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Urban sprawl: metrics, dynamics and modelling using GIS

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Abstract

Urban sprawl refers to the extent of urbanisation, which is a global phenomenon mainly driven by population growth and large scale migration. In developing countries like India, where the population is over one billion, one-sixth of the world's population, urban sprawl is taking its toll on the natural resources at an alarming pace. Urban planners require information related to the rate of growth, pattern and extent of sprawl to provide basic amenities such as water, sanitation, electricity, etc. In the absence of such information, most of the sprawl areas lack basic infrastructure facilities. Pattern and extent of sprawl could be modelled with the help of spatial and temporal data. GIS and remote sensing data along with collateral data help in analysing the growth, pattern and extent of sprawl. With the spatial and temporal analyses along with modelling it was possible to identify the pattern of sprawl and subsequently predict the nature of future sprawl. This paper brings out the extent of sprawl taking place over a period of nearly three decades using GIS and Remote Sensing. The study also attempts to describe some of the landscape metrics required for quantifying sprawl. For understanding and modelling this dynamic phenomenon, prominent causative factors are considered.

Keywords: Urban sprawl; Urbanisation; GIS; Remote sensing; Urban dynamics; Spatial and temporal analyses; Modelling

1. Introduction

The process of urbanisation is a universal phenomenon taking place the world over, where humans dwell. All countries are prone to this bewildering phenomenon chiefly responsible due to the increase in population growth, economy and infrastructure initiatives. The extent of urbanisation or the sprawl is one such phenomenon that drives the change in land use patterns. The sprawl normally takes place in radial direction around the city centre or in linear direction along the highways. Usually sprawl takes place on the urban fringe, at the edge of an urban area or along the highways. The study on urban sprawl (The Regionalist, 1997; Sierra Club, 1998) is attempted in the developed countries (Batty et al., 1999; Torrens and Alberti, 2000; Barnes et al., 2001, Hurd et al., 2001; Epstein et al., 2002) and recently in developing countries such as China (Yeh and Li, 2001; Cheng and Masser, 2003) and India (Jothimani, 1997; Lata et al., 2001; Sudhira et al., 2003). In India alone currently 25.73% of the population (Census of India, 2001) live in the urban centres, while it is projected that in the next fifteen years about 33% would be living in the urban centres. This indicates the alarming rate of urbanisation and the extent of sprawl that could take place. In order to understand this increasing rate of urban sprawl, an attempt is made to understand the

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sprawl dynamics and evolve appropriate management strategies that could aid in the region's sustainable development. Understanding such a phenomenon and its pattern helps in planning for effective natural resource utilisation and provision of infrastructure facilities.

The built-up is generally considered as the parameter for quantifying urban sprawl (Torrens and Alberti, 2000; Barnes et al., 2001; Epstein et al., 2002). It is quantified by considering the impervious or the built-up as the key feature of sprawl, which is delineated using toposheets or through the data acquired remotely. The convergence of GIS, remote sensing and database management systems has helped in quantifying, monitoring, modelling and subsequently predicting this phenomenon. At the landscape level, GIS aids in calculating the fragmentation, patchiness, porosity, patch density, interspersion and juxtaposition, relative richness, diversity, and dominance in order to characterise landscape properties in terms of structure, function, and change (ICIMOD, 1999; Civco et al., 2002). Modelling the spatial and temporal dimensions has been an intense subject of discussion and study for philosophy, mathematics, geography and cognitive science (Claramunt and Jiang, 2001). Modelling of the spatial dynamics rests mostly with the land cover/land use change studies (Lo and Yang, 2002) or urban growth studies. In order to predict the scenarios of land use change in the Ipswich watershed, USA over a period of two decades, Pontius et al. (2000) predict the future land use changes based on the model validated for 1971, 1985 and 1991.

In urban growth modelling studies, the spatial phenomenon is simulated geometrically using techniques of cellular automata (CA). The CA technique is used extensively in the urban growth models (Clarke et al., 1996) and in urban simulation (Torrens and O' Sullivan, 2001; Waddell, 2002). The inadequacy in some of these is that the models fail to interact with the causal factors driving the sprawl such as the population growth, availability of land and proximity to city centres and highways. Cheng and Masser (2003) report the spatial logistic regression technique used for analysing the urban growth pattern and subsequently model the same for a city in China. Their study also includes extensive exploratory data analyses considering the causal factors. The inadequacies in their technique related to accurately pinpoint spatially where the sprawl would occur. This problem could be effectively addressed when neural network is applied to the remote sensing data especially for classification and thematic representation (Foody, 2001). The neural spatial interaction models would relieve the model user of the need to specify exactly a model that includes all necessary terms to model the true spatial interaction function (Fischer, 2002).

However, monitoring of urban land use change using the techniques of remote sensing and GIS and its subsequent modelling to arrive at a conventional approach is lacking in the context of India. The objective of this investigation is to analyse and understand the urban sprawl pattern and dynamics to predict the future sprawls and address effective resource utilisation for infrastructure allocation.

In order to quantify the urban forms such as built-up in terms of spatial phenomenon, the Shannon's entropy (Yeh and Li, 2001) and the landscape metrics (patchiness, map density) were computed for understanding the built-up dynamics. The landscape metrics, normally used in ecological investigations, is being extended to enhance the understanding of the urban forms. Computation of these indices helped in understanding the process of urbanisation at a landscape level.

2. Methodology to measure urban sprawl

Understanding the dynamic phenomenon such as urban sprawl requires land use change analyses, urban sprawl pattern identification and computation of landscape metrics. Drainage network (sea, rivers, streams and water bodies), roads and railway network and the administrative boundaries were digitised from the toposheets as individual layers. The highway passing between the two cities was digitised separately and a buffer region of 4 km on either side of the highway was created using MAPINFO 5.5, for detailed field investigations. Land cover and land use analysis for this region is done using IRS 1C data. Urban sprawl over the period of three decades (1972–1999) is determined by computing the built up area of all the settlements from the Survey of India (SOI) toposheets of 1971–1972 and comparing it with the area obtained from the classified satellite imagery for the built-up theme.

Urban sprawl is a process, which can affect even the smallest of villages; hence each and every village was analysed. Attribute information like village name, taluk it belongs to, population density, distance to the cities, etc. was extracted from census records (1971, 1981 and 1991) and from vector layers and were added to the database. The built-up area (for 1972) was computed and appended to this attribute database.

The multispectral LISS satellite imagery procured from NRSA, Hyderabad, India, was used for the analysis using Idrisi 32 (Eastman, 1999; http://www.clarklabs.org). The image analyses included bands extraction, restoration, classification, and enhancement. The Gaussian maximum likelihood classifier (MLC) was employed for classification. The original classification of land-use of 16 categories was aggregated to vegetation, built-up (residential and commercial), agricultural lands and open, and water bodies. Area under built-up theme was recognised and extracted from the imagery and the area for 1999 was computed. Further, by overlaying village boundaries, village wise built-up area was calculated.

3. Study area

Mangalore, Udupi region in Karnataka state, was chosen based on the preliminary investigation where urban sprawl is prevalent. This region is located within co-ordinates of latitudes 12°49′35″N and 13°22′50″N and longitudes 74°42′5″E and 74°54′55″E surrounding the National Highway (NH 17) passing between Udupi and Mangalore, Karnataka, India (Fig. 1). The distance between the two urban centres is 62 km. A buffer region of 4 km on each side is marked as the specific area for detailed investigation.

The total study area is 434.2 km^2. The annual precipitation in this area is approximately 4242.5 mm in Mangalore and 4128.1 mm in Udupi. The southwest monsoon during the months of June to October is mainly responsible for the precipitation. The next round of precipitation occurs in the months of November and December due to the northeast monsoon. The relative humidity is considerably high mainly due to the proximity of the region to the coast. Mean annual temperature ranges from 18.6 to 34.9 °C (Census of India, 1981).

Mangalore is the administrative headquarters of Dakshin Kannada district, southwestern Karnataka state, southern India. The modern port 10 km north of Mangalore, beside the highway towards Udupi, is India's ninth largest cargo handling port. Until 1997, Udupi was also in the Dakshin Kannada district, after which it has been bifurcated as a new district. There are 39 and 35 villages in Mangalore and Udupi

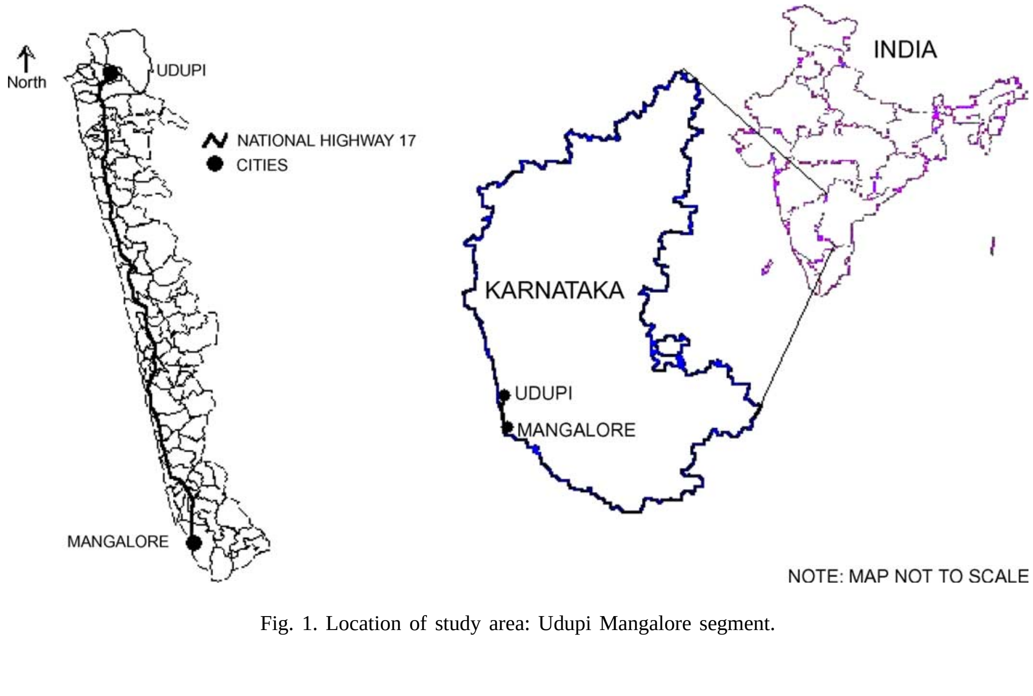

Fig. 1. Location of study area: Udupi Mangalore segment.

taluks, respectively, falling under the study area, a shipbuilding centre. The region is a leader in more than one-way in banking, private entrepreneurship and in general awareness amongst people. Mangalore city has given birth to four nationalised banks apart from general insurance companies. Industrialisation has crept in along with the financial institutions, in the form of Iron Ore Pelletization Unit, Fertilizer, Refinery and Petrochemical and such numerous industries. The regions' economy is complemented by agricultural processing and port-related activities apart from the industrial and financial sectors. Apart from these this region has the distinction of having the highest number of literate. The other distinguishing factor is that the sex ratio, i.e. number of females per 1000 males is 1020. Thus, the entire region, which exhibits a host of vibrant economic activities as evinced from the growth of cities and infrastructure developments, was selected for investigation.

4. Data collection

The data collection was done from both primary and secondary data sources. The primary data collected were the Survey of India toposheets of 1:50,000 scale for the corresponding region and the multispectral satellite imagery of the Indian Remote Sensing (IRS) satellite, LISS-3 dated 29 March 1999 from the National Remote Sensing Agency, Hyderabad, India for the corresponding path (97) and row (64). The secondary data collected included the demographic details from the primary census abstracts of all the villages in the study area for 1971, 1981, 1991 and 2001, from the Directorate of Census Operations, Census of India. The village maps of this region was obtained from the Directorate of Survey Settlements and Land Records, Government of Karnataka.

5. Results and discussion

5.1. Image analyses

The standard image processing techniques such as, image extraction, rectification, restoration, and classification were applied in the current study. The image obtained from the NRSA in three bands, viz., band 2 (green), band 3 (red) and band 4 (near infrared), was used to create a false colour composite (FCC) as shown in Fig. 2. Training polygons were chosen from the composite image and corresponding attribute data was obtained in the field using GPS. Based on these signatures, corresponding to various land features, image classification was done using Gaussian MLC and the classified image is given in Fig. 3.

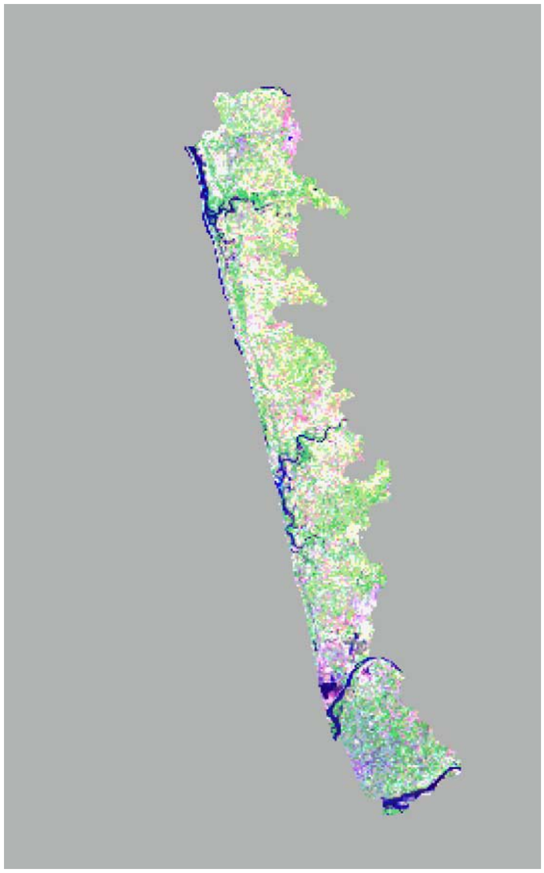

Fig. 2. False colour composite.

5.2. Population growth and built-up area

The rate of development of land in Udupi, Mangalore region, is outstripping the rate of population growth. This implies that the land is consumed at excessive rates and probably in unnecessary amounts as well. Between 1972 and 1999, population in the region grew by about 54% (Census of India, 1971, 1981, 1991) while the amount of developed land grew by

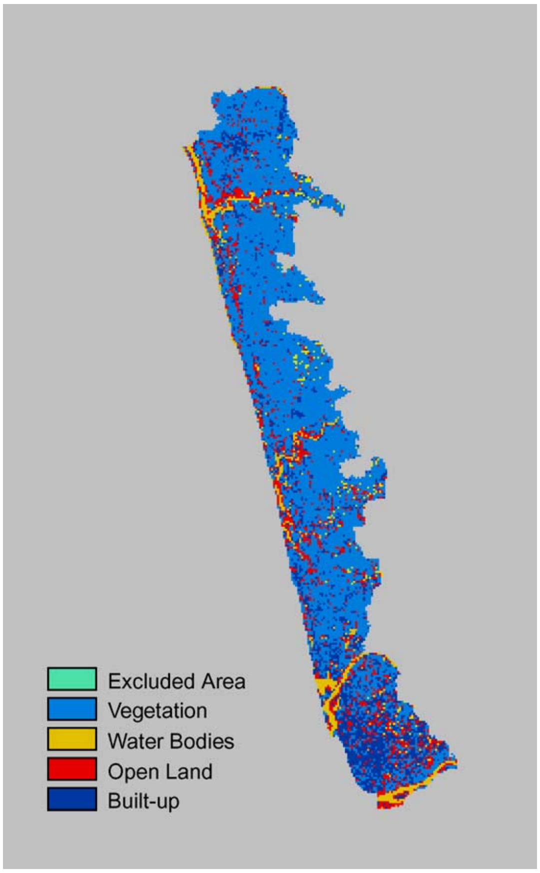

Fig. 3. Classified image.

about 146%, or nearly three times the rate of population growth (Fig. 4). This means that the per capita consumption of land has increased exceptionally over three decades. The per capita land consumption refers to utilisation of all lands for development initiatives like the commercial, industrial, educational, and recreational establishments along with the residential establishments per person. Since most of the initiatives pave way for creation of jobs and subsequently help in earning livelihood, the development of land is seen as a direct consequence of a region's economic development and hence one can conclude that the per capita land consumption is inclusive of all the associated land development.

5.3. Metrics of urban sprawl

Characterising pattern involves detecting and quantifying it with appropriate scales and summarising it statistically. There are scores of metrics now available to describe landscape pattern. The only major components that were considered for this study are composition and structure. The landscape pattern metrics are used in studying forest patches (Trani and Giles, 1999; Civco et al., 2002). Most of the indices are correlated among themselves, because there are only a few primary measurements that can be made from patches (patch type, area, edge, and neighbour type), and all metrics are then derived from these primary measures.

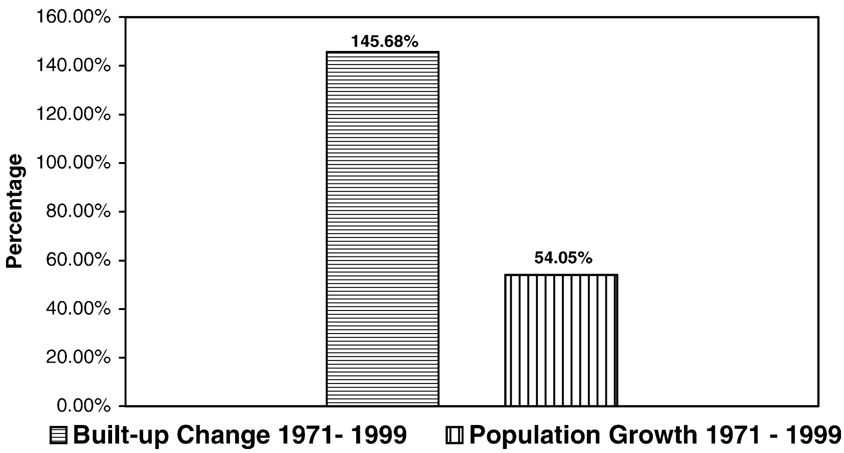

Fig. 4. Rates of growth in population and built-up from 1971–1999.

Table 1
built-up area, population and Shannon's entropy for the study area

Segment	Built-up area (km^2)		Population		Shannon's entropy		
	1972	1999	1972	1999	1972	1999	Log N
Udupi , Mangalore	25.1383	61.7603	312003	483183	1.7673	1.673	1.9138

The landscape metrics applied to analyse the built-up theme for the current study are discussed next.

5.3.1. Shannon's entropy (H_n)

The Shannon's entropy (Yeh and Li, 2001) was computed to detect the urban sprawl phenomenon and is given by,

$$H_n = -\Sigma P_i \log_e(P_i) \quad (1)$$

where; P_i is the Proportion of the variable in the ith zone n the Total number of zones

This value ranges from 0 to $\log n$, indicating very compact distribution for values closer to 0. The values closer to log n indicates that the distribution is very dispersed. Larger value of entropy reveals the occurrence of urban sprawl. Table 1 shows the built-up area, population and Shannon's entropy for 1972 and 1999.

Shannon's entropy was calculated from the built-up area for each village, considered as an individual zone (n is the total number of villages). The results show that the distribution of built-up in the region in 1972 was more dispersed than in 1999. However, the degree of dispersion has come down marginally and distribution is predominantly dispersed. The values obtained here, 1.7673 in 1972 and 1.673 in 1999, are closer to the upper limit of $\log n$, i.e. 1.914, showing the degree of dispersion of built-up in the region.

5.3.2. Patchiness

Patchiness or number of different classes (NDC) is the measurement of the density of patches of all types or number of clusters within the $n \times n$ window. In other words, it is a measure of the number of heterogeneous polygons over a particular area. Greater the patchiness more heterogeneous the landscape is (Murphy, 1985). In this case the density of patches among different categories was computed for a 3×3 window. The computation of patchiness using 3×3 moving window revealed that two heterogeneous classes category was maximum (57.15%) and five heterogeneous classes category was the least (0.02%) in the study area (Table 2). This reveals that about 20.7% of the study area is homogeneous while the rest are heterogeneous with patch class ranging from two to five (Fig. 5).

5.3.3. Map density

Map density values are computed by dividing number of built up pixels to the total number of pixels in a kernel. This when applied to a classified satellite image converts land cover classes to density classes, which is given in Fig. 6. Depending on the density levels, it could be further grouped as low, medium and high density (Fig. 7). Based on this, relative share of each category was computed (area and percentage). This enabled in identifying different urban growth centres and subsequently correlating the results with Shannon's entropy for identifying the regions of high dispersion.

The computation of built-up density gave the distribution of the high, medium and low-density built-up clusters in the study area. High density of built-up would refer to clustered or more compact nature of the built-up theme, while medium density would refer to relatively lesser compact built-up and low density referred to loosely or sparsely spread built-up areas. The percentage of high-density built-up area was only 12.67% as against 25.67% of medium density and as much as 61.66% of low-density built-up area (Table 3). This revealed that more compact or highly

Table 2
Percentage distribution of patchiness

Number of classes	Percentage distribution
1	20.7
2	57.15
3	20.18
4	1.95
5	0.02

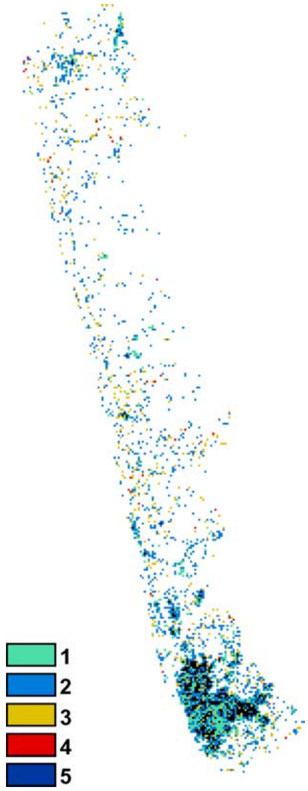

Fig. 5. Patchiness or number of different classes.

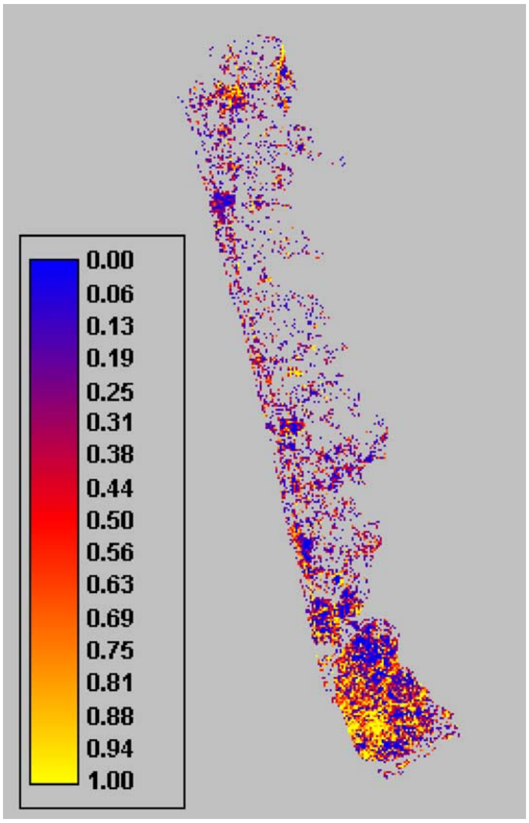

Fig. 6. Map density.

dense built-up was a smaller amount and more dispersed or least dense built-up was larger in the study area. An important inference that could be drawn out of this was that high and medium density was found all along the highways along with the city centres. Most of the high density was found to be within and closer to the cities. However, medium density was also found mostly along the city periphery and on the highways. The distribution of low density was the maximum in the study area and this could be inferred as the higher dispersion of the built-up in the study area. This further substantiates the results of Shannon's entropy, which revealed a high dispersion of the built-up theme in the study area.

Table 3
different densities of built-up and their area

Category	Area (km^2)	Percentage
Low density	93.88	61.66
Medium density	39.08	25.67
High density	19.29	12.67

5.3.4. *Dynamics of urban sprawl*

Defining this dynamic phenomenon and predicting the future sprawl is a greater challenge than the quantification of sprawls. Although different sprawl types were identified and defined there has been an inadequacy with respect to developing mathematical relationships to define them. This necessitates characterisation and modelling of urban sprawl, which will aid in regional planning and sustainable development.

Urban sprawl dynamics was analysed considering some of the causal factors. The rational behind this is to identify such factors that play a significant role in the process of urbanisation. The causal factors that

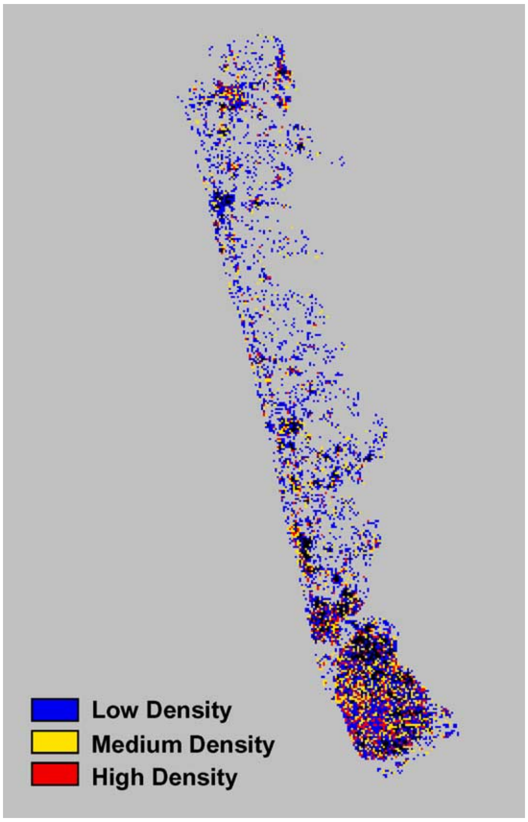

Fig. 7. Classification of built-up densities.

were considered responsible for sprawl were:

- population (POP99),
- α-population density (POPADEN) and β-population density (POPBDEN),
- annual population growth rate (AGR),
- distance from Mangalore (MANGDIST), and
- distance from Udupi (UDUPIDIST).

The factor population has been accepted as a key factor of urban sprawl. The percentage built-up is the proportion of the built-up area to the total area of the village. The α population density (POPADEN) is the proportion of the population in every village to the built-up area of that village. The β population density (POPBDEN) is the proportion of population in every village to the total area of that village. The β population density is often referred as population density. Since the built-up area plays an important role in the current study for the purpose of analyses, the percentage built-up, α and β population densities are computed and analysed village-wise and categorised as a sub-zone. The annual population growth rate (AGR) is computed from the population data available from 1961 for all the villages. This growth rate is used in predicting the population for 1999 and subsequent future populations. The distance from the city centres, viz. Udupi and Mangalore to each village was calculated. Thus, the effects of proximity of the cities on the urban sprawl of these sub-zones were analysed. With these causal factors identified the modelling studies were undertaken.

5.3.5. Modelling of urban sprawl

In order to explore the probable relationship of percentage built-up (dependent variable) with causal factors of sprawl (population, α- and β-population densities, etc.), regression analysis was undertaken. Various regression analyses (linear, quadratic, exponential and logarithmic) were carried out to ascertain the nature of significance of the causal factors (independent variables) on the sprawl, quantified in terms of percentage built-up. The linear, quadratic (order = 2), and logarithmic (power law) regression analyses were tried and the results are tabulated in Annexure. All these regression analyses reveal the individual contribution by the causal factors on the sprawl. The most significant relationships are outlined in Eqs. (2)–(6). The linear regression analyses revealed that the population has a significant influence, which is evident from the x coefficient. The quadratic regression analyses for second order revealed that the β-population density and distance from urban centre (Mangalore) have a considerable role in the sprawl phenomenon. It is evident from the result that the sprawl declines with increase in distance from urban centres. The logarithmic (power law) regression analyses revealed that the α population density has influenced the sprawl phenomenon, which is evident from the value of exponent. Positive value of the exponent infers that built-up area increases exponentially with increase in POPADEN. The probable relationships are,

$$\text{PCBUILT} = 0.000611 \times \text{POP99} + 10.87149 \; (r = 0.5789) \qquad (2)$$

$$\text{PCBUILT} = 0.005651 \times (\text{POPBDEN})^2 - 1.2 \times 10^{-7} \times (\text{POPBDEN}) + 6.8950\ (r = 0.6823) \quad (3)$$

$$\text{PCBUILT} = -1.7953 \times (\text{MANGDIST})^2 + 0.02593 \times (\text{MANGDIST}) + 36.8607\ (r = 0.60) \quad (4)$$

$$\text{PCBUILT} = -0.9027 \times (\text{UDUPIDIST})^2 + 0.002242 \times (\text{UDUPIDIST}) + 15.9731\ (r = 0.583) \quad (5)$$

$$\text{PCBUILT} = 0.270 \times (\text{POPADEN})^{1.6938}\ (r = 0.4779) \quad (6)$$

To assess the cumulative effects of causal factors, stepwise regression analysis considering multivariate was done. In the multivariate regression it is assumed that the relationship between variables is linear. The multivariate regression gives the cumulative relationship among the variables and the probable relationships are,

$$\text{PCBUILT} = -27.08 + 0.002496 \times \text{POPBDEN} + 0.5743 \times \text{MANGDIST} + 0.8139 \times \text{UDUPIDIST}\ (r = 0.719) \quad (7)$$

$$\text{PCBUILT} = -18.9358 - 0.00027 \times \text{POP99} + 0.005452 \times \text{POPBDEN} + 0.3797 \times \text{MANGDIST} + 0.6249 \times \text{UDUPIDIST}\ (r = 0.761) \quad (8)$$

$$\text{PCBUILT} = -38.6985 - 0.00031 \times \text{POP99} + 0.006024 \times \text{POPBDEN} - 1.677991 \times \text{AGR} + 0.7577 \times \text{MANGDIST} + 1.0346 \times \text{UDUPIDIST}\ (r = 0.784) \quad (9)$$

$$\text{PCBUILT} = -21.7633 - 0.00031 \times \text{POP99} - 0.12529 \times \text{AGR} - 0.0004 \times \text{POPADEN} + 0.006417 \times \text{POPBDEN} + 0.5289 \times \text{MANGDIST} + 0.7451 \times \text{UDUPIDIST}\ (r = 0.86) \quad (10)$$

Considering all the causal factors in the stepwise regression, Eq. (10) indicates the highest correlation coefficient. It is to be noted that Eq. (9) has the next best correlation coefficient when POPADEN is not considered. The anomaly in considering Eq. (10) for prediction is that, POPADEN is nothing but the proportion of the population in every village to the built-up area of that village. However, the relationships 7–10 confirm that the causal factors collectively have a significant role in the sprawl phenomenon, as can be understood from the positive correlation coefficients.

5.3.6. Predicting scenarios of urban sprawl

Likely increase in the built-up area is predicted using Eq. (9). To project built-up for 2020 and 2050, corresponding population was computed considering annual growth rate based on the historical population data of 1961–2001.

It is found that the percentage built-up for 2020 and 2050 would be 18.10 and 30.47%, respectively. This implies that by 2050, the built-up area in the region would rise to 127.7 km^2, which would be nearly 106% growth in the change in built-up area to the current sprawl of 61.7703 km^2 over the region. Thus, indicating that the pressure on land would further grow and the agriculture fields, open grounds and region around the highways would become prime targets for sprawl. This would also give a picture of the pressures on the land, which the planners have to address in their planning exercises. With an understanding of the land requirement under the current trend, the techniques of GIS and remote sensing can be applied for effective infrastructure facilities and resource utilisation.

6. Conclusion

With the population of India increasing as ever, the pressures on land and resources are also increasing. The urban sprawl is seen as one of the potential threats to sustainable development where urban planning with effective resource utilisation and allocation of infrastructure initiatives are key concerns. The study attempts to identify such sprawls, quantify by defining few metrics, understand the dynamic process and subsequently model the same to predict for future. The study was carried out along the Mangalore, Udupi highway using the techniques of GIS and remote sensing to identify and quantify the sprawl. The spatial data along with the attribute data of the region aided to analyse statistically and define few of the landscape metrics. Further, the statistical analyses helped in quantifying and modelling the same. It was found that the percentage change in built-up over the period of nearly thirty years was 145.68% and by 2050, the built-up area in the region would rise to 127.7 km^2, which would be nearly 106% growth in the change in built-up area to the current sprawl of 61.7703 km^2 over the region.

Acknowledgements

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Appendix A. Coefficients of causal factors and percentage built-up by linear regression analyses

Dependent variable (y)	Independent variable (x)	Equation ($y = ax + b$)	S.E. of 'y' estimate	Correlation coefficient, r
PCBUILT	POP99	$y = 0.000611x + 10.87149$	13.0163	0.5327
PCBUILT	POPADEN	$y = -0.0004x + 19.5719$	11.2594	0.2070
PCBUILT	POPBDEN	$y = 0.005774x + 7.849476$	10.1397	0.6474
PCBUILT	AGR	$y = 0.635301x + 13.0499$	13.2391	0.0990
PCBUILT	MANGDIST	$y = -0.31149x + 22.93755$	12.2142	0.3965
PCBUILT	UDUPIDIST	$y = 0.315763x + 5.584017$	12.1528	0.4070

Appendix B. Coefficients of causal factors and percentage built-up by polynomial (order = 2) regression analyses

Dependent variable (y)	Independent variable (x)	Equation ($y = ax^2 + bx + c$)	S.E. of 'y' estimate	Correlation coefficient, r
PCBUILT	POP99	$y = 0.0006x^2 - 1.5 \times 10^{-9}x + 9.7776$	10.9210	0.5784
PCBUILT	POPADEN	$y = -0.00037x^2 - 2.7 \times 10^{-9}x + 18.555$	13.0577	0.2208
PCBUILT	POPBDEN	$y = 0.005651x^2 - 1.2 \times 10^{-7}x + 6.8950$	9.7880	0.6823
PCBUILT	AGR	$y = 0.66679x^2 + 0.05754x + 13.3308$	13.3190	0.1017
PCBUILT	UDUPIDIST	$y = -0.9027x^2 + 0.002242x + 15.9731$	10.8729	0.5835
PCBUILT	MANGDIST	$y = -1.7953x^2 + 0.02593x + 36.8607$	10.6784	0.6032

Appendix C. Coefficients of causal factors and percentage built-up by logarithmic regression analyses

Dependent variable (y)	Independent variable (x)	Equation ($\log y = \log(a) + b \log x$)	S.E. 'y' estimate	Correlation coefficient, r
LNPCBUILT	LNPOP99	$y = -0.429 + 0.331x$	0.7656	0.3835
LNPCBUILT	LNPOPADEN	$y = -1.308 + 0.527x$	0.7282	0.4779
LNPCBUILT	LNPOPBDEN	$y = +7.796 - 0.593x$	0.6754	0.3363
LNPCBUILT	LNAGR	$y = +2.275 + 0.104x$	0.8263	0.0799
LNPCBUILT	LNMANGDIST	$y = +3.718 - 0.456x$	0.7208	0.4939
LNPCBUILT	LNUDUPIDIST	$y = +2.008 + 0.114x$	0.8192	0.1527

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