in south west, Asrama, Bhesan, Palnpore, Jahangirbad, Vihel, Jahangirpura,Pisad and Variav in north west directions. Major urban growth drivers behind this urban sprawl were two outer ring roads proposed by Surat Urban Development Authority (SUDA) in SUDA Development Plan (DP) 2035, declaration of Surat airport as an international airport, a proposal of a dream city for Diamond Industry, the commencement of metro work and passing of Dedicated Freight Corridor(DFC) proposed by the central government from city boomed the urban growth within central part as well as urban sprawl in peri-urban areas. These development proposals will boost the economy of Surat city. Now, a central part of cities within a distance of 10 km became fully saturated and they started shifting from inner parts to outer parts. Because they are getting more carpet area after 10 km from the city center in the same price as in within 10 km from the city center.

3.3. Discussion

In previous studies, mainly, researchers have applied different spatial techniques like urban extent metric, density metric, sub urbanization metric, contiguity and openness metric and compactness metric (Angel et al. 2007; Xu et al. 2020), patch metrics like relative richness (Japelaghi et al. 2019), edge density (Aguilera-Benavente et al. 2014; Japelaghi et al. 2019), patch areas (Aguilera et al. 2011; Japelaghi et al. 2019), patch compactness (Aguilera et al. 2011; Taubenböck et al. 2009) for spatial growth of urban areas. But the rate of urbanization in developing countries like India, also required to understand the emerging growth nodes due to implementation of different policies and schemes to avoid haphazard development within city areas and sub urban areas. Therefore, in this study city is divided into grid of 1km x 1km to understand the role of growth drivers in driving the cities from 1991 to 2021 based on patch density and change in patch wise urban areas at an interval of five years.

Spatio-temporal analysis showed that mainly three types of drivers lead the Surat city in a span of 30 years i.e.(1) proximity factors like proximity to highway (Shafizadeh-Moghadam et al. 2017), proximity to railway station (Yang et al. 2020), proximity to airport (Kantakumar et al. 2020), proximity to bus station (Bharath et al. 2018), proximity to parks (Jokar et al. 2013; Lu et al. 2018), proximity to public institutions (Jun 2021), proximity to central business district (CBD) (Thapa & Murayama 2020) and proximity to planned new district center (Yin et al. 2018) (2) Socio-economic factors such as employment potentials (Dadashpoor et al. 2019) and land prices (Jokar et al. 2013; Tang et al. 2020; Yilmazer & Kocaman 2020; You and Yang 2017) (3) Government intervention such as town planning and development plan policies (Herold et al. 2005). There is no role found of environmental and topographical factors in restricting the urban expansion of city in any direction. However, these factor played role in growth of city as study carried out by (Chang & Joyce 2018; Dendoncker et al. 2007; Huang & Song 2019; Jun 2021; G. Li et al. 2018; Liang et al. 2021; Shafizadeh-Moghadam et al. 2017; Thapa & Murayama 2020; Yang et al. 2020; Yin et al. 2018; Zhou et al. 2020).

Hence, this study will help in providing precise information of urban growth patterns and Land use land cover change to policy makers and urban planners, in order to estimate and assess the rate of urbanization, its location, consequences of before and after development to ensure planned urban growth (Jokar et al. 2013; Sheladiya, 2023).

4. Conclusion

Grid wise patch density analysis from 1991 to 2021 based on remote sensing and geographic information system showed that Surat city primarily expanding in the north east, north west, and south east directions, as opposed to the south west direction. In 1991, 81.57% of patches having urban land density less than 0.2 which reduced to 32.63% by 2021. Also, it is surprising that there were just 0.91% with density between 0.8 and 1.0 in 1991, but this has climbed to 25.68% by 2021.

From 1991 to 2021, the city was driven by socioeconomic criteria such as land price, availability of good health and educational facilities, water and sewerage networks, fire stations, proximity factors such as proximity to major roads, bridges, bus stations, metro, railway stations, airport, environmental factors such as the development of riverfront and linear park, bio-diversity park, and government interventions in terms of TPS. These growth sources are sufficient to demonstrate that the city's growth is primarily policy driven. However, as time passes, the spatial behavior of the metropolis changes, and it shifts from monocentric to polycentric.

Based on the patch density analysis and change in built up area, identified growth nodes are; Adajan,Fulpada,Karnaj,Khatodara,Limbayat,Udhna,Majura,Umarwada,Navagam,Pandesara,Pandesara GIDC and Anjana in year 1991; Pandesara, Anjana, Kapodara, Pandesara GIDC, Udhna and Rander in year 1996; Dindoli,Kosad,Magob,Parvat,Puna,Singapore,Bhatar,Adajan,Katargam and Tunki in year 2001; Puna, Dindoli, Adajan, Nana Varachha and Mota Varachha in year 2006; Ichhapore, Jhangirabad, Khatodara, Kosad, Mota Varachha,Nana Varachha,Vesu and Sarthana in year 2011; Bharthana Vesu, Mota Varachha, Chhaprabhatha, Pal, Pasodara and Rundh in year 2016 and Vesu, Bharthana Kosad, Bharthana, Chhaparabhatha, Bhedvad, Saroli, Jhangirpura, Parvat, Mota Varachha, Magob and Variav by year 2021. Further, this study can be linked in urban growth modelling for inspecting specific scenarios for implementation of new government schemes by using advanced machine learning models.

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