Urban Growth Analysis of Rajkot City Applying Remote-Sensing and Demographic Data

Shaily Raju Gandhi*
CEPT University, Ahmedabad

Urban sprawl is one of the most avidly followed urban issues in India. The spatial and demographic processes of urban growth, and the societal implications along with cultural and financial aspects of economic development, need to be monitored closely while working on smart city projects. For decades, urban planners and governments aim at monitoring the dynamics of urban expansion. This paper applies a remote-sensing analysis of Rajkot, one of the fastest developing cities in India, during 1961-2011 and proposes a forecast for the development of the area by 2031. By doing that, the paper provides a methodology for the creation and the analysis of remote-sensing data in different wards and presents population scenarios for the city.

Keywords: *Urban Growth, Geographic Information System, Spatial, Temporal, Remote Sensing*

INTRODUCTION

As more and more people leave their villages and farms to live in cities, urban growth extends the spatial and demographic process and urbanization takes place. In addition to the natural increase of population, the migration from neighboring towns and villages results in the increased importance of towns and cities as a concentration of population within a particular economy and society (Clark, 1982). The rapid growth of cities strains their capacity to provide services such as social, economic and physical infrastructure (United Nations, 2005B). This is one of the many implications of urban development in the recent social and economic history. The broad view on urban sprawl and the related infrastructure systems is necessary to create a comprehensive analysis and understanding of urban sustainability and to facilitate better planning (Rahnama et.al., 2020).

Fast urban growth and the deficiencies related to urban sprawl are among the main concerns in cities today, including patterns such as low density (Glaeser & Kahn, 2004; Fulton et.al., 2001), leapfrogging, distance to central facilities, disper-

* CEPT Research & Development Foundation (CRDF), Near AES Boys Hostel Campus, University Ground, Navrangpura ,Ahmedabad, India. shaily.gandhi@cept.ac.in; shaily.gandhi@gmail.com

sion of employment and residential development, and continuous strip development (Galster et.al., 2001). According to Angel et al. (2007), the extension of the area of cities beyond the walkable range, and the emergence of endless cities are described as sprawl (Angel et.al., 2007). "Sprawling" means the spreading of urban area towards rural areas surrounding it (Eryilmaz et.al., 2008). The concept of sprawl describes a situation of unauthorized and unplanned development, often at the fringe areas of cities in haphazard and piecemeal construction, sometimes in non-conforming land-uses, along roads adjacent to specified city limits. The field of urban sprawl is characterized by a situation where urban development adversely interferes with the environment (Rahman et.al., 2008).

Urban sprawl has aroused wide social focus because it can impede regional sustainable development. An empirical research by Bengston et.al. (2005) shows that public concern about the impacts of sprawling increased over the latter half of the 1990s. Related studies have come out consequently which mainly cover patterns, processes, causes, consequences, and counter measures.

While urban sprawl has been widely criticized in both developed and developing countries, planning and administration of urban growth still need quantitative dimensions of growth patterns for better monitoring and analysis. With the progress of modern remote sensing techniques, earth-observation-based monitoring of urban growth has been widely accepted and implemented by national, regional and local governments as a prerequisite for spatial and temporal comparisons to detect change. Various methods have been put forward in recent literature (Li and Yeh, 2001), applying multi-temporal and multi-source imagery. These methods include spatial, statistical, economic and integrated indicators.

Urban growth was classified into five main categories based on levels of compactness and sprawling (Batty et. al., 2003) as shown in Figure 1. Classification and quantification of urban sprawl are the starting points towards combating ill-effects of urban sprawl.

When we consider urban growth as a system, in particular a complex system, we need to uncover the unique characteristics shared in the system and those that distinguish it from other systems. This exploration can be conducted along the system's boundaries with questions like: Where is urban growth occurring from a systemic perspective? How does the transition from non-built to built urban areas and land uses such as residential or commercial functions, take place? Although the focus of this research is on the physical expansion and the effect of demography on the expanding of urban boundaries, the functional aspects have to be taken into account in interpreting the causal effects. For example, activities at a ward may influence the change in space at another ward; and the same with activities in different periods and future spatial changes. Therefore, space and activity are basic elements to monitor, e.g., demographic data indicate employment rates, household and residential units, and other factors of sprawling.

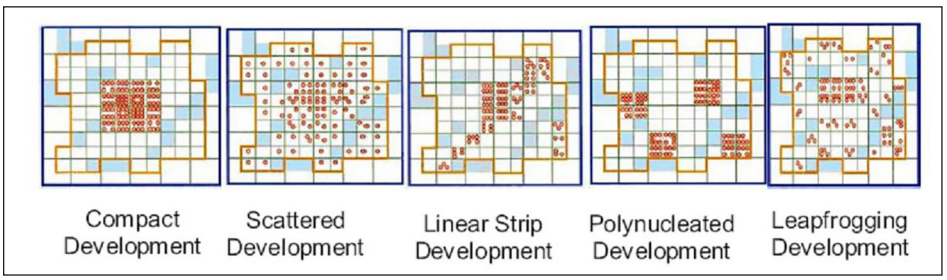


Figure 1: Urban Sprawl Pattern (Source: Batty et.al., 2003)

Previous works indeed tried to define comprehensive indicators to monitor urban progress toward various goals. For example, do all urban areas experience greenness loss with urban growth? (Czekajlo et al., 2020). Can an urban greenness score indicate such dynamics?

Remote sensing technology can play an important role in studying the pattern of urban growth and provide spatial and temporal information about almost any element, infrastructures, land cover and land use (Bhatta, 2010), detecting and measuring urban form and functions based on morphological features such as the shape and density of built areas (Webster, 1995). The resources, costs and time required for satellite data compared to traditional survey methods (Dong et. al., 1997) made these techniques a viable alternative to conventional survey and ground-based urban mapping methods, especially for developing countries.

To add on the more technical level, four dimensions in remote sensed images (spatial, spectral, radiometric and temporal) are considered to capture, store, retrieve, manipulate, analyze and present the geospatial data to support decision making, e.g., for planning and management of land–use, natural resources, environment, transportation, urban facilities and more public and private goals. With multi-temporal analyses, remote sensing provides a unique perspective of how cities evolve, continuously monitoring urban areas in a synoptic view. In a previous study by Pathan & Jothimani (1985), for example, the urban sprawl of Rajkot, Bhavnagar and Jamnagar was assessed using multidate data (Landsat MSS) in a digital technique useful to classify dense, moderate and sparse built urban environments (enhanced false color composites prepared using linear stretched data).

The objective of this study is to analyze the spatio-temporal change in the urban area of Rajkot city in India, and specifically, to determine the pattern and direction of Rajkot's demographic growth from 1961 to 2011 using parameters like the number of households, population, literacy and employment. The temporal data is used to project future population trends.

STUDY AREA

India's urbanization rate is increasing day by day. With a population of more than 1.2 million, Rajkot is one of the fastest developing cities, located in Saurashtra region of Gujarat State, in the western part of India. Gujarat is one of the fastest urbanizing states in India, after Tamil Nadu and Maharashtra. Growing urbanization leads to increasing number of cities as well as the population growth which has a great impact on cities' spatial growth. In this study, Rajkot's urban area has been analyzed using the historical data and the remote sensing satellite data. The analysis shows that Rajkot urban area has grown 1209% in size from 1900 to 2011 and almost doubled during 1992 to 2011. A detailed ward level study has been taken up which is useful in understanding the causes of rapid vs. slow development in different wards.

Effects of urbanization include change in urban density and administration services. Rajkot had adopted smart city solutions, being among 100 cities selected to the Smart City Mission of the Ministry of Urban Development (MoUD) that was launched by the Government of India in June 2015.

The history of the city is important for the analysis of historical expansion of the area and its urban development. Rajkot was founded by the ruler of Sardhar in 1608 A. D. on the west bank of the river Aji as a small fortified town, became a Princely State in 1805, and developed to a prosperous metropolitan area today. After the British government established its camp in 1822 the town opened new directions of growth. The industrial development of the city started when the first textile mill in the region was founded, towards the end of 1910; about 60 industrial units came into existence between 1900 and 1920, which induced development. Around the year 1940, new industrial estates, residential areas, schools, colleges, and cinema houses came into being. In the earlier period, the establishment of cloth mills in the city led to the development of new residential areas like Millpara, Harishchandra Plot, Gundawadi, Kevdawadi, and transport companies opened head offices at Rajkot. The Industrial Estates known as Bhaktinagar Industrial Estate and Aji Industrial Estate were established. Trade and industry fast developing in the city attracted foreign investment during these periods. With increasing industrial and commerce activity, there has been tremendous growth in the population of the town (Rajkot Municipal Corporation, 2005). The built-up area has become nearly double in the past ten years.

Rajkot is situated in the middle of the peninsular Saurashtra in the central plains of Gujarat State of Western India at a height of 138 m above mean sea level, and it lies between latitude 20°18′ N and longitude 70°51′ E. Rajkot city is well connected with other parts of the country by rail, road and air. The city has several natural water reservoirs (lakes) on the eastern part (Rajkot City Development Plan, 2012). Total administrative area of Rajkot is 104 km^2 (Census of India, 2011). Figure 2 shows the map of Rajkot city with its ward boundaries. The study area for this study includes the Rajkot urban area with its outgrowths: Madhapar and Manharpur in

the North West of Rajkot city; Bedi in north east direction of the city; Munjka and MotaMava outgrowth in the western region; and Vavdi and Kotharia outgrowth in the south.

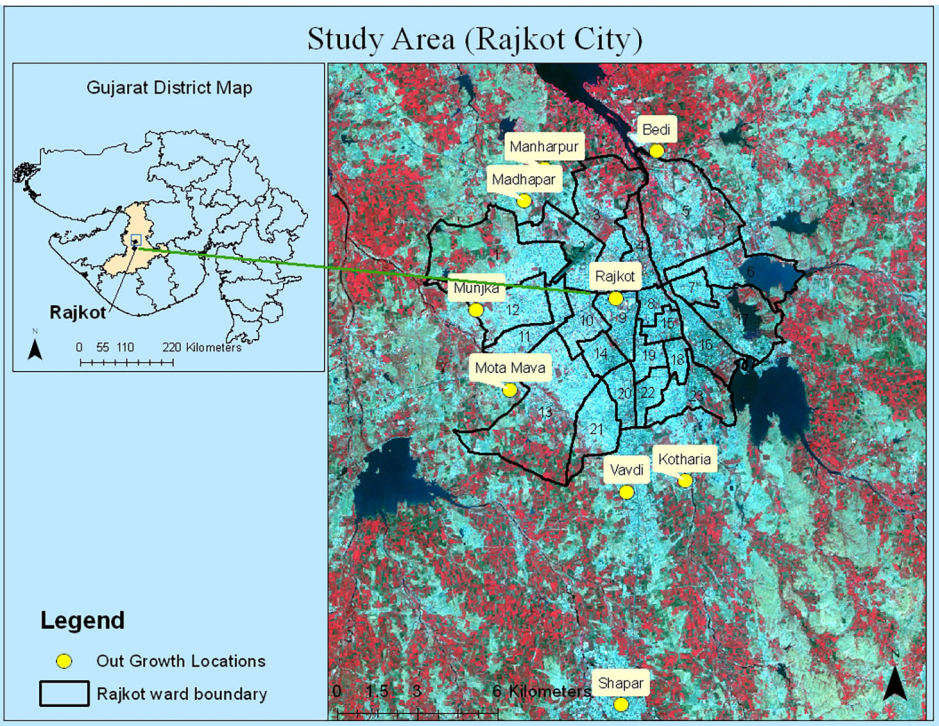


Figure 2: Study Area Rajkot City with Out Growth

METHODOLOGY

Data used for the study is as follows:

- Historical urban area maps, collected from Rajkot Urban Development Authority which has data from 1259 to 1947 with population data

High quality digital satellite images as follows:

- For the years 1980 and 1992: 30 meters resolution (LANDSAT TM);
- For the year 2001: 23.5 meters resolution (IRS 1C LISS III);
- For the years 2005 and 2011: 5.8 meters resolution (Resourcesat-2 LISS IV).

Rajkot Ward boundary data was collected from Rajkot Municipal Corporation.

Demographic data obtained from Census reports for 1971 to 2011.The census data, collected from the census office Gandhinagar, was in hard copy. Different pa-

rameters like the number of households, population, literacy, numbers of workers and non-workers were studied from 1961 to 2011. Ward level study was carried out for the growth rate from 2001 to 2011 for the above parameters. Gross density and net density were calculated to identify the maximum developing ward. A composite growth index is derived to show the growth rate at ward level.

Remote sensing data and historical maps, obtained from Rajkot Urban Development Authority, were spatially adjusted with the existing data. Maps for the years 1980, 1992, 2001, 2005 and 2011 were digitized and georectified (UTM WGS 84 projection system, and using visual interpretation). Microsoft Excel 2011 was used for processing census data and ArcGIS 10.2 was used for spatial analysis.

The urban maps extracted from all the 12 time period data have been resampled to 25m pixel size to bring uniformity in all the urban maps. Overlaying of urban built up on each other in Geographical Information System (GIS) environment provided the urban growth pattern map of the study area i.e., Rajkot from year 1259 to 2011. This map has been analyzed to understand the urban sprawl pattern and direction.

Buffer rings at intervals of 1 km incremental buffer has been created from core city center of Rajkot and overlaid on the urban growth pattern map. Urban growth in various directions such as north, north-east, east, south-east, south, south-west, west and north-west was analyzed.

The structural features, as captured in this study, are related to functional features, among them human wellbeing and other SDGs (Giles-Corti, Lowe & Arundel, 2020). Planning urban environments means also shaping cities for health (e.g., Glouberman et al., 2006; Angel et al., 2011).

FINDINGS

Figure 3 presents the growth of Rajkot city from 1259 A.D. to 2011. The growth pattern observed is compact development around the CBD. After 2000, development has been noticed all along the fringe and more along the transport corridor.

In 1259 A.D., when Rajkot city was established on the east bank of river Aji, it had an area of 0.0078 sq. km. Land utilization had just begun in that time. A small black dot in the center of the map in Figure 3 shows the area of Rajkot city in 1259 AD. Light pink color in the map shows the area of Rajkot city from 1550 to 1646 AD. During that period land utilization for residential and agrarian purpose had started. It was a hamlet stage and the area had increased to 0.0184 sq. km. The Green color shows the boundary of Rajkot urban area for 1646-1744 when permanent establishment of the village took place. Area had increased to 0.0595 sq. km. Development was observed in linear pattern in both North and South directions. By 1813 town fortification had taken place and administrative headquarters were established. Orange boundary shows extent of urban area which is 0.3039 sq. km.

Development was seen in a western direction of Aji River. Until 1813 development was within half kilometer from the core city center. Light blue boundary shows extent of urban area from 1882 to 1990. After British government established its camp in 1822 the town opened new directions of growth. The western side of river Aji was expanding and the urban area increased to 2.6 sq. km.

More development was observed in a North West direction during this period and the development in this direction had gone up to 2 km from the core city center. Red color shows the urban development on both the sides of the river from 1990 to 1947 in north, south, south west directions at a distance of 2km from the core city center and the area has increased to 5.16 sq. km. The development had taken place around the exiting urban area.

Purple color in the map shows the urban area of Rajkot from 1947 to 1961, during this time development had occurred on both the sides of the river. In this period development was observed in east and south west direction due to establishment of the Industrial Estates known as Bhaktinagar Industrial Estate and Aji Industrial Estate. The urban area increased to 6.93 sq km. Cream color shows the urban area extracted from satellite image. During 1980 the area had become double that of 1961. More urban growth was observed in the east and south directions compared to the west side of Aji river. Development has been expanded to 3 kms from city center in west and south west directions.

Pink color shows the urban area for the year 1992 after the tremendous growth in all directions from 1980 to 1992. In 1992 the urban area increased to 30 sq. km. Lesser development has been seen in the northern direction but maximum development is seen in the other three directions. The development in various directions such as north, west and east has been expanded up to 3 kms from city center, in south and south east directions. Urban development has expanded to 4 kms, and in south-west and west directions urban development has expanded to 5 kms.

Purple color shows the urban area in 2001 where only 7 sq. km of urban growth is seen. From 1992 to 2001 a new area has developed in the south. Growth is observed up to 4 km in a north-west direction and urban development is seen up to 7 km from the city center in south, south-west and western direction.

Magenta color shows the urban area in 2005. Lots of small villages and urban growth are seen in from 2001 to 2005. Liner growth is observed in various directions such as north development 2kms from city center; south-west, north-east and south-east urban development 6 kms from the city center in a linear strip; south urban development is seen beyond 10kms from the city center in a linear strip; west and north west urban development is seen beyond 10 kms from the city center in a leapfrog pattern.

Dark green color in the map shows the urban area for 2011, observed as 67.55 sq. km. Most of the urban growth is seen on the fringes of the urban area in 2005. There is a scattered development pattern as well as leapfrog urban sprawl pattern during 2001 to 2011 as development is in an uncontinuous manner. Liner growth

is observed in various directions in south west urban development, 7kms from the city center in a linear strip; south urban development is seen beyond 10 kms from the city center in a linear strip; and west and north-west urban development is seen beyond 10 kms from the city center in a leapfrog pattern.

When cities grow, infrastructures expand as well, and the features of the built environment affect human behaviors – and are influenced by them. Density of homes and workplaces, for example, may reduce motorized mobility (e.g., ULI, 2007) and have social advantage of creating public spaces that enhance social interactions. Economic and environmental advantages are also expected, e.g., reducing gas emissions, car ownership costs, and more.

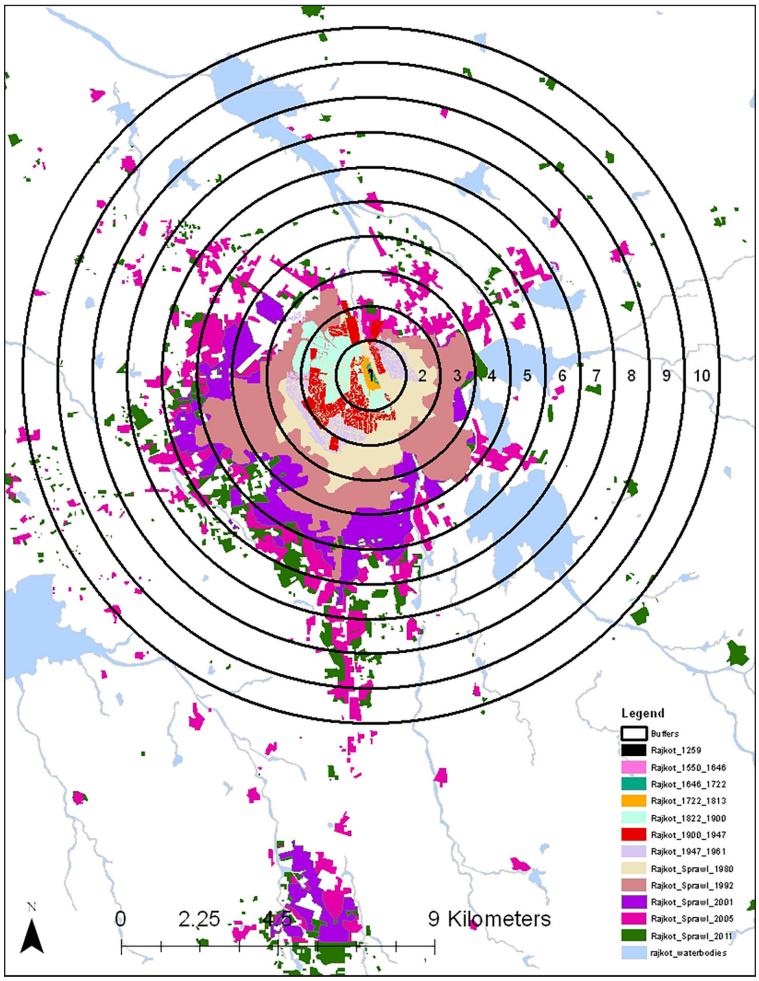


Figure 3: Rajkot Urban growth from 1259 to 2011

Density

Table 1: Geographical Area and Population of Rajkot

Year	Area in sq km	Population	Density
1646	0.059	3000	50369
1722	0.3	8000	26666
1822	2.69	15000	5576
1900	5.16	56000	10852
1947	6.93	80000	11544
1980	12.38	445076	35951
1992	30.94	559407	18080
2001	37.19	1002000	26942
2005	57.99	1036319	17870
2011	67.55	1323363	19590

Table 1 shows the geographical area, population and density of Rajkot city. Populations have been increasing and so has the urban area hence the density has decreased from 50369 per sq. km in 1646 to 19590 per sq. km in 2011 (Rajkot Municipal Corporation, 2012). A decrease in the density is observed in 1822, when increase in area and population are not in the same pace. Density increases from 1900 to 1980 and then drops to nearly half with increased urban area, to 30.94 square kilometers, and population to 559,407. In 2001 the population density had increased which shows compact development, as opposed to the low-density development in the previous period. In 2005 urban land utilization increased by 20 square kilometers and population density decreased. In 2011 the urban area increased in around 10 square kilometers and population has increased by 27% hence the population density has also increased to 19590.

Figure 4 shows the parallel increase in urban area and population until 1947, and the population growth being higher than urban area growth in 1980, and in 1992 again an equal growth. Patterns change in 2001, and a constant growth has been observed from 2001 to 2011.

Figure 5 shows that with increase in urban area population is also increasing. There is a drop in the density from 1646 to 1822 as population growth was slow compared to the urban area growth. Density increases from 1822 to 1980 due to the British establishment in 1822 and the following economic development. Density changes again from 1980 to 2011 (Census of India, 2001; 2011).

The population of Rajkot is 1,323,363 people as per 2011 census, an increase of 32% in ten years (the population of Rajkot city was 1,002,000 people as per the 2001 census). In the previous decade, an average annual growth rate was 3.29%

(from 560,000 in 1991). During the independence period Rajkot city experienced the highest growth rate, 99.04% in between 1941 to 1951 because of large refugee immigrants from Pakistan. In the last decade the growth rate was 79.12% attributed to merging the three surrounding villages in June 1998 (Census of India, 2001; 2011).

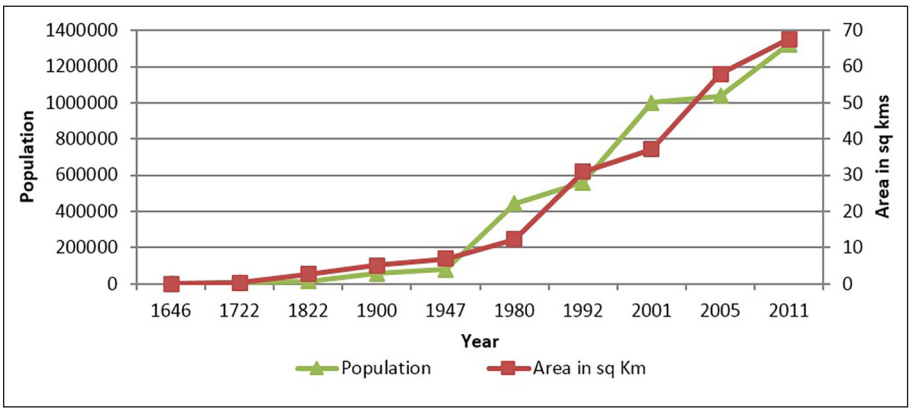


Figure 4: Rajkot Urban Area and Population Growth

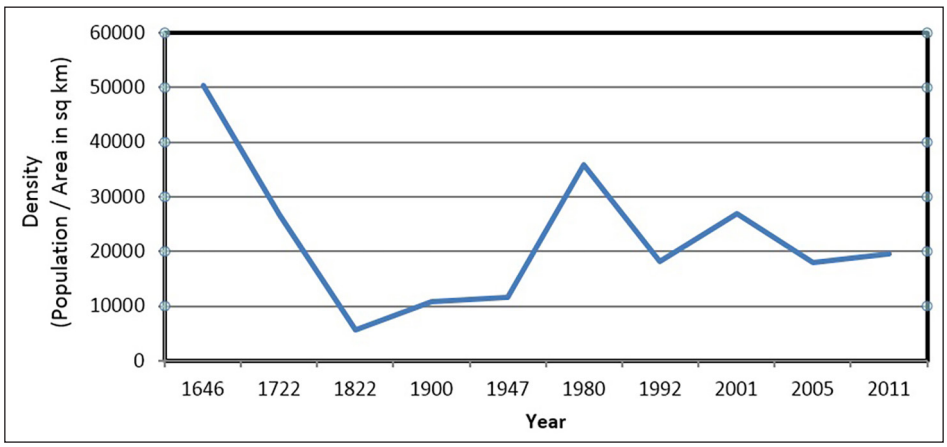


Figure 5: Population density vs area

Table 2: Population Growth Rate (Source: Rajkot Municipal Corporation, 2005)

Year	Population	Growth Rate
1901	36151	
1911	34191	-5.42
1921	45845	34.08
1931	59122	28.96
1941	66353	12.23
1951	132069	99.04
1961	194145	47.00
1971	300112	54.58
1981	445076	48.30
1991	559407	25.69
2001	1002000	79.12
2011	1323363	32.07

Table 2 shows the growth rate from 1901 to 2011. A growth rate of 99.04% from 1941 to 1951 moderates to 79.12% from 1991 to 2001. There was a decrease in population in 1911. Least population growth is seen in 1931 to 1941 which is 12.23%.

Wards

With the increase in population and in area, urban boundaries changed, wards were merged, and new wards were developed. In the graph given below change in number of wards is shown. In 1961 there were 10 wards which increased to 13 wards in 1971. The number of wards was again increased in 1981 to 18 wards, after which two wards were merged and in 1991 there were 17 wards. In 2001 the out growths were added and 24 wards were taken into Rajkot municipal boundary. In 2011 again two wards are merged and there are 23 wards in the current system.

Figure 7 reflects Rajkot population growth for 2031 and the trend of the population growth rate has been studied by using a polynomial curve. The population has been seen increasing and the population growth rate is decreasing. There is a major increase in growth rate from 1991 to 2001, because 6 wards had been added which leads to sudden rise in the growth rate. R^2 value for population growth is 0.98 showing high correlation whereas in the case of growth rate as the growth rate values are dispersed it is showing low correlation and R^2 value is 0.03. The population data for 2031 is predicted to be 2,121,652. Apart from population, households, workers, male female ratio and literacy also play important roles in development.

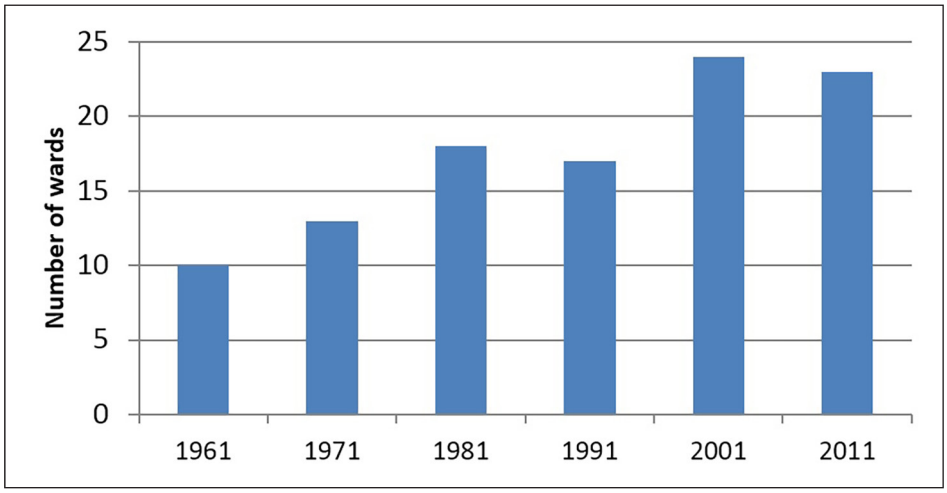
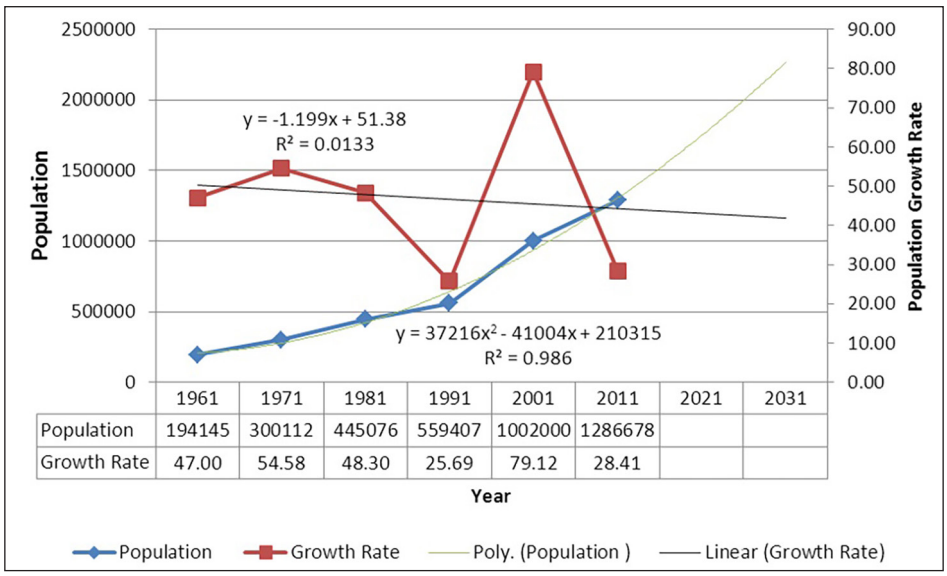


Figure 6: Number of wards Year wise



	1961	1971	1981	1991	2001	2011	2021	2031
Population	194145	300112	445076	559407	1002000	1286678		
Growth Rate	47.00	54.58	48.30	25.69	79.12	28.41		

Figure 7: Rajkot Population projections for 2031

Figures 7 and 8 show that population has increased in the past 50 years and male-female population ratio has increased after 1991. Literacy rate has increased for both male and female. The growth of literacy rate has become almost double from 1991 to 2001 and has increased 5 times from 1961 to 2011. The number of workers has increased from 1961 to 2011 around 7 times and female employment is much lower

compared to male employment throughout in past 50 years which suggests male dominance in society.

Figure 8: Demographic growths from 1961 to 2011

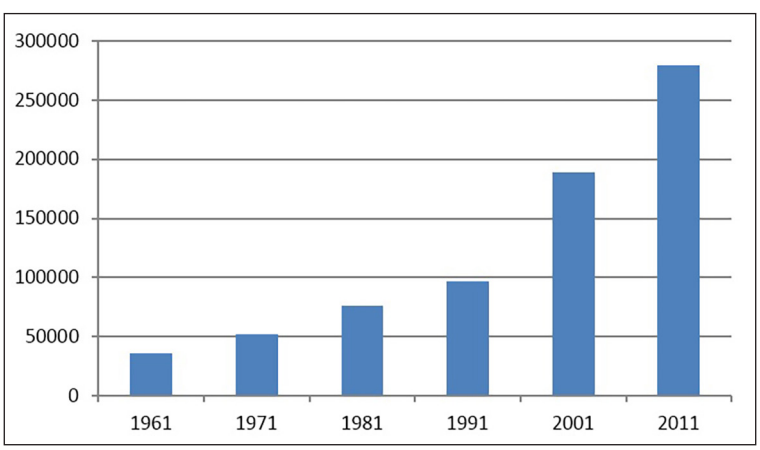


Figure 9: Household's graph

Figure 9 shows the increase in households, 4 times in the past 50 years. Maximum growth has been seen from 1991 to 2001.

Demographic data for each ward is presented in Figure 10. The gross density of each ward shows a pattern in which there is much change from 2001 to 2011 gross density. Apart from wards number 7 and 19 all the wards have undergone increase in gross density. Wards in red are the inner wards which have less chances of growth as these areas are already developed. Outer wards have more scope of development as there is lots of barren land.

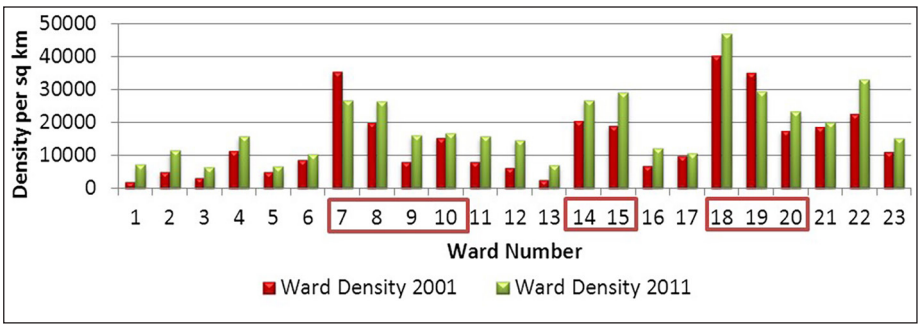


Figure 10: Gross Density

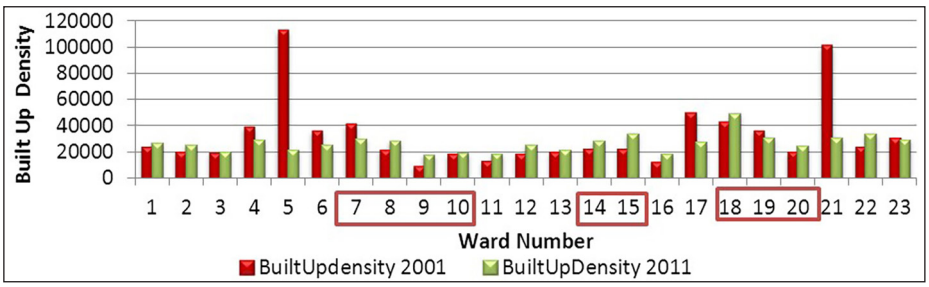


Figure 11: Net Density

Net density is calculated by dividing population of each ward with built-up area of that ward. This shows a drastic change in the population distribution from gross density. Population density has decreased most in wards 5 and 21 which means that lots of built-up areas have increased. Due to development in infrastructure there has been growth in wards 1, 2, 3, 4, 5, 6, 7, 21 and 22 shown in Figure 10 and Figure 11. Here we can see that there is a vast difference between ward density and built up density. Density is reduced in 2011 hence population is more distributed.

Formula for gross density and net density are as follows:
Ward Density = Ward Population / Ward Area
Built Up Density = Ward Population / Built Up Area in a Ward

Lesser change between ward density and built up density is observed in inner wards compared to outer wards, as new built up areas can develop in the outer wards. This can be clearly observed in Figure 12 and Figure 13. The combined growth rate is calculated on the basis of growth rate of the built-up area, population, households, workers, and non-workers. Using these five parameters, a combined growth rate for all wards is calculated and the highest growth ward is identified. Figures 14-17 show the growth rate of population, households, workers and non-workers, and Figure 18 shows the combined growth rate. The growth rate has been calculated from 2001 to 2011 using the following formula:

$$\text{Growth Rate} = (\text{End Value} / \text{Start Value})^{(1 / \text{Periods} - 1)} - 1$$

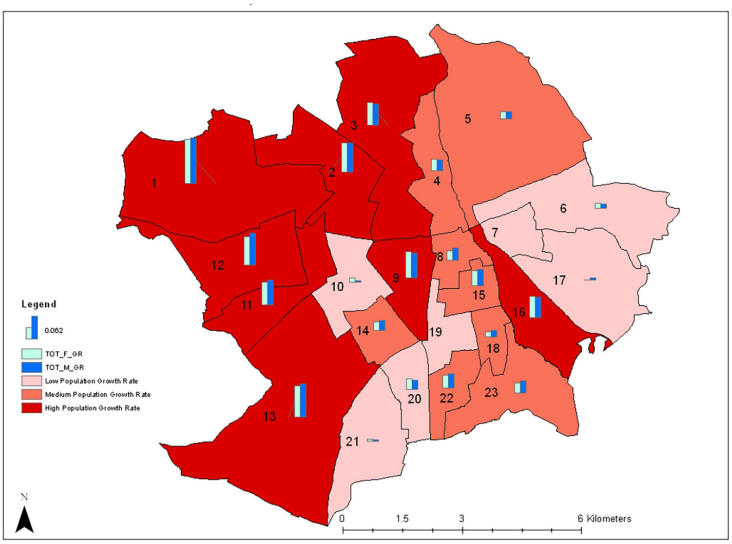


Figure 14: Population growth rate 2001 to 2011

Population growth rate is seen more in the western side of the river. Wards 1, 2, 3, 9, 11, 12, 13 and 16 have high population growth rate. Whereas in wards 4, 5, 8, 14, 15, 18, 22 and 23 there is medium growth rate and ward number 6, 7, 10, 17, 19, 20 and 21 have very low growth

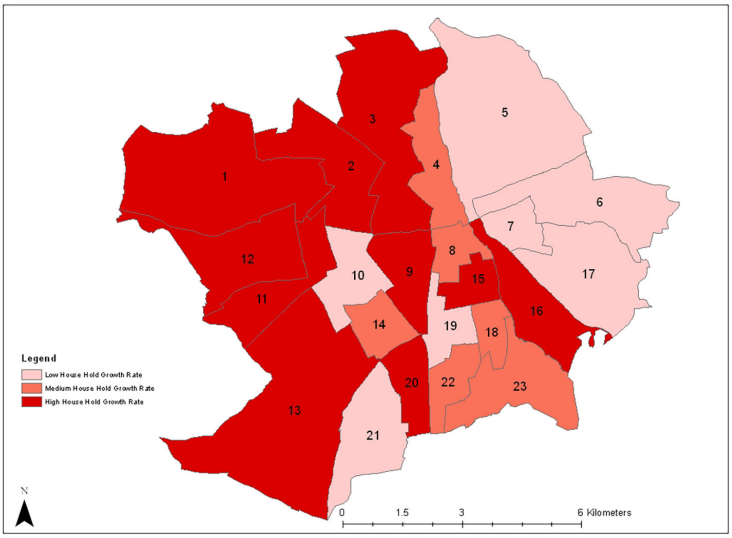


Figure 15: Household growth rate 2001 to 2011

Household's growth rate is seen more in the western side of the river. Wards 1, 2, 3, 9, 11, 12, 13, 15, 16 and 20 have high household growth rate. Whereas in wards 4, 8, 14, 15, 18, 22 and 23 there is medium growth rate and wards 5, 6, 7, 10, 17, 19 and 21 have very low growth

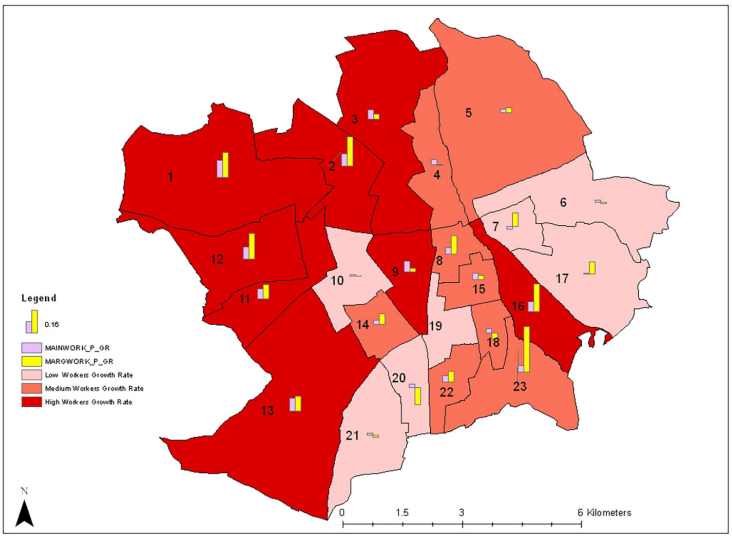


Figure 16: Workers growth rate 2001 to 2011

Workers growth rate is seen more in the western side of the river. Wards 1, 2, 3, 9, 11, 12, 13 and 16 have high workers growth rate due to industrialization. Where as in wards 4, 5, 8, 14, 15, 18, 22 and 23 there is medium growth rate and ward number 6, 7, 10, 17, 19, 20 and 21 have very low growth.

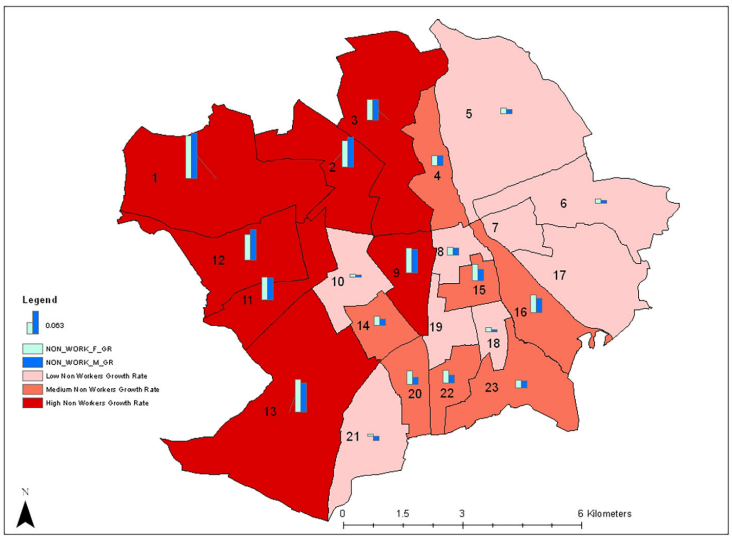


Figure 17: Non Workers growth rate 2001 to 2011

Non-workers growth rate is seen more in the western side of the river. Wards 1, 2, 3, 9, 11, 12 and 13 have high number of non-workers growth rate. Where as in ward number 4, 14, 15, 16, 20, 22 and 23 there is medium growth rate and wards 5, 6, 7, 8, 10, 17, 18, 19 and 21 have very low growth

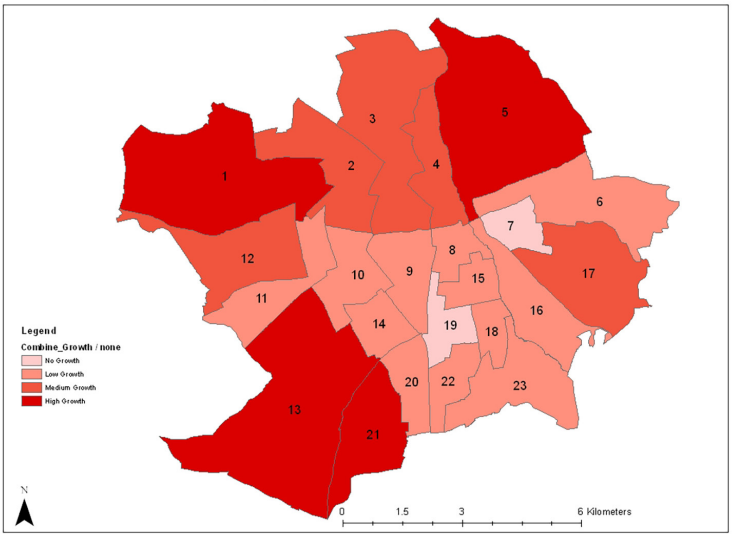


Figure 18: Combined growth rate calculated on the basis of growth rate of built-up area, population, households, workers, non-workers

Figure 18 shows the composite growth rate, with maximum growth in wards 1, 5, 13 and 21. Ward 1 is located on the West Zone of RMC, which had the highest infrastructure development throughout this period of time. The increased growth is the result of infrastructure development in the last 5 years. Maximum number of housing projects was carried out in West Zone of Rajkot Municipal Corporation. West zone is also having population of Middle-Class and Upper Middle Class categories, thus more investment is seen on the western part of the city. Institutional facilities & recreational facilities like schools, colleges, university, hospitals, shopping malls, and gardens are in higher number in the western part of the city. Bus rapid transit (BRT) lines with multiple routes create a corridor for public transportation in the western part of the city and improves the attraction of the western zone. Fast implementation of town planning schemes also plays a significant role in the development of ward number 1. Apart from the observed changes in the infrastructure and institutional development in the western part of the city, influence of political leaders also affects the growth of the western part of the city. At the eastern part of the city, being on the banks of Aji River, industrial growth is higher than residential development. No growth is shown in wards 7 and 19 because of lower residential preference in the industrial and commercial areas that occupy theses wards.

SUMMARY

The analysis clearly shows that Rajkot urban area has increased 1209% in size from 1900 to 2011 and almost doubled in two decades during 1992-2011, after becoming metro city. More thrust on growth was seen in South, South West, North and North West directions. Lower growth is seen in the eastern direction as land area is almost saturated in eastern and south-eastern directions due to several natural water reservoirs. A trend of growth in all directions is visible till 1992 after which the development is seen more on the fringes and along the highways connecting two cities. Leap frog development is visible from 2005 to 2011, and a trend of linear growth towards the south is visible during 2001 to 2011.

In the southern direction urban development has reached 10 kilometers from the city center till 2011. In the western direction the urban development is observed up to 7 kilometers and in north-west direction the urban development is visible up to 8 kilometers and in north east direction liner growth is observed 6 kilometers from the city center. There is urban development up to 5 kilometers from city center in south-east direction. There is around 3 kilometers growth in the eastern direction from city center and around 2 kilometers urban development in northern direction.

CONCLUSIONS

This study focuses on the gross and net density of the wards showing actual urban area population scenarios. The analysis of this study can be used by urban planners to envision the growth of the city. The analysis of remote sensing data enables in-depth monitoring of urban growth pattern. The monitoring of urban growth using GIS is easy to understand and provides a clear view of how urban growth has taken place over a period of time in different directions. Rajkot area has grown at a very high rate. The pressure on infrastructure and surrounding land has also increased manifold. This is required for properly manage and proactively plan the growing urban area and infrastructure for sustainable development. Attempts were made to model the relationship between social diversity and the spatial configuration of growth, whether to other regions or into the inner-city. As stated by Taubenböck et al. (2020; 2), "Modeling approaches tried to better understand the complex underlying processes shaping urban patterns. The complexity is also reflected in the fact that, like DNA, each city developed its own unique configuration. The most obvious configuration is the morphologic-spatial structure". The differences between cities across the globe, in their spatial firm, depend on geographical and cultural aspects.

The analysis of urban growth patterns with respect to direction and distance from city center provides significant inputs for understanding the causes and consequences of growth in particular directions. The analysis can be further used to understand the urban sprawl dynamics in the area, further modeling the growth scenarios. Future growth patterns can be assumed, to preplan the necessary infrastructure for the growing direction of the sprawl for sustainable development. Major challenges come in when sprawling takes place and the roads, drainage, water supply lines and many more basic facilities are developed to connect the sprawl location. This study provides a foundation to plan the direction of expanding the infrastructure to cater the requirement of the new growing areas.

Gross density and net density of the wards show the real scenario of the population of the urban area. There is a saturation of the population density in inner wards whereas the outer wards sprawl but their density is also changing. Density, destination and distance are among the features of the built environment that play a key role for walkability, according to the Draw-Down project that evaluated the environmental impact of having more walkable cities, together with demand, design and diversity.

Growth rate is calculated for sprawling, population, households, workers and non-workers for each ward and a composite growth is calculated which shows that highest growth has took place in wards 1, 5, 13, and 21. No growth has been seen in wards 7 and 9 as they are inner wards of industrial and commercial areas. While compact development belongs mainly to the planning domain, the related environmental features (Drawdown) are a matter of technological infrastructures, such

as streetlights, perceived public safety, and the coordination between the different means for mass transportation and last mile accessibility.

To conclude it can be observed that use of technology can make the planners better prepared for taking measures to make sure that all facilities are available in the direction of growth. It is also observed that rapid growth is majorly impacted by the industrialization which proves to be a major pull factor. Urbanization is a process which can be studied by understanding the temporal growth of the city along with the upcoming industrialization and investments. It is highly recommended to use remote sensing data to study the past growth of the city and its direction before planning the future expansion of the city. Therefore, providing a framework to arrange and analyze the differences in urban sprawl and density is important for understanding the dynamics of the spatial aspects of urban growth.

ACKNOWLEDGEMENT

The author is thankful to ISRO for providing the satellite data used in this study. The author is also thankful to Rajkot Municipal Corporation and Rajkot Urban Development Authority for their cooperation and support for this study. The author is highly thankful to CEPT University for providing the computing facilities. This paper is a part of Minor study for PhD degree carried out by Shaily Gandhi, CEPT University.

REFERENCES

Angel, S., Parent, J., and Civco, D. (2007) Urban Sprawl metrics: An analysis of global urban expansion using GIS. Proceedings of ASPRS 2007 Annual Conference (pp. 1-12). Tampa, Florida May 7-11.

Batty, M., Desyllas, J., & Duxbury, E. (2003) Safety in numbers? Modeling crowds and designing control for the Notting Hill Carnival. *Urban Studies*, 40(8): 1573–1590.

Bengston, D. N., Potts, R. S., Fan, D. P., & Goetz, E. G. (2005) An analysis of the public discourse about urban sprawl in the United States: Monitoring concern about a major threat to forests. *Forest Policy and Economics*,7: 745–756.

Bhatta, B. (2010) *Analysis of Urban Growth and Sprawl from Remote Sensing Data*. Kolkata: Springer.Census of India (1971) New Delhi: Government of India.

Census of India (1981) New Delhi: Government of India.

Census of India (1991) New Delhi: Government of India.

Census of india (2001) New Delhi: Government of India.

Census of india (2011) New Delhi: Government of India.

Clark, D. (1982) *Urban Geography: An Introductory Guide*. London: Taylor & Francis.

Czekajlo, A., Coops, N. C., Wulder, M. A., Hermosilla, T., Lu, Y., White, J. C., & van den Bosch, M. (2020) The urban greenness score: A satellite-based metric for multi-decadal characterization of urban land dynamics. *International Journal of Applied Earth Observation and Geoinformation*, 93. 102210. https://doi.org/10.1016/j.jag.2020.102210

Dong, Y., Forster, B., & Ticehurst, C. (1997) Radar backscatter analysis for urban environments. *International Journal of Remote Sensing*, 18(6): 1351–1364.

Drawdown project: https://drawdown.org/solutions/walkable-cities

Eryilmaz, S. S., Cengiz, H., & Eryilmaz, Y. (2008) The urban sprawl model for an affected metropolis. 44th ISoCaRP Congress 2008, (p. 12). China.

Fulton, W., Pendall, R., Nguyen, M., & Harrison, A. (2001) Who Sprawls the Most? How Growth Patterns Differ Across the US. Washington, DC: The Brookings Institution center on Urban and Metropolitan Policy.

Galster, G., Hanson, R., Wolman, H., Coleman, S., & Freihage, J. (2001) Wrestling sprawl to the ground: Defining and measuring an elusive concept. *Housing Policy Debate* ,12(4): 681–717.

Giles-Corti, B., Lowe, M., & Arundel, J. (2020) Achieving the SDGs: Evaluating indicators to be used to benchmark and monitor progress towards creating healthy and sustainable cities. *Health Policy*, 124(6): 581-590. https://doi.org/10.1016/j.healthpol.2019.03.001

Glaeser, E. L., & Kahn, M. E. (2004) *The Handbook of Urban and Regional Economics*. Oxford: Oxford University Press.

Glouberman, S., Gemar, M., Campsie, P., Miller, G., Armstrong, J., Newman, C. & Groff, P. (2006) A framework for improving health in cities: A discussion paper. *Journal of Urban Health*, 83(2): 325-338. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2527162 and https://dx.doi.org/10.1007/s11524-006-9034-9

Li, X., & Yeh, A. (2001b) Zoning land foragricultural protection by the integration of remote sensing, GIS, and cellular automata. *Photogrammetric Engineering and Remote Sensing* ,67(4), 471-477.

Pathan, S.K. and Jothimani.P. (1985) Mapping and monitoring of urban sprawl using Landsat MSS data: Case studies of three major cities (Rajkot, Bhavangar, and Jamnagar) of saurashtra region, Gujarat. ISRS symposium on Remote Sensing for Planning and Environmental aspects of Urban and Rural settlements , December 27-28, 1985, Visakhapatnam, India, 45-52.

Rahman, G., Alam, D., & Islam, S. (2008) City growth with urban sprawl and problems of management. Proceedings of 44th ISOCARP Congress Dalian (pp. 19-23). China, September 19–23: International Society of City and Regional Planners and Urban Planning Society of China.

Rahnama, M. R., Wyatt, R., & Shaddel, L. (2020) A spatial-temporal analysis of urban growth in Melbourne; Were local government areas moving toward compact or sprawl from 2001–2016?. *Applied Geography*, 124, 102318. https://doi.org/10.1016/j.apgeog.2020.102318

Rajkot Municipal Corporation (2005) Rajkot City Development Plan. Rajkot: Rajkot Urban Development Authority

Rajkot Municipal Corporation (2012) Preparation of Second Generation City Development Plan for RMC as well as RUDA. Rajkot: CRISIL Risk and Infrastructure Solutions Limited.

Taubenböck, H., Debray, H., Qiu, C., Schmitt, M., Wang, Y., & Zhu, X. X. (2020) Seven city types representing morphologic configurations of cities across the globe. *Cities*, 105, 102814. https://doi.org/10.1016/j.cities.2020.102814

ULI (2007) Compact Development: Changing the Rules to Make It Happen. Urban Land Institute (ULI) Community Catalyst Report Number 6: Washington, D.C. http://uli.org/wp-content/uploads/ULI-Documents/Report-6-Compact-Development.ashx_.pdf

United Nations (2005b) *World Urbanization Prospects: The 2005 Revision Population Division Department of Economics and Social Affairs*. UN.

Webster, C. J. (1995) Urban morphological fingerprints. *Environment and Planning B*, 22: 279–297.