Evaluation of Urban growth and expansion using Remote sensing and GIS

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Abstract

Monitoring of urban expansion is inevitable to urban planners. Thiruvananthapuram district, housing the capital of Kerala, has tremendous potential for transforming into a leading position, which can be achieved only through spatial planning interventions. As per demographic studies, Thiruvananthapuram is a high density districts when compared to the neighbouring districts within the State. In this study, GIS based buffer gradient analysis is employed to evaluate the spatiotemporal characteristics of urbanisation in Thiruvananthapuram district. Satellite images for different time stages are utilised. The intensity and proportion of urban growth are computed using two urbanisation indices. Also, desakota pattern of growth is identified by considering the population density and land use type. The results of the analysis display the interactions in regional urbanisation. Among the municipalities, the urban expansion is observed to be comparatively active for Attingal and Varkala. The major directional growth is observed to be in the North North-East slice of the district.

Keywords: *Urban growth, Gradient analysis, Buffer system, Remote sensing, GIS*

1. Introduction

Urbanisation is a worldwide phenomenon. This has profoundly impacted the natural landscape. Generally, the factors driving urban expansion can be grouped into economic factors (globalisation, rising living standards, land prices, national policies), demographic factors, housing preferences, social aspects, transportation and regulatory frameworks. It is possible to identify the land cover lost as a result of new urban developments. The stress induced on the environment as a result of urbanisation has to be addressed at the local scale.

Urban landscape pattern change is not only the indicator of urban landscape heterogeneity, but also the result of process of human activities [5]. Owing to the lack of analysis tools, the results of early studies on the quantification of landscape structure were limited. In recent years, the development of remote sensing and geographic information system (GIS) makes timely temporal and spatial information accessible. Moreover, the capability of spatial analysis and presentation makes GIS a useful tool for studying landscape spatial structure and landscape change analysis.

Temporal effects are any factors that change the spectral characteristics of a feature over time. Spatial effects refer to factors that cause the same type of features at a given point in time to have different characteristics at different geographic locations [7]. Since the 1960s, various theories were used to characterise urban form: for example fractals, cellular automata, dissipative structure theory, or landscape metrics. In urban growth modelling studies, the spatial phenomenon is simulated geometrically using techniques of cellular automata (CA). The inadequacy in some of these models was that they failed to interact with the causal factors driving the growth such as availability of land and proximity to city centres and highways.

The basic indicator to quantify urban footprint is the proportion of built-up area and the reduction of other land use types. The spatiotemporal characteristics of urban expansion can be quantified by integrating Remote Sensing (RS) data and Geographic Information System (GIS) techniques.

As per Census 2011, the population of Thiruvananthapuram district in absolute numbers is 3,301,427. Though Thiruvananthapuram accounts for

5.64% of the State's area, it comprises 9.88% of the State population. The population density of Thiruvananthapuram is 1508 which is 1.8 times higher than the State average. As per the demographic studies, Thiruvananthapuram is one of the high density districts when compared to the neighbouring districts within the State. The industrial and commercial influences near Kazhakkuttom, Sreekaryam, Kudappanakunnu, etc. have contributed to the expansion of urban areas towards the outskirts of the city.

Evaluating the spatio-temporal characteristics of urban expansion is inevitable to study the trends in urbanisation process within the district. Conducting a spatio-temporal analysis on a regional basis, covering the entire district, is needed to capture the interaction between the various urban centres. Being the capital city of the State, Thiruvananthapuram district has tremendous potential for transforming into a leading position in the future, which can be achieved only through spatial planning interventions. Urbanisation gradient analysis of the district can serve as the basis for the planning process, whereby the pace and intensity of urban growth can be quantified, thus making it possible to predict the future trends.

Different methodologies were adopted by different researchers for urban growth studies. Some of the studies have proved that a gradient analysis is efficient in bringing out regional trends in the urbanisation process. It is necessary to identify a standard set of measures that can be used to quantify urbanisation gradients. The most commonly used measures relate to land-use or land-cover at both local and regional scales [3]. Xiaoying et al. did a case study in Lanzhou to characterise the spatial behavioural features of urban expansion using landscape metrics and urbanisation gradient analysis [6]. In their study the intensity of urbanisation was expressed using the index USEII (urbanization spatial expansion intensity index) which is the ratio between constructed area and total area of spatial unit. The pace of urban growth could not be captured using this index. Xiaowen et al. conducted buffer gradient analysis on the Shanghai metropolitan region using the urbanisation indices: urbanisation proportion index (UPI) and urbanisation intensity index (UII) [5]. The study was done primarily to overcome the shortcomings of transect-gradient analysis. The transecting gradient method has a limitation in characterising the complexity of urban form. This is because in a metropolitan area the regional urbanisation process is not only determined by the urban growth of the central city but also shaped by the rural urbanisation of satellite towns [5]. In a study conducted by Taubenbock et al., a comparative analysis of the spatial growth of twelve largest Indian cities was done using a set of landscape metrics and zonal based gradient analysis [4]. In Asian developing countries, urban-rural continuum exists which is characterised as desakota pattern of growth. GIS-based spatial analysis and modelling approach was developed by Daniel and Hui to study the landscape dynamics of the desakota regions in southeast China [1]. These are the most stressed regions of urban expansion.

Our focus in this paper is to study the urban growth of Thiruvananthapuram district using buffer gradient analysis. The general profile of the district was studied from the District Urbanisation Report – Thiruvananthapuram prepared by the Department of Town and Country Planning [2]. The study addresses the urbanisation of Thiruvananthapuram district in both spatial and temporal contexts. The urban expansion of the central city and the satellite towns has been explored. Buffer gradient analysis is employed by integrating the prospects of remote sensing and GIS. Areas surrounding the city where desakota pattern of growth is seen are also identified. The period of study ranges from 1990 to 2006. The satellite images used for analysis are Landsat Thematic mapper dataset (1990), IRS LISS III image (1999) and Landsat Enhanced Thematic mapper dataset (2006).

Gradient analysis is a useful tool to present the spatial and temporal changes of landscape pattern between urban and rural areas. The overall spatiotemporal dynamics of urban expansion can be determined by examining variations in the urbanisation gradient extending from the city centre, through the suburbs, to the rural outskirts or urban fringes, and combining temporal data with GIS-buffer gradient analysis can serve this purpose. Transecting gradient analysis captures the urban changes only along selected transects [5]. The spatio-temporal analysis on a regional level can be performed using buffer gradient analysis. The expansion rate for each spatial unit can be analysed by establishing buffer zones over the entire region. By reviewing various indices used by researchers, Urbanisation proportion index (UPI) and Urbanisation intensity index (UII) were adopted for evaluating the proportion and intensity of urbanisation for each spatial unit in the entire study area.

The environment is being stressed differentially across varied geographies by the processes of technology-led economic globalisation. This has created rapid social responses of livelihood transformations in the form of migration and more market-dependent activities. These regions are linked to major urban centres by cheap transport axes where much more intense commercial agricultural and non-agricultural economic activities take place than in purely rural areas. The desakota phenomenon refers to closely interlinked rural-urban livelihoods, communication, transport and economic systems. The term ‘desakota region’ is a combination of two Indonesian words: “desa” for village and “kota” for town. The rapid urbanisation in Asia is characterized by the economic transformation of the heavily populated areas from agricultural activities to non-agricultural activities. Desakota regions in Asia refer to those areas with an intense mixture of agricultural and non-agricultural activities that often stretch along corridors between large city cores. The McGee-Ginsburg model challenges the conventional, Western division between rural and urban areas, which is too narrow and dichotomous to reflect the Asian urban reality [1].

On the basis of the literatures reviewed, the following objectives were formulated for the study:

1. Evaluate the spatiotemporal trends of urbanisation from 1990 to 2006
2. Compare the urban growth pattern of the four municipalities with the city centre (Thiruvananthapuram Corporation)
3. Identify regions of desakota pattern which are identified as villages developing into towns

The urban growth of Thiruvananthapuram district after the year 1990 was considered in two phases. The first phase was from 1990 to 1999. It was during the year 1990 that India's first industrial park, Technopark, was established in the city for the development of electronics and information technology in the state.

1.1 Study area

Thiruvananthapuram is the southernmost district of Kerala state. The district is a slice of Kerala as it covers all the three topographical features of the land, i.e. the low lying coastal belt along Lakshadweep Sea, undulating terrain of mid land and the green mountain forests of Western Ghats. The district is located at 8º17’ N and 8º51’N latitudes and 76º41’E and 77º17’E longitudes. The district stretches along the shores of the Lakshadweep Sea for a distance of 73.6 km and is surrounded by Kollam district on the North, Thirunelveli and Kanyakumari districts of Tamil Nadu on the East and the South respectively (Figure 1).

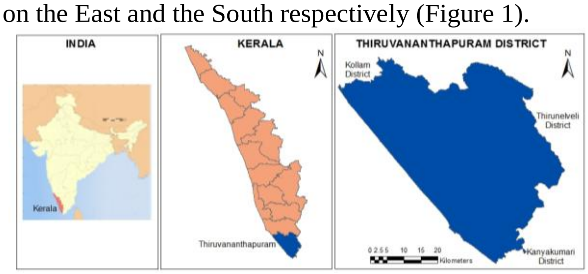


Fig. 1 Study Area - Thiruvananthapuram District

The entire district is treated as one revenue division, spread over 2192 sq.km. The district has one Corporation i.e. Thiruvananthapuram Corporation and four municipalities namely, Varkala, Attingal, Nedumangad and Neyyattinkara.

2. Methodology

Evaluation of urban expansion was carried out by establishing buffer zone systems followed by calculation of urbanisation indices. For this study, three sets of satellite images covering the entire district (1990- Landsat TM, 7 bands, resolution 30m; 1999- IRS LISS III 4 bands, resolution 23.8m; 2006- Landsat ETM, 7 bands, resolution 30m and panchromatic band, resolution 15m) were used. In addition, topographic maps and administrative boundary maps were used. Then, the desakota pattern of growth was mapped to identify the urban-rural continuum.

The satellite images were processed with ERDAS IMAGINE software, which involved geometric correction, supervised classification, and GIS reclassification. For the Landsat TM and Landsat ETM imagery, the six bands, excluding the thermal infrared band, were stacked. For Landsat ETM dataset, in addition to layer stacking, panchromatic sharpening was done using the panchromatic band of 15m resolution. All the images were rectified to Universal Transverse Mercator projection based on 1:50,000 scale topographic maps. Bilinear interpolation algorithm was used during this process. The bilinear interpolation method uses the average of four nearest pixel values from three linear interpolations. Maximum likelihood classifier was used, which quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel, to classify the various land use types in the district. The district was delineated into five land cover classes namely, agricultural land, built-up land, forest, wasteland and water body.

The magnitude and pace of urban growth were quantified based on two indices:

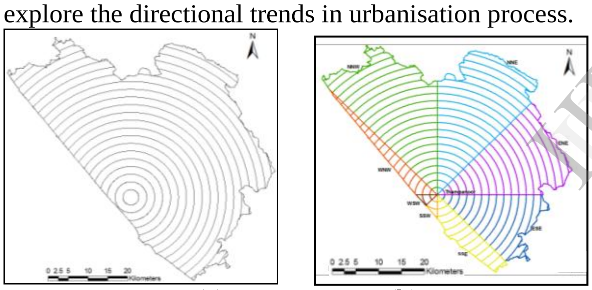
a) Urbanisation intensity index (UII), and
b) Urbanisation proportion index (UPI)

where
$$UII_{i,t\text{-}t+n} = \frac{\left[\frac{(ULA_{i,t+n} - ULA_{i,t})}{n}\right]}{TLA_i} \times 100 \quad (1)$$

$$UPI_{i,t\text{-}t+n} = \frac{(ULA_{i,t+n} - ULA_{i,t})}{TLA_i} \times 100 \quad (2)$$

where, $UPI_{i,t\text{-}t+n}$ and $UII_{i,t\text{-}t+n}$ are indices of the proportion of urbanisation and the intensity of urbanisation within a spatial unit i during a time period t to t+n. $ULA_{i,t+n}$ and $ULA_{i,t}$ are the areas of urban land-use for years t+n and t, respectively and n denotes the number of years. TLA_i is the total area of the spatial unit i. The percentage of the total area occupied within a spatial unit by urban expansion over the entire course of the study from 1990 to 2006 is expressed by UPI. UPI reveals the total magnitude and spatial distribution patterns of expansion throughout this period. UII is used to compare the pace and intensity of urban expansion over various periods. UII calibrates the average annual urban expansion rates for each spatial unit [5].

GIS-based buffer analysis was adopted in this study. It involved circular buffer zones surrounding the city centre. ArcGIS software was used for the analysis. For the purpose of the study, three different buffer systems were established. The first was a circular buffer zone system with a buffer width of 2 km covering the entire region (Figure 2(a)). This was designed to explore the overall urbanisation process over the district. The second system consisted of dividing the buffer analysis system into eight slice areas (Figure 2(b)). This system analyses the directional variation of urbanisation. Calculations of the UPI and UII were made separately for each slice to explore the directional trends in urbanisation process.



(a) (b)

Fig. 2 (a) Buffer system surrounding Thiruvananthapuram Central
(b) Buffer system sliced into eight directional regions

The division of the eight slice areas, taken in clockwise order, is shown in table 1.

Table 1 Eight directional regions

Zone	Direction	Angular range
1	WNW (West-North	0-45º
2	NNW (North-North	45º-90º
3	NNE (North-North East)	90º-135º
4	ENE (East-North East)	135º-180º
5	ESE (East-South East)	180º-225º
6	SSE (South-South East)	225º-270º
7	SSW (South-South West)	270º-315º
8	WSW (West-South West)	315º-360º

The third buffer system was established by delineating separate buffer zones to compare spatiotemporal characteristics of urban growth between Thiruvananthapuram Central and the four municipality centres (Figure 3). In the third buffer analysis, the buffer zones covering the main urban centre of the district included 10 buffer zones of 1 km width, and these were created outwards from the city centre. For the other four urban bodies, 10 buffer zones of 0.5 km width were created and these were enough to include the primary urban areas of each municipality. For each buffer system, the urban centre was derived from the topographic maps which revealed the origin of urban expansion.

Each buffer zone was considered as a basic spatial unit to characterise the urban growth behaviour using UPI and UII values for a given time period.

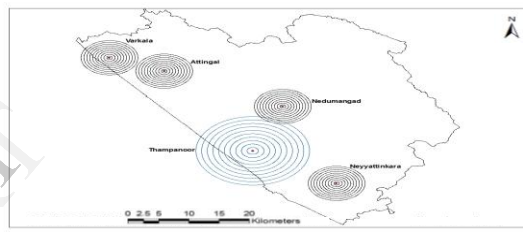


Fig 3 Separate buffer zones around Thiruvananthapuram central and the four municipalities

The primary factors governing desakota regions are population density and the land use category. The limiting density for population was decided depending on the least average population density for the already developed urban bodies. Built-up area is an indicator for urban development. Also, desakota regions are linked to the main city centre by a transportation corridor. Thus, the different criteria selected for identifying the village areas developing into towns are listed below:

a) Population density greater than 1300 per sq.km
b) Land use type: built-up
c) Road connectivity with major centre

3. Results and discussions

3.1Changes in built-up area in thiruvananthapuram district

The results of the classification process are shown in fig. 4. The classified maps displayed the incremental growth of built-up area. This served as the basis for further analysis of the urbanisation process. The growth in built-up area accounted for the reduction in agricultural land. It could be observed that the process of urban expansion was concentrated in the low lying coastal belt.

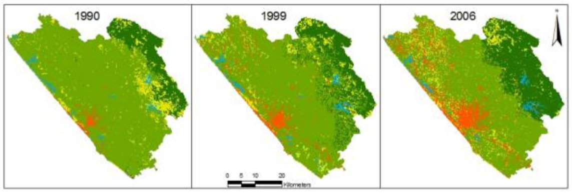


Fig. 4 Land use changes during 1990, 1999, 2006

For each year of study, the total built-up area was extracted from the classified results. The percentage changes in built-up area with respect to the area covering the entire district is shown in fig. 5.

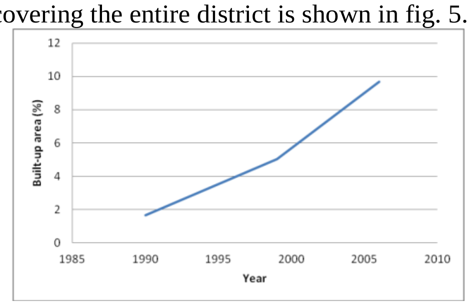


Fig. 5 Percentage changes in built-up area

3.2 Spatiotemporal trends of UII based on buffer analysis during 1990-2006

The spatio-temporal trends for the entire district during the study periods 1990-1999 and 1999-2006 are displayed in fig. 6.

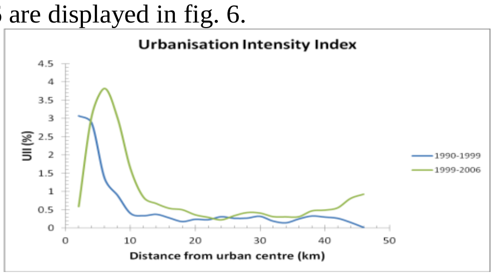


Fig. 6 Changes in UII with distance to the urban centre over the entire Thiruvananthapuram district

During the period of study 1990-1999, the plot showed that the initial and peak values coincided. A general declining trend was observed from the centre outwards. This indicated that during this period, urbanisation intensity was highest in the region immediately surrounding the city centre, with a rapid downtrend within a distance of 10 km from the urban core. The rapid downtrend showed that urbanisation intensity was sensitive to the distance from the urban centre within 10 km. Within this zone, large scale urbanisation took place. It could be concluded that the primary effects of urbanisation were experienced within this 10 km. Beyond 10 km distance, UII showed a comparatively gentle decline. This was largely due to the local township urbanisation rather than the direct influences of Thiruvananthapuram Central.

A linear transition zone could be seen along a narrow stretch between Balaramapuram and Parassala (Fig. 5.2). Moreover dispersed settlements were spread between Attingal and Kilimanoor near the proximity of road junctions.

During the period of study 1999-2006, the most active region of urban growth was pushed outward to 8 km. The areas near to Kudappanakkunnu contributed to this shift in peak. There was a sharp increase in UII upto 8 km from the urban centre. Beyond 8 km upto 12 km, there was a rapid decline in urbanisation intensity. Beyond 12 km, a slow gradual downtrend in UII could be seen. For the second phase, the UII values were higher when compared to the first phase of study for distances ranging from 4 km to 22 km. This indicated a clear intensification of urbanisation in this extent. An intensification of urbanisation was also evident beyond 40 km in the second phase. This is due to the clustering of built-up spaces near Kappil and Pallickal. The strategic locations of growth are shown in fig.7.

Fig. 7 Important centres of growth

3.3 Spatial directional variation of UII based on buffer analysis during 1990-2006

For both the phases, 1990-1999 and 1999-2006, the maximum intensity of growth was seen in NNE direction. The peak values of UII for the first phase ranged between 20% and 63 %. For the second phase, the peak intensity values were in the range between 9% and 100% (Table 2).

Table 2 Peak values of UII in each direction

Direction	1990-1999	1999-2006
ENE	40.2	83.5
ESE	20.2	21.5
NNE	40.9	100.0
NNW	27.3	95.8
SSE	28.5	81.4
SSW	53.0	95.5
WNW	41.5	20.6
WSW	62.7	9.1

For ENE slice, the peak intensity shifted to 6 km from the centre during the second time phase. This was due to the developments near Tirumala, Vattiyurkavu etc. and the outer zones around the centre remained dormant. For ESE slice, the maximum intensity remained within 4 km for both time periods. The intensification of expansion which was seen near Parassala during 1990-1999 was almost absent during 1999-2006.

Rapid decline was seen within 4 km in the SSE directional slice during 1990-1999. During the second phase period, the intensity values remained approximately steady from centre to the periphery. Also, scattered developments were seen near Kalliyoor, Vizhinjam, Poovar. In the SSW slice, maximum intensity was seen at 8 km near Muttathara due to proximity to Thiruvananthapuram International airport.

The pattern of urban growth remained constant in the WSW slice with minor changes. The WNW slice displayed a series of sharp peaks in UII from the centre upto 42 km. This was due to the several scattered urban growth, seen as small-scale townships near Varkala, Chirayinkeezhu, Kazhakkuttom, etc. During the period 1999-2006, the highest peak intensity shifted 12 km outward from urban centre, near Kazhakkuttom. It could be concluded that this shift in peak was due to the industrial developments in and around TechnoPark.

NNW slice showed a similarity in trend for both time periods, yet the intensity values were higher for the second time stage. In the NNE slice, the maximum peak value of UII, approximately 7% was obtained. This was observed as due to the urban developments near Peroorkada, Sasthamangalam, etc.

3.4 Spatiotemporal characteristics of UII for the four municipalities

Figure 8 presents the trends in the UII with distance from municipality centre. During each time period, each urban centre's UII curve showed a distinct association with the overall trend of the district, even though the intensity variations showed major differences. This reveals that each urban centre has its own relatively independent expansion processes.

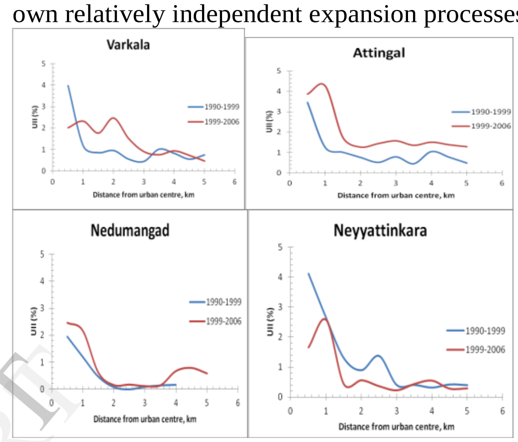


Fig. 8 Variation in UII with distance to urban centre for the four municipalities

The UII curves shown in fig. 8 gives a clear indication of the urban expansion characteristics of the municipalities. For Varkala municipality, the peak intensity of growth during 1999-2006 was shifted to 2 km from the centre while the shift in peak was not prominent for the remaining municipalities. The UII trend of Attingal municipality was similar to that for the corporation centre and at all distances within 5 km, the values were comparatively higher during 1999-2006. Towards the outskirts, intensity of growth was steady. For Neyyattinkara, even though the intensity values were lower for the second time phase, the urban core remained active. For Nedumangad municipality, a small outgrowth was seen as a peak value in UII at 5 km distance from urban centre. This was due to the urban growth in the outskirts near Karakulam.

3.5 Spatiotemporal trends of upi for thiruvananthapuram central and the municipalities

The variation of UPI surrounding the centre of Thiruvananthapuram Corporation and its main suburbs was plotted as a function of distance (Figure 9) from the urban centre over the entire study period 1990-2006. The results showed that the corporation region had the dominant urban expansion compared to the municipalities, both in terms of magnitude and intensity. The UPI index was very low for Thiruvananthapuram Central near the urban centre, which indicated that the urban centre was already formed before 1990. At the same time, UPI curved downward gradually and maintained 12% at 10 km from the urban centre.

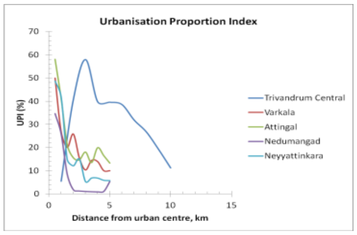


Fig. 9 Variation of UPI with distance to urban centres

Among the municipalities, the decline of urbanisation was seen to be rapid in Nedumangad whereas, the degree of urbanisation in Varkala and Attingal was observed to be stronger than the other centres. This could be attributed to the growth of smaller townships near Chirayinkeezhu, Alamkodu, Avanavancheri, Edava, etc. For Attingal municipality, the UPI index was approximately 13% at 5 km indicating that this outer zone was still undergoing active urbanisation.

3.6 Identifying village-towns (desakota pattern)

Based on the criteria discussed in the methodology, the areas with land use category built-up, having a population density greater than 1300 per sq. km and having connectivity with the main urban centre were mapped as villages developing into towns. The result of the analysis is mapped in fig. 10.

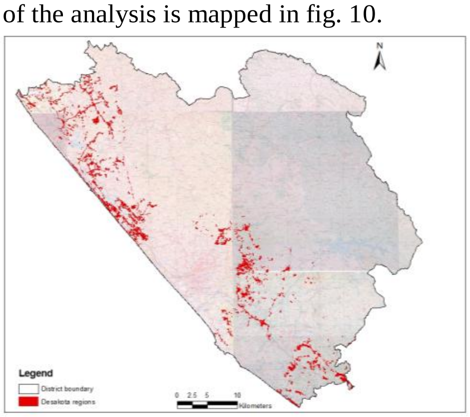


Fig. 10 Map showing urban-rural continuum (desakota growth)

The regions surrounding the town centres that were mapped as village areas developing to towns are listed in table 3. Among them, the most densely populated areas were identified as Anchuthengu, Vakkam and Venganoor were observed to be the most densely populated areas.

Table 3 Village areas developing into towns

Sl. No:	Panchayat area	Sl. No:	Panchayat area
1	Navayikkulam	21	Vilappil
2	Elakamon	22	Poovachal
3	Edava	23	Vilavoorkkal
4	Karavaram	24	Malayinkeezhu
5	Chemmaruthi	25	Kattakkada
6	Ottoor	26	Maranalloor
7	Manampoor	27	Pallichal
8	Cherunniyur	28	Kalliyoor
9	Vettoor	29	Kunnathukal
10	Vakkam	30	Balaramapuram
11	Kizhuvilam	31	Venganoor
12	Kadakkavoor	32	Athiyannoor
13	Anchuthengu	33	Kollayil
14	Chirayinkeezhu	34	Chenkal
15	Mangalapuram	35	Parasala
16	Azhoor	36	Thirupuram
17	Kadinamkulam	37	Kottukal
18	Andoorkkonam	38	Poovar
19	Karakulam	39	Karode
20	Aruvikkara	40	Kulathoor

4. Conclusion

The integration of remotely sensed data and geographic information system served as an excellent aid in conducting the spatio-temporal analysis of the study area. The synoptic coverage of satellite images and availability of temporal data were utilised effectively. Moreover, the potential capability of GIS to separate information in layers, and then combine it with other layers of information was made use of in performing the gradient analysis. GIS analysis also facilitated the display of patterns, relationships, and trends in the geographic data.

Thiruvananthapuram, the capital city of Kerala, is a coastal district. The urbanisation gradient study conducted on the district led to the following conclusions:

1. The initial phase of urban growth which took place before 1990 could be seen along the major roadways and railways which run parallel to the coastal stretch. The later phases of urban growth could be seen as a dispersed growth in the interiors of the district.

2. The major directional growth was observed to be in the NNE slice. All the major clustered growth was seen near to the road junctions.
3. The urban planning process for the region need to consider the major nodes of urban growth that is seen outside the city centres. These nodes of urban expansion were evident from the peak values of UII.
4. Among the municipalities, the urban expansion was observed to be comparatively active for Attingal and Varkala. This is an indicator that for the suburban areas of these municipalities, urban development planning should be given due importance.
5. The areas of desakota pattern of growth were identified and mapped. 40 panchayat areas of urban-rural continuum were identified based on the criteria considered. These are the regions where the environment is continually undergoing continual stress. Thus the ecosystem balance should be monitored in such places. Also, regulatory principles should be formulated for the settlements in these regions.

5. Acknowledgement

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