Urban Sprawl Pattern Analysis Using GIS

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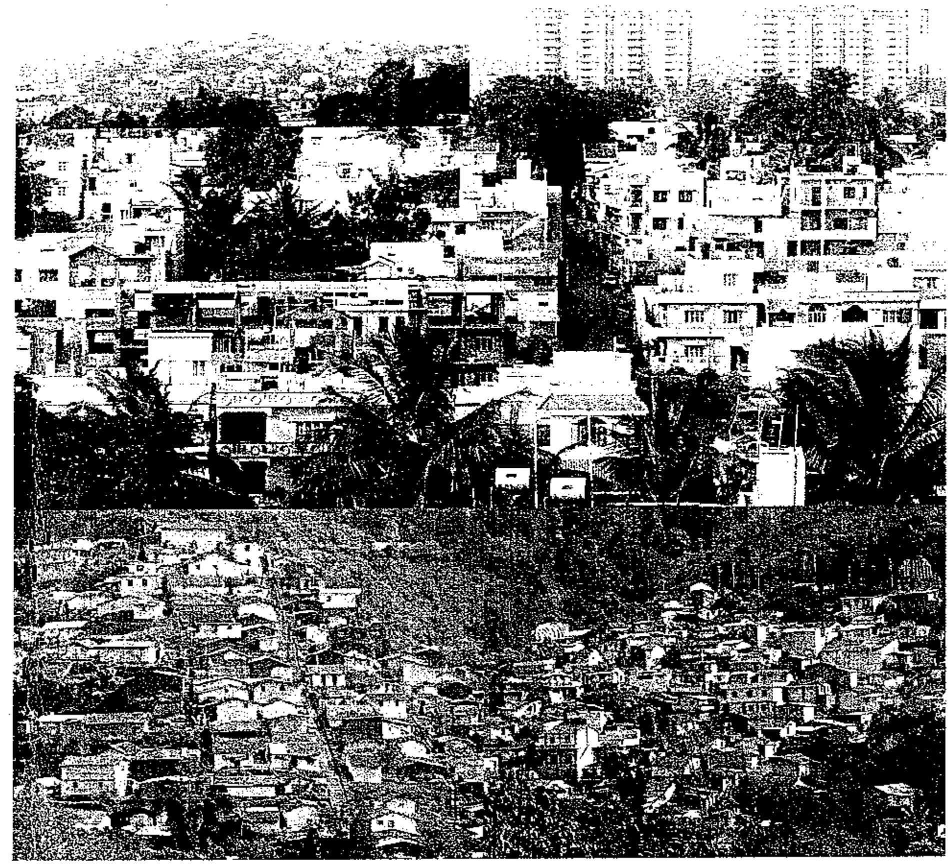

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Preface

The study of urbanisation has evinced interest from a wide section of the society including experts, amateurs, and novices. The multidisciplinary scope of the subject invokes the interest from ecologists to urban planners and civil engineers, to sociologists, to administrators and policy makers, students and finally the common man. With the development and infrastructure initiatives mostly around the urban centres, the impacts of urbanisation and sprawl would be on the environment and the natural resources. The wisdom lies in how effectively we plan the urban growth without—hampering the environment, excessively harnessing the natural resources and eventually disturbing the natural set-up. The research on these help urban residents and policymakers make informed decisions and take action to restore these resources before they are lost. Ultimately the power to balance the urban ecosystems rests with regional awareness, policies, administration practices, management issues and operational problems. This publication on urban systems is aimed at helping scientists, policy makers, engineers, urban planners and ultimately the common man to visualise how towns and cities grow over a period of time based on investigations in the regions around the highways and cities. Two important highways in Karnataka, South India, viz., Bangalore – Mysore highway and the Mangalore – Udupi highway, in Karnataka and the Tiruchirapalli – Tanjavore – Kumbakonam Thiruvarur highway network in Tamil Nadu, South India, were considered in this investigation.

Geographic Information System and Remote Sensing data were used to analyse the pattern of urbanisation. This was coupled with the spatial and temporal data from the Survey of India toposheets (for 1972), satellite imageries procured from National Remote Sensing Agency (NRSA) (LANDSAT TM for 1987 and IRS LISS III for 1999), demographic details from the Census of India (1971, 1981, 1991 and 2001) and the village maps from the Directorate of Survey Settlements and Land Records, Government of Karnataka. All this enabled in quantifying the increase in the built-up area for nearly three decades. With the intent of identifying the potential sprawl zones, this could be modelled and projected for the future decades. Apart from these the study could quantify some of the metrics that could be used in the study of urban sprawl.

Synopsis

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 in this part of the globe 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 modeling it was possible to identify the pattern of sprawl and subsequently predict the nature of future sprawl

This study brings out the extent and pattern 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 modeling this dynamic phenomenon, prominent causative factors are considered.

1 Introduction

The study of urbanisation has evinced interest from a wide range of experts. The multidisciplinary gamut of the subject invokes the interest from ecologists to urban planners and civil engineers, to sociologists, to administrators and policy makers, students and finally the common man This is because of the multitude of activities and processes that take place in the urban ecosystems everyday Urban ecosystems are the consequence of the intrinsic nature of humans as social beings to live together Thus, when the early humans evolved they settled on the banks of the rivers that dawned the advent of civilisations With the development of their communication skills in the form of languages through speech and script, humans effectively made enormous progress in their life styles. All this eventually led to the initial human settlements, villages, towns and then into cities. In the process, humans now live in complex ecosystems called urban ecosystems

An unprecedented population growth and migration, an increased urban population and urbanisation are inadvertent More and more towns and cities bloomed with a change in the land use along the myriad of landscapes and ecosystems found on earth. Today, humans can boast of living under a wide range of climatic and environmental conditions This has further led to humans contributing to urban centres in almost every corner of the earth. These urban ecosystems, a consequence of urbanisation through rapid industrial centres and blooming residential colonies, also became a hub of economic, social, cultural, and political activities

To understand the various components and processes that play an important role in the ecosystems, requires a holistic approach in management dealing with the various components of the ecosystem Looking back from the formation of the earth, the origin of life and subsequent evolution of life adds more light into the understanding of the current significance of urban ecosystems. The role of scientific and technological innovations in driving the urban ecosystems is an important aspect that is to be considered in the prevalent conditions. The changing lifestyles coupled with rapid urbanisation have an implication on the material and energy cycles that have a participation in the urban ecosystems apart from the living organisms Ultimately a clear-cut understanding of the urban ecosystem will enable us to appreciate various life processes and phenomena, taking place. The paradox of the human civilisation today is the inability to appreciate the enormous amounts of biotic and abiotic interactions that play a role in the survival and normal operation of the various ecosystem functions.

In recent years "sustainable development" is a commonly used terminology among various sections of the society subsequent to the publication of Brundtland report in 1987 The Rio 1992, Agenda 21, all endorsed this need. The sustainable development is defined as, "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" (World Commission on Environment and Development, 1987). In order to sustain development, the supply and quality of major consumables and inputs to our daily lives and economic production - such as air, water, energy, food, raw materials, land, and the natural environment needs to be taken care of. Land is essential because our food and raw materials originate from them and is a habitat for flora and fauna. Similar to other resources it is a scarce commodity. Any disturbance to this resource by way of change in land use e g. conversion of forestland and agricultural land into built-up, is irreversible. The use of land unsuitable for development may be unsustainable for the natural environment as well as to humans.

1.1 Urbanisation and Urban Sprawl

In India, with an unprecedented population growth and migration, an increased urban population and urbanisation is inadvertent. More and more towns and cities are blooming with a change in the land use along the highways and in the immediate vicinity of the city. This dispersed development outside of compact urban and village centres along highways and in rural countryside is defined as sprawl (Theobald, 2001). Urbanisation is a form of metropolitan growth that is a response to often bewildering sets of economic, social, and political forces and to the physical geography of an area. Some of the causes of the sprawl include - population growth, economy, patterns of infrastructure initiatives like the construction of roads and the provision of infrastructure using public money encouraging development. The direct implication of such urban sprawl is the change in land use and land cover of the region.

Sprawl generally infers to some type of development with impacts such as loss of agricultural land, open space, and ecologically sensitive habitats. Also, sometimes sprawl is equated with growth of town or city (radial spread). In simpler words, as population increases in an area or a city, the boundary of the city expands to accommodate the growth; this expansion is considered as sprawl. Usually sprawls take place on the urban fringe, at the edge of an urban area or along the highways

1.1.1 Need for Studying Urban Sprawl

In industrialised countries the future growth of urban populations will be comparatively modest since their population growth rates are low, and over 80% of their population already live in urban areas Conversely, developing countries are in the middle of the transition process, when growth rates are highest. The exceptional growth of many urban agglomerations in many developing countries is the result of a threefold structural change process: the transition away from agricultural employment, high overall population growth, and increasing urbanisation rates (Grubler, 1994). The biggest challenge for science, engineering and technology in the 21st century is how to ensure adequate housing, sanitation and health, and transportation services in a habitable urban environment in developing countries. Sprawl is seen as one of the potential threats for such development.

Normally, when rural pockets are connected to a city by a road, in the initial stages, development in the form of service centres such as shops, cafeteria, etc. is seen on the roadside, which eventually become the hub of economic activities leading to sprawl. A significant amount of upsurge could be observed along these roads This type of upsurge caused by a road network between urban/semi-urban/rural centres is very much prevalent and persistent in most places in India. These regions are devoid of any infrastructure, since planners are unable to visualise this type of growth patterns. This growth is normally left out in all government surveys (even in national population census), as this cannot be grouped under either urban or rural centre. The investigation of patterns of this kind of growth is very crucial from regional planning point of view to provide basic amenities in these regions Further, with the Prime Minister of India's pet project, "Golden Quadrilateral of National Highways Development Project" initiative of linking villages, towns and cities and building 4-lane roads, this investigation gains importance and significance.

Prior visualising of the trends and patterns of growth enable the planning machineries to plan for appropriate basic infrastructure facilities (water, electricity, sanitation, etc.) The study of this kind reveals the type, extent and nature of sprawl taking place in a region and the drivers responsible for the growth. This would help developers and town planners to project growth patterns and facilitate various infrastructure facilities In this direction, an attempt is made to identify the sprawl pattern, quantify sprawl across roads in terms of Shannon's entropy, and estimate the rate of change in built-up area over a period with the help of spatial and statistical data of nearly three decades using GIS

1.1.2 Causes of Urban Sprawl

The process of urbanisation is fairly contributed by population growth, migration and infrastructure initiatives resulting in the growth of villages into towns, towns into cities and cities into metros. However, in such a phenomenon for ecologically feasible development, planning requires an understanding of the growth dynamics Nevertheless, in most cases there are too many inadequacies to ascertain the nature of uncontrolled progression of urban sprawls. Sprawl is considered to be an unplanned outgrowth of urban centres along the periphery of the cities, along highways, along the road connecting a city, etc. Due to lack of prior planning, these outgrowths are devoid of basic amenities like water, electricity, sanitation, etc. Provision of certain infrastructure facilities like new roads and highways, fuel such sprawls that ultimately result in inefficient and drastic change in land use affecting the ecosystem. With respect to the role of technology in urbanisation, Berry (1990) has illustrated a new linkage between transport infrastructure development cycles and spurts in urbanisation.

Urban infrastructure development is unlikely to keep pace with urban population growth. Both local environmental impacts, such as deterioration of water quality in streams and an increased potential for harbouring disease vectors, and offsite land cover changes, such as the loss of woodland and forest to meet urban fuel wood demands, are likely to occur (Douglas, 1994)

1.1.3 Urban Sprawl—Forms, Patterns, Types

Box 1 Forms of Sprawl

Sprawl development consists of three basic spatial forms:

Low-density sprawl
Low-density sprawl is the consumptive use of land for urban purposes along the margins of existing metropolitan areas This type of sprawl is supported by piecemeal extensions of basic urban infrastructures such as water, sewer, power, and roads.

Ribbon
Ribbon sprawl is development that follows major transportation corridors outward from urban cores Lands adjacent to corridors are developed, but those without direct access remain in rural uses/covers Over time these nearby "raw" lands may be converted to urban uses as land value increases and infrastructure is extended perpendicularly from the major roads and lines

Leapfrog development
Leapfrog development is a discontinuous pattern of urbanisation, with patches of developed lands that are widely separated from each other and from the boundaries, albeit blurred in cases, of recognised urbanised areas This form of development is the most costly with respect to providing urban services such as water and sewerage.

Source. http://chesapeake.towson.edu/landscape/urbansprawl/

1.1.4 Urban Sprawl—Spatial and Temporal Changes: Pattern Assessment

Mapping urban sprawl provides a "picture" of where this type of growth is occurring, and helps to identify the environmental and natural resources threatened by such sprawls, and suggests the likely future directions and patterns of sprawling growth. Analysing the sprawl over a period of time will help in understanding the nature and growth of this phenomenon Ultimately the power to manage a sprawl resides with local municipal governments that vary considerably in terms of will and ability to address sprawl issues

1.2 GIS, Remote Sensing and Image Processing Techniques

GIS and remote sensing are very useful in the formulation and implementation of the spatial and temporal changes, which are essential components of regional planning to ensure the sustainable development The different stages in the formulation and implementation of a regional development strategy can be generalised as determination of objectives, resource inventory, analysis of the existing situation, modelling and projection, development of planning options, selection of planning options, plan implementation, and plan evaluation, monitoring and feedback (Yeh and Xia, 1996). GIS and remote sensing techniques are quite developed and operational to implement such a proposed strategy. The spatial patterns of urban sprawl on temporal scale are studied and analysed using the satellite imageries and cadastral data from Survey of India, mapped, monitored and accurately assessed from satellite data along with conventional ground data The image processing techniques are also quite effective in identifying the urban growth pattern from the spatial and temporal data captured by the remote sensing techniques. These help in delineating the growth patterns of urban sprawl such as, the linear growth and radial growth patterns.

1.3 Modelling Aspects

Mathematical models and computational techniques merely increase the capabilities of generating information that can be used in the decision making process A model is a simplified representation of the physical system Some simplified definitions of models are - a representative of the system that attempts to reproduce the significant elements of the system A model is simply the symbolic mathematical form in which a physical principle is expressed. Models are basically built by consideration of the pertinent physical principles operated on by logic and modified by experimental judgment and plain intuition.

It is important to recognise that modeling is a part of science and part of art. The science part involves identifying the physical principles that affect the system. The artistic part consists of deciding which of these processes are sufficiently important with respect to the goals and objectives of the study to be included in the model and placing the processes in a form that reflects the

interaction involved The artistic part also involves simplification of the system so that model solutions can be achieved with a reasonable effort but without a loss of rationality or accuracy

Models synthesise and act as the "glue" between the perception and problem, the observational data from the laboratory and field, and the current state of scientific understanding. However, it should always be stressed that modellers and their models do not make management and control decisions but only provide information to the process.

The model should and can reflect the dynamic characteristic and evolutionary nature of the environment Its most important function is to establish a basis for a comprehensive plan of the entire area Given a set of criteria, the model would analyse the alternate engineering solutions to achieve this level Given the necessary social inputs and constraints, it would be possible to arrive at optimal solutions between the limits of some acceptable minimal treatment and maximum technologically practicable treatment The main objectives of models are:

- Descriptive — to integrate observations, information and theories concerning a system; to aid understanding of system behaviour.
- Predictive — to predict the response of the system to future changes
- Optimised Allocation — to allocate certain resources in order to optimise certain conditions within the system.

Environmental modelling as one of the scientific tools for prediction and assessment is well established in the field of environmental research (Ferda K, 1993) Environmental modelling has a considerable history and development. The analytical approaches applied to biological and ecological problems date back to Lotka-Volterra and the fields like hydrology - water quality modelling also date back to early twentieth century with Streeter-Phelps With the enhanced computational techniques using microcomputers, the numerical solutions to these have become feasible There are a variety of models in environmental studies, which will suit specific situations For urban growth modelling, suitable models can be used as effective tools in management of urban growth and population growth leading to land pressures. Depending on the type of method employed in the construction of equations, the models can be classified into four types:

i *Analytical Models*—These are the models, which involve construction of solutions of partial differential equations, which represent the urban systems and the land use changes considered spatially

ii. *Numerical Models*—These are the models in which an attempt has been made to represent the natural systems and to solve the equations, which describe the conventional, numerical methods.

iii. *Physical Models*—These models involve construction of physical system at a smaller scale These types of models are least employed because of the lack of knowledge of scaling relationships, and thus limitations experienced in simulating urban growth processes.

iv *Cartographic Models*—A cartographic model is a graphical representation of the data and analytical procedures followed methodically in a specific study. The purpose of a cartographic model is to help the analyst organise and structure the necessary procedures as well as identify all the data required for the analysis

There are two basic reasons for constructing representations of urban systems through mathematical modeling. Firstly, it is the need to increase the level of understanding of the cause-effect relationships operative in urban growth dynamics, and secondly, apply that increased understanding to aid the decision making process for the urban growth management.

GIS serves theoreticians, programmers, and practitioners alike. An understanding of GIS modeling is important for practitioners who will create the models; theoreticians, who develop the concepts of new models; and programmers, who must code to make the models work inside a GIS The GIS automates geographic concepts, assists in decision-making, helps explain distributions and can assist in hypothesis formulation and testing. These tasks can be applied to a wide range of both practitioners and theoreticians by allowing them to manipulate portions of the earth that are stored as map data in the computer. The current popularity of GIS is in the multitude of domains in which they can be applied and in their ability to automate simple but repetitive map based tasks as well as complex ones (DeMers, 2002). Especially these tools enable the user to collate, integrate, analyse and model a large amount of spatial data along with their attribute information Harnessing the total potential of the GIS in environmental modeling rests with the user capable of understanding the concepts of environmental systems and applications of GIS

The real world cannot solely be represented in two dimensions as is commonly accepted. This certainly is a very limiting view of the reality that we perceive around us Most modelling in GIS has been two dimensional especially in the context of urban planning. The development in the field of "fuzzy logic" and "artificial neural networks" is providing the option of incorporating indeterminate and ambiguous information from the real world into GIS. This will be particularly useful while considering the cognitive models and individual perception of people and incorporating them for reference into GIS (Agarwal, P., 2000).

1.4 Study Objectives

The main objectives of this study are:

- Identify the patterns of urban sprawl – spatially and temporally;
- Analyse the urban sprawl pattern through remote sensing and geographic information system techniques;
- Analyse causal factors of urban sprawl, and
- Model urban sprawl

These objectives are attained through the following approach:

- Collateral data: temporal population data from the government agencies, cadastral data from land records department and toposheets from Survey of India.
- Creation of GIS layers: digitisation of built up area, drainage network and village boundaries from the toposheets (1972) for the study area.
- Remote sensing data from National Remote Sensing Agency, Hyderabad.
- Geo-correction of remote sensing data and collection of training data.
- Application of image processing techniques (temporal data - remote sensing data) to identify the spatial changes in built up area over the period.
- Modelling of these changes (both spatial and temporal).

2 GIS, Remote Sensing, and Image Processing in Studying Urban Sprawl

2.1 Geographic Information System (GIS)

The Geographic Information System (GIS) is a computer-assisted system for acquisition, storage, analysis and display of geographic data. GIS allows for creating, maintaining and querying electronic databases of information normally displayed on maps. These databases are spatially oriented, the fundamental integrating element being their position on the earth's surface This system consists of a set of computerised tools and procedures that can be used to effectively encode, store, retrieve, overlay, correlate, manipulate, analyse, query, and display land-related information. They also facilitate the selection and transfer of data to application specific analytical models capable of assessing the impact of alternatives on the chosen environment. The underlying foundation of sound GIS is an effective digital map database, tied to an accurate horizontal control survey framework

The spatial data generally is in the form of maps, which could be showing topography, geology, soil types, forest and vegetation, land use, water resource availability etc , stored as layers in a digital form Integrating many layers of data in a computer can easily generate new thematic maps. Thus, a GIS has a database of multiple information layers that can be manipulated to evaluate relationships among the selected elements. GIS can create maps, integrate information, visualise scenarios, solve complicated problems, present powerful ideas, and develop effective solutions

GIS works with two fundamentally different types of geographic models, the "vector" model and the "raster" model Raster organises spatial features in regular spaced grid of pixels, while the vector data structure organises spatial feature by the set of vectors, which are specified by starting point co-ordinates. A single *x, y* co-ordinates, can describe the location of a point

feature, such as a location of boreholes. Point features are represented as vectors without length and direction Linear features such as roads and rivers can be stored as point co-ordinates. Polygon features, such as land parcels and river catchments, can be stored as a closed loop of co-ordinates. Compared to a line designated in a raster format, a vector line is 1-*d* and has no width associated with it. The vector model is extremely useful for describing discrete features, but less useful for describing continuously varying features such as soil top.

Advantages of vector type data

- The vector storage type uses less storage space.
- It supports greater precision in the computation and processing of spatial features.

The smallest feature in a raster data structure is represented by a single pixel The raster model has evolved to model continuous features. A raster image comprises a collection of grid cells rather like a scanned map or a picture. Both the vector and raster models for storing geographic data have unique advantages and disadvantages.

Advantages of raster data type are:

- Provides better representation of continuous surfaces
- Map overlays are efficiently processed if thematic layers are coded in a simple raster structure.
- Because the raster grid defines pixels that are constant in shape, spatial relationships among pixels are constant and easily traceable.

GIS has been touted as a great boon to engineering, science, planning, and decision-making in every field. Some of the noteworthy applications of GIS are:

- Map generation;
- Calculation of land use;
- Analysis of optimal land use allocations;
- Determining changes over time - Temporal Analyses;
- Route guidance and planning;

- Targeted marketing;
- Habitat prediction; and
- Ecosystem simulation/Environmental modeling.

2.2 Remote Sensing

Remote sensing refers to obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Kiefer, 1996). The eyes are an excellent example of a remote sensing device. With this, it is possible to gather information about the surroundings or even reading the text as in this case. However, this simple definition of remote sensing is more commonly associated with the gauging of interactions between the earth surface and the electromagnetic energy. These days the data gathering of the earth surface is enabled with various sensors that are able to efficiently absorb reflected energy from the earth's surface. The satellites with onboard sensors, play an important role in data capture.

Remote sensing systems are a very important source of information for GIS, as they provide access to spatio-temporal information on surface processes on scales ranging from regional to global. A wide range of environmental parameters can be measured including land use, vegetation types, surface temperatures, soil types, precipitation, phytoplankton, turbidity, surface elevation and geology. Remote sensing and GIS aid immensely in urban sprawl studies.

In the case of a combined application, an efficient, even though more complex, approach is the integration of remote sensing data processing, GIS analyses, database manipulation and models into a single analysis system (Michael and Gabriela, 1996). Such an integrated analysis, monitoring and forecasting system based on GIS and database management system technologies requires the analyst to understand not only the problem but also the available technologies yet without being a computer expert.

The integration of GIS and remote sensing with the aid of models and additional database management systems (DBMS) is the technically most advanced and applicable approach today.

The remote sensing applications are growing very rapidly with the availability of high-resolution data from the state of the art satellites like IRS-1C/1D/P4 and Landsat. The advancement in computer hardware and software in the area of remote sensing also enhances remote sensing applications. IRS-1C/1D/P4 provides data with 5.8 m resolution in panchromatic mode giving more information of the ground area covered. The remote sensing satellites with high-resolution sensors and wide coverage capabilities will provide the data with better resolution, coverage and revisit (once in 24 days for IRS 1C) to meet the growing applications needs. Many applications like crop acreage and yield estimation, drought monitoring and assessment, flood mapping, wasteland mapping, mineral prospects, forest resource survey etc., have become an integral part of the resources management system. These resource management systems need the data to be transferred in real time or near real time for processing.

The land use classification is primarily to understand the spatial distribution of various land features and plan accordingly for optimum utilisation of the land with least effects on the associated systems. The pattern and extent of land use is influenced mainly by two factors - physical and anthropogenic. Physical factors include topography, climate and soils, which set the broad limits upon the capabilities of the land, and the anthropogenic factors are, density, occupation of the people, socio-economic institutions, the technological level, and infrastructure facilities. GIS and remote sensing collectively help in understanding and undertaking these applications effectively.

2.3 Image Processing—Restoration, Enhancement, Classification, Transformation

The digital image processing is largely concerned with four basic operations: image restoration, image enhancement, image classification, and image transformation (Eastman, 1999). The image restoration is concerned with the correction and calibration of images in order to achieve as faithful representation of the earth surface as possible. Image enhancement is predominantly concerned with the modification of images to optimise their appearance to the visual system. Image classification refers to the computer-assisted interpretation of images that is vital to GIS. The image transformation refers to the derivation of new imagery as a result of some mathematical treatment of the raw image bands.

The operation of image restoration is to correct the distorted image data to create a more faithful representation of the original scene This normally involves the initial processing of raw image data to correct for geometric distortions, to calibrate the data radiometrically, and to eliminate the noise present in the data Image rectification and restoration are also termed as pre-processing operations

Enhancement is concerned with the modification of images to make them more suited to the capabilities of human vision. Regardless of the extent of digital intervention, visual analysis invariably plays a very strong role in all aspects of remote sensing Enhancement of the imagery can be done by the histogram equalisation method or linear saturation method before analysis.

Digital image classification is the process of assigning a pixel (or groups of pixels) of remote sensing image to a land cover or land use class. The objective of image classification is to classify each pixel into one class (crisp or hard classification) or to associate the pixel with many classes (fuzzy or soft classification). The classification techniques are categorised based on the training process - supervised and unsupervised classification.

Supervised classification has three distinct stages namely training, allocation and testing Training is the identification of a sample of pixels of known class membership gathered from reference data such as ground truth, existing maps and aerial photographs. In the second stage, the training pixels are used to derive various statistics for each land cover class and so are correspondingly assigned as signature. In the third stage, the pixels are allocated to the same class with which they show greatest similarity based on the signature files.

Unsupervised classification techniques share a common intent to uncover the major land cover classes that exist in the image, without prior knowledge of what they might be. Such procedures often come under cluster analysis, since they search for clusters of pixels with similar reflectance values. Unlike the supervised classification, only major land classes are separated as clusters, while smaller classes may be ignored The decision for the number of clusters can be based on the histogram analysis of the reflectance values. The most prominent number of classes as seen in the histogram can be considered as the number of clusters.

The Indian Remote Sensing (IRS) satellite's Linear Imaging Self Scanning Sensor (LISS) imagery contains four bands. National Remote Sensing Agency (NRSA) distributes the satellite data for India This will have image in Band Interleaved by Line (BIL) format i.e , this file contains first line from first band, first line from second band, first line from third band and first line from fourth band in one interleaved line and in second interleaved line it contains second line from first band, second line from second band, second line from third band, second line from fourth band and so on Band extraction is implemented to separate these bands

The 23 5 m ground resolution IRS-LISS3 multispectral image has the following bands

Green	0 52–0 59 micrometer
Red	0 62–0 68 micrometer
Near-Infrared	0 77–0 86 micrometer
Short-wave Infrared	1 55–1 7 micrometer

Imagery obtained from the satellites will have geometric errors due to the nature of motion of satellite and high altitude of sensing platform Prominent Ground Control Points (GCPs) from toposheets (which is always correct) are taken to rectify geometric errors. This procedure is also called as geo-correction/geo-rectification

Image processing, neural network and other techniques are used to analyse the satellite imagery. The decision rule based on geometric shapes, sizes, and patterns present in the data is termed as Spatial Pattern Recognition. Similarly, visual interpretation is done on satellite imagery by considering the elements of image interpretation such as, shape, size, tone, texture, pattern and size for pattern recognition The pattern recognition of urban sprawl is identified after classification of the remote sensed images for the built-up area and is then further analysed.

2.4 Decision Support System

In recent years, considerable interest has been focused on the use of GIS as a decision support system. For some, this role consists of simply informing the decision making process. However, it is more likely in the realm of resource allocation that the greatest contribution can be made with the aid of GIS and remote sensing. The use of GIS as a direct extension of the human decision-making process, most particularly in the context of resource allocation decisions, is indeed a great challenge and an important milestone. With the incorporation of many software tools to GIS for multi-criteria and multi-objective decision-making, an area that can broadly be termed decision strategy analysis, there seems to be no bounds for the application of GIS Closely associated with the decision strategy analysis is the uncertainty management Uncertainty is not considered as a problem with data, but it is an inherent characteristic of the decision making process With the increasing pressures on the resource allocation process, the need to recognise uncertainty as a fact of the decision making process has to be understood and carefully assessed. Uncertainty management thus lies at the very heart of effective decision-making and constitutes a very special role for the software systems that support GIS (Eastman, 1999).

The decision support is based on a choice between alternatives arising under a given set of criterion for a given objective A criterion is some basis for a decision that can be measured and evaluated. Criterion can be of two kinds: factors and constraints, and this can pertain either to attributes of the individual or to an entire decision set In this case the objective being to urbanise; constraints include the already existing built-up area, road-rail network, water bodies, etc., where there is no scope for further sprawl; and factors include the components of population growth rate, population density and proximity to the highway and cities The decision support system evaluates these sets of data using multi-criteria evaluation. This predicts the possibilities of sprawl in the subsequent years using the current and historical data giving the output images for the objective mentioned

3 Literature Review

Urban sprawl is also referred as irresponsible, and often poorly planned development that destroys green space, increases traffic, contributes to air pollution, leads to congestion with crowding and does not contribute significantly to revenue, a major concern. Increasingly, the impact of population growth on urban sprawl has become a topic of discussion and debate. Typically conditions in environmental systems with gross measures of urbanisation are correlated such as population density with built-up area (Smart Growth America, 2000; The Regionalist, 1997; Berry, 1990). The relation of population growth and urban sprawl is that the population growth is a key driver of urban sprawl The population growth variable was responsible for about 31 percent of the growth in land area leading to suburban sprawl over the course of the 1980s in 282 metropolitan areas of United States of America. The population increased from 95 million to 140 million (47 percent) while urbanised land increased from 25,000 square miles to 51,000 square miles (107 percent) among 213 urbanised areas in USA between 1960 and 1990 (The Regionalist, 1997). This implied that density per square mile decreased by 28%.

The study on urban sprawl (The Regionalist, 1997; Sierra Club, 1998) was 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 and Lata et al., 2001). 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. The spatial patterns of urban sprawl over different time periods, can be systematically mapped, monitored and accurately assessed from satellite data along with conventional ground data (Lata et al., 2001). The physical expressions and patterns of sprawl on landscapes can be detected, mapped, and analysed using remote sensing and geographical information system (GIS) technologies (Barnes et al , 2001). The patterns of sprawl are being described using a variety of metrics, through visual interpretation techniques, all with the aid of software and other application programs. The earth scientists with the Northeast Applications of Useable Technology In Land Use Planning for Urban Sprawl (NAUTILUS) program are using techniques of statistical software to characterise urbanising landscapes over time and to calculate spatial indices that measure dimensions such as contagion, the patchiness of landscapes, fractal dimension, and patch shape complexity (Hurd et al., 2001; NAUTILUS 2001). Hurd et al, (2001) focused on a method to generate images depicting the pattern of forest fragmentation and urban development from the derived classifications of satellite imagery.

The built-up is generally considered as the parameter of 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. Yeh and Li (2001) use Shannon's entropy, which reflects the concentration of dispersion of spatial variable in a specified area, to measure and differentiate types of sprawl. This measure is based on the notion that landscape entropy, or disorganisation, increases with sprawl. The urban land uses are viewed as interrupting and fragmenting previously homogenous rural landscapes, thereby increasing landscape disorganisation. Lata et al. (2001) employed a similar approach of characterising urban sprawl for Hyderabad City, India, in terms of Shannon's entropy. In an attempt to map the sprawling trends and changes in the urban core Jothimani (1997) used Landsat-MSS and IRS LISS-II data through visual interpretation techniques for analysis and identified the trends of emergence of sprawl along transportation network for Surat and Ahmedabad cities.

The impacts of urban patterns on ecosystem dynamics should focus on how patterns of urban development alter ecological conditions (e.g. species composition) through physical changes (e.g. patch structure) on an urban to rural gradient. The use of gradient analysis for studying urban-to-rural gradient of land-use intensity to explain the continuum of forest change from city centre to non-urban areas might help to explore ecosystem effects of different urban configurations, but current applications do not differentiate among alternative urban patterns (Alberti et al., 1999). Most studies of the impacts of urbanisation do not differentiate among various urban patterns. Planners need this ecological knowledge, so that their decisions can minimise impacts of inevitable urban growth. Decisions by urban dwellers, businesses, developers, and governments all influence patterns. Spatial pattern is one (of very few) such environmental variable, which can be controlled to some extent by land-use planning. Design strategies for reducing urban ecological impacts will remain poorly understood and ineffectual if spatial pattern issues are not addressed in ecological studies of urban areas.

The convergence of GIS, remote sensing and database management systems has helped in quantifying, monitoring, modeling and subsequently prediction of the process. 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). Modeling 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). Mostly modeling of the spatial dynamics rests 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 in the Ipswich watershed based on the model validated for 1971, 1985 and 1991.

In urban growth modeling 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 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 highway. 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 these were 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).

4 Description of Study Area

4.1 Study Area 1: The Bangalore – Mysore Highway

This study was carried out on the Bangalore – Mysore highway. Eight taluks straddle the Bangalore – Mysore highway as well as areas adjacent to these, which have been influenced by the highway. It includes Mysore taluk of Mysore district, Srirangapatna, Mandya and Maddur taluks of Mandya district, Channapatna, Ramanagaram, Bangalore South and Bangalore North taluks of Bangalore district. This is one of the well-linked regions of Karnataka state and covers an area of 4,152 sq. km with about 1,013 settlements. This segment happens to be one of the prime urban corridors of the state. The cities like Mysore, Srirangapatna and Bangalore have been capitals of erstwhile kingdoms and so naturally development has its effect since historical time. However expansion of Bangalore in recent times, as a major economic centre with development of industries and commercial establishments has given impetus to the growth. Early 90's boom in the software sector with consequent infrastructure initiatives, has contributed to hike in population, mainly due to migration from other parts of India to Karnataka. The radial sprawl due to Bangalore city's growth is seen curbing smaller villages on the periphery. The details of the villages are shown in Appendix D.

The present investigation analyses the growth pattern within a buffer of 4 km across the roads connecting Bangalore with Ramanagaram, Ramanagaram with Channapatna, Channapatna with Maddur, Maddur with Mandya, Mandya with Srirangapatna and Srirangapatna with Mysore (Figure 1). During the exploratory survey, it was found that there was a strong presence of sprawl within a buffer of 4 km around the highway and hence detailed investigations within a buffer of 4 km around the highway were undertaken.

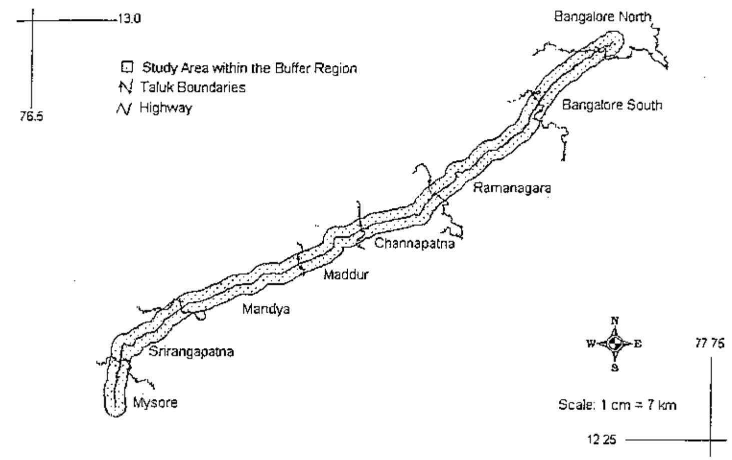

Figure 1 *Location of Study Area*

4.2 Study Area 2: The Tiruchirapalli – Tanjavore – Kumbakonam – Thiruvarur Highway

This study was carried out in the region surrounding the highway between Tiruchirapalli, Tanjavore and Kumbakonam, Tamil Nadu, India (Figure 2). The highway passing between these cities is the region for detailed investigation. A buffer region of 4 km on each side is marked as the specific area for thorough investigation.

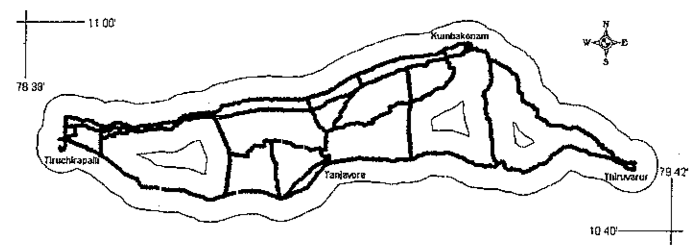

Figure 2 *Tiruchirapalli – Tanjavore – Kumbakonam – Thiruvarur with the Road Network*

4.3 Study Area 3: The Udupi – Mangalore Highway

This study was carried out in the region surrounding the National Highway between Udupi and Mangalore, Karnataka, India (Figure 3). The National Highway (NH) no. 17 passes through Mangalore and Udupi. 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 thorough investigation

The total study area is 434.2 sq. km 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 ° C to 34.9 ° C (Census of India, 1981)

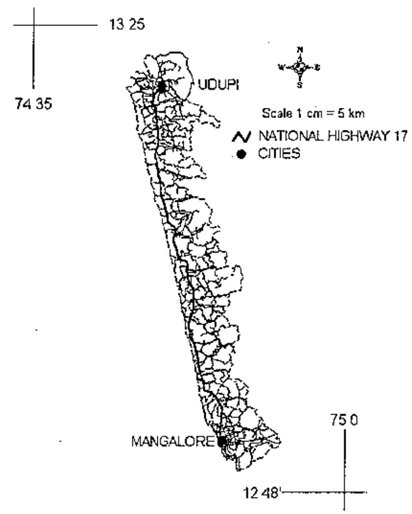

Figure 3 *Location of Study Area - Udupi Mangalore Segment*

Since the region is in the coastal zone and has of a harbour from a long time, this region has been one of the major ports of coastal India. The entire region

is very famous for financial institutions and hence has brisk economic activity as evinced from the growth of cities and infrastructure developments.

Mangalore is the headquarters of Dakshin Kannada district. Until recently Udupi was also in the Dakshin Kannada district, while now it is a new district. There are 39 and 35 villages in Mangalore and Udupi taluks respectively, which fall under the study area, the details of which are shown in Appendix.

5 Data Collection—Materials and Methods

The data collection involved collection of toposheets, village maps, satellite data and demographic details. The nature of these data and their source are shown in Table 1. The Survey of India toposheet of 1:50000 scale was used for the current study, which has the following features:

- Drainage, water bodies, irrigation systems;
- Contours;
- Roads and rail network;
- Built-up area;
- Administrative boundaries

Table 1 *Data Collection Details for the Study Area*

Mysore Bangalore	Udupi Mangalore	Tiruchirapalli Tanjavore Kumbakonam	Source
Toposheets No. 57 H/2, 57 H/5, 57 H/6, 57 H/9, 57 D/11, 57 D/14, & 57 D/15	Toposheets No 48 K/11, 48 K/12, 48 K/15, 48 K/16, & 48 L/13	Toposheets No 58 J/9 58 J/10, 58 J/13, 58 J/14, 58 N/1 & 58 N/5	Survey of India, Scale 1:50000
Satellite imagery – **LISS3**; Path: 100, Row: 64 & Path: 99 Row: 64	Satellite imagery – **LISS3**; Dt: 29th March 1999 Path: 97 & Row: 64 **LANDSAT TM**; Dt: 4th April 1987 Path: 144 & Row: 52	Satellite imagery – **LISS3**; Dt: 9th April 1999 Path: 102 and Row: 66	National Remote Sensing Agency (NRSA)
Demographic details from primary census abstracts for 1971 1981 & 1991	Demographic details from primary census abstracts for 1971, 1981 & 1991		Directorate of Census Operations, Census of India
Village maps for taluks, namely, Bangalore South Bangalore North Ramanagaram, Channapatna, Maddur, Mandya, Srirangapatna, Mysore	Village maps for taluks. namely, Mangalore and Udupi		Directorate of Survey Settlement and Land Records. Government of Karnataka

6 Data Analysis and Interpretation

6.1 Measuring Urban Sprawl

The complexity of a dynamic phenomenon such as urban sprawl could be understood with the analyses of land use changes, sprawl pattern and computation of sprawl indicator index. As a prelude to this analysis, GIS base layers such as, road network and the administrative boundaries from the toposheets as shown in Table 1 were created. The highway passing between the cities was digitised separately and a buffer region of 4 km around this was created. This buffer region is created to demarcate the study region around the road. Following this, land cover analyses were done using remote sensing data.

The growth of urban sprawl over a period of three decades was determined by computing the area of all the settlements from toposheets of 1972 and comparing it with the area obtained from the classified satellite imagery for the built-up area. The detailed methodology followed is depicted in the flow chart (Figure 4). The toposheets (Table 1) in digital format were scanned and then geo-registered. The area under built-up (for 1972) was added to this attribute database after digitisation of the toposheets for the built-up feature for the study area.

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, were extracted from census books of 1971 and 1981 and were added to the database. The area under built-up (for 1972) was computed and appended to this attribute database.

The multispectral IRS – LISS III satellite imagery procured from National Remote Sensing Agency (NRSA), Hyderabad, India, was used for the analysis using IDRISI 32 (http://www.clarklabs.org). The image analyses included bands extraction, restoration, classification, and enhancement. Band extraction was done initially through a programme written in C++ and subsequently

IDRISI 32 was used for image analyses. Geo-registered LISS III data obtained from NRSA (bands 2, 3 and 4 corresponding to G, R, MIR) were geo-corrected using resampling techniques. This is done with the help of known points on the Survey of India toposheets or/and ground control points (GCPs) using GPS. The data acquired in bands — Green, Red and Near Infrared were used to generate a False Colour Composite (FCC). To create the composite image from three input bands, each of the three bands is stretched to 6 levels ($6 \times 6 \times 6 = 216$). The composite image consists of colour indices where each index = Green + (Red × 6) + (Near Infrared × 36) assuming a range from 0–5 on each of the three bands. For example, a pixel value of 3, 5, 1 respectively for the three bands, Green, Red and Near Infrared would have an index of $3 + (5 \times 6) + (1 \times 36) = 69$. The 256 Colour Composite palette colours correspond to the mix of Green, Red and Near Infrared in the stretched images. In the composite image, heterogeneous patches were identified and the corresponding attribute data was collected using GPS (Global Positioning System).

Corresponding to the training data, signature files with attribute information were created. For the image classification supervised classification by the Maximum Likelihood Classifier (MLC) or Gaussian classifier was employed. Area under built-up theme was recognised and extracted from the imagery and the area for 1998–99 was computed. Further, by overlaying village boundaries, villagewise built-up area was calculated.

6.2 Built-up Area as an Indicator of Urban Sprawl

The percentage of an area covered by impervious surfaces such as asphalt and concrete is a straightforward measure of development (Barnes et al., 2001). It can be safely considered that developed areas have greater proportions of impervious surfaces, i.e. the built-up areas as compared to the lesser-developed areas. Further, the population in the region also influences sprawl. The proportion of the total population in a region to the total built-up of the region is a measure of quantifying sprawl.

Considering the built-up area as a potential and fairly accurate parameter of urban sprawl has resulted in making considerable hypothesis on this phenomenon. Since the sprawl is characterised by an increase in the built-up area along the urban and rural fringe, this attribute gives considerable

information for understanding the behaviour of such sprawls. This is also influenced by parameters such as, population density, population growth rate, etc.

Pattern recognition helps in finding meaningful patterns in data, which can be extracted through classification. Digital image processing through spectral pattern recognition wherein the spectral characteristics of all pixels in an image were analysed. By spatially enhancing an image, pattern recognition can also be performed by visual interpretation.

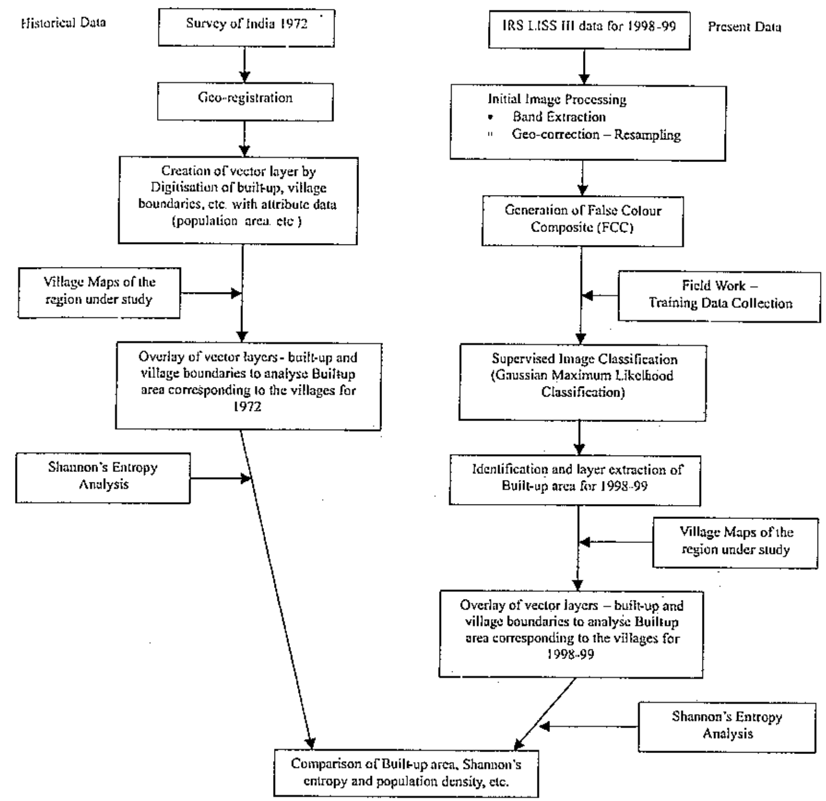

Figure 4 *Flow Chart of Methodology of Analysis of Urban Growth*

6.3 Metrics of Urban Sprawl

Characterising pattern involves detecting it, quantifying with appropriate scales and summarising it statistically The agents of pattern formation include the physical abiotic component, demographic responses to this component, and disturbance regimes overlaid on these. An interest in landscape dynamics necessarily invokes models of some sort because landscapes are large and they change over timescales that are difficult to embrace empirically. Spatial heterogeneity matters to populations, communities, and ecosystems and these are the essentials of conservation and ecosystem management. Various landscape metrics were applied to analyse the built-up theme for the current study The landscape pattern metrics are used in studying forest patches (Trani and Giles, 1999; Civco et al., 2002). The landscape metrics applied to analyse the built-up theme for the current study are discussed next

6.3.1 Quantifying Landscape Pattern

There are scores of metrics now available to describe landscape pattern, but there are still only two major components—composition and structure, and only a few aspects of each of these. 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

Need for computing indices of landscape pattern:

1. For comparative purposes, to summarise the differences between or among study areas or landscapes
2. To infer underlying agents of pattern formation, that is, as an exploratory analysis that is a precursor to more strategic hypothesis testing.

The latter goal is fundamental to landscape ecology if not ecology in general Also, the task of attributing causal mechanism (process) to observed pattern is more daunting than expected Some of the common objectives of landscape studies are:

1. To detect and quantify pattern in the spatial heterogeneity of landscapes;

2. To develop and test a set of indices that capture important aspects of landscape pattern;
3. To relate the indices with ecological phenomena;
4. To link small-scale ecological information (i e , field data) with pattern at the landscape level

6.3.2 Indices of Landscape Configuration

i. Shannon's Entropy

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

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

where

P_i = Proportion of the variable in the ith zone (i e. proportion of built up area in each village)

n = Total number of zones (i.e number of villages in the region)

The value of entropy ranges from 0 to log n. Value of 0 indicates that the distribution is very compact, while values closer to log n reveal that the distribution is very dispersed. Higher values of entropy indicate the occurrence of sprawl (refer annexure for computation details)

ii. Patchiness

Patchiness or NDC (Number of Different Classes) 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 measurement of the number of polygons over a particular area. The greater the patchiness, the more heterogeneous the landscape is (Murphy, 1985).

iii. Map Density

In order to compute the map density initially the class frequency of the required feature is computed. The class frequency is the number of times a specified characteristic value occurs within a kernel. The kernel can be of 3 × 3, 5 × 5, or 7 × 7. The kernel is centred on each built-up pixel of the classified image in the manner of a moving window. A new value for the centre pixel is assigned to the corresponding position of the output image For the value to be counted it must fall within one of the positions marked by a 1 in the selected kernel: 3 × 3

1	1	1
1	1	1
1	1	1

The kernel size selected depends upon the scale of the information to be derived

7 Results and Discussion

7.1 Study Area 1: The Bangalore – Mysore Highway

7.1 1 Image Analyses

The built-up area for 1972 was extracted from the digitised toposheets and is shown in Figure 5. The villagewise built-up area was computed by overlaying the layer with village boundaries (taluk map with village boundaries) and added to the attribute database for further analyses

LISS III sensor data obtained from the NRSA in three bands, namely, Band 2 (green), Band 3 (red) and Band 4 (near infrared), were used to create a False Colour Composite (FCC). Training polygons (with their co-ordinates) were chosen from the composite image and corresponding attribute data was obtained in the field for these polygons (using GPS) Based on these signatures, corresponding to various land features, image classification was done using Guassian Maximum Likelihood Classifier. From the original classification of land-use of 16 categories the image was reclassified to four broader categories as vegetation, water bodies, open land, and built-up. The built-up theme identified from the image is shown in Figure 6.

From the classified image the area under the built-up theme was computed Area under villagewise built-up theme in the study area was also computed by overlaying a vector layer with village boundaries and tabulated accordingly for further analyses.

7.1 2 Built-up Area

The built-up area computed for temporal data indicated that there was 194% increase in the built-up area from the seventies to late nineties. A more detailed investigation of the distribution of the built-up (Table 2) revealed that the change is higher as the proximity to Bangalore increases. The Bangalore North - South segment had the highest increase in built-up area while it was least in Srirangapatna – Mysore segment with 128%. It can also be observed that there is a declining trend in the change in built-up area as one moves from Bangalore towards Mysore.

Table 2 *Built-up Area and Shannon's Entropy for the Study Area*

Segment	Built-up Area (sq. km)		Percentage Change in	Shannon's Entropy		$\log_e n$
	1972	1998	Built-up Area	1972	1998	
Bangalore – Mysore	8 2679	24.3344	194%	2 658	2.556	4.477
Bangalore – Ramanagaram	0 7494	3.2232	330%	2.69	2 699	3.5835
Channapatna – Mysore	7 5185	21 1112	181%	2 320	2 083	3 9512
Bangalore North – South	0 1296	0 8538	559%	2 427	2 338	2 565
Ramanagaram – Channapatna	0 9682	3.2777	239%	2.717	2.592	3.401
Mandya – Maddur	5 9324	17 3804	193%	1.662	1.434	3 434
Srirangapatna – Mysore	1.2377	2.8226	128%	1.803	1.922	2.639

7.1.3 Metrics of Urban Sprawl

i. Shannon's Entropy

Shannon's entropy was computed for villagewise built-up area, wherein each village was considered as an individual zone (n = total number of villages). This revealed that the distribution of built-up in the region in 1972 was slightly dispersed than in 1999. However, the degree of dispersion has come down marginally and that distribution is less dispersed or there is the less presence of sprawl when the entire stretch is considered. The values obtained ranges from 2.658 (in 1972) to 2 556 (in 1998) and log n for this region is 4 477. These are higher than the half way mark of log n (that is 2.238) and show some degree of dispersion of built-up in the region. This non-uniform dispersed growth along the road connecting Bangalore and Mysore necessitated further detailed investigations for identifying the pockets of higher growth.

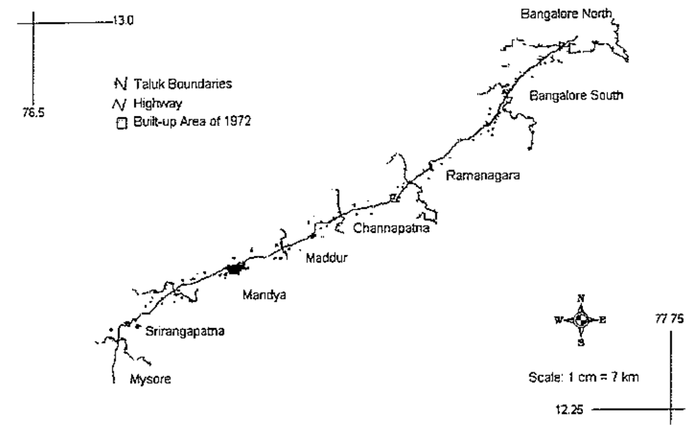

Figure 5 *Built-up area in the Bangalore – Mysore segment in 1972*

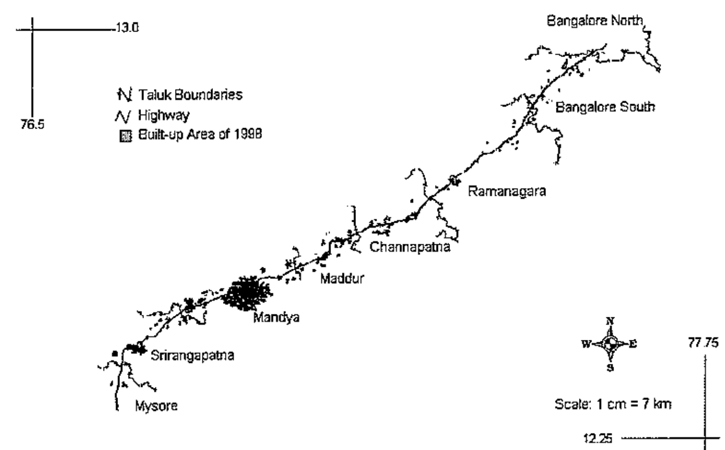

Figure 6 *Built-up area in the Bangalore – Mysore segment in 1998*

Detailed investigation on the phenomenon was done in the next phase by dividing the study area in to segments/zones. The entire segment of Bangalore – Mysore was split in to two as Bangalore – Ramanagaram and Channapatna – Mysore segments. The percentage built-up change and entropy was calculated for these two segments. The Bangalore – Ramanagaram segment had a higher value of percentage built-up change (330%) than the Channapatna – Mysore segment (181%). The entropy values for the Bangalore – Ramanagaram segment ranges from 2.690 (for 1972) to 2.699 (for 1998) while log n for this region is 3.583 suggesting a similar trend. In the Channapatna – Mysore segment the entropy value ranged from 2.320 (for 1972) to 2.083 (for 1998) and log n is 3.951. This analysis reveals that the distribution is more dispersed in Bangalore – Ramanagaram segment compared to the later.

On further division of the two segments into four to identify where the actual sprawl is occurring, segments such as, Bangalore North - South, Ramanagaram – Channapatna, Maddur – Mandya and Srirangapatna - Mysore were obtained. The results of these (Table 2) clearly indicated that there was more dispersed distribution of built-up in the region closer to Bangalore and this decreased as the proximity to the city increased. The Bangalore North - South taluks had the highest increase in terms of the percentage built-up change and the entropy values also showed that there was more dispersion in this taluk, thus indicating higher sprawl in this region. Higher sprawl due to the proximity of Bangalore is observed till Channapatna – Ramanagaram segment and declines towards Mandya. It also infers that in the Mandya – Maddur segment the distribution was slightly compact with radial sprawl. But in the Srirangapatna – Mysore segment the value of entropy showed marginal change in entropy. Here, the degree of sprawl is not as severe as that in case of other segments, but the marginal increase in entropy value certainly indicates the possibility of increasing sprawl due to enhanced economic activities at Mysore.

ii. Bangalore Segment Analyses

With the results of the Shannon's entropy indicating that regions nearer to Bangalore city had more degree of sprawl, it was decided to work out and understand the patterns of growth in the regions surrounding Bangalore city, in all directions. It was seen that Bangalore was sprawling in radial direction from the city centre and linear growth was noticed along all five major roads connecting the city — spreading as five arms stretched outwards (Figure 7). The space between the arms or the major roads acts as the sinks for city develop-ment. Further, it is seen that the development occurred around the ring roads that connected these major roads.

Figure 7 *FCC of Bangalore city showing radial pattern of growth from the city centre and linear pattern along the highways*

iii. 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 Figure 8. Depending on the density levels, it could be further grouped as low, medium and high density (Figure 9). The relative share of each category was computed (area and percentage)

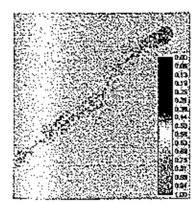

Figure 8 *Map Density*

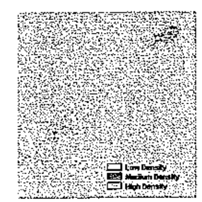

Figure 9 *Classification of Built-up Densities*

Table 3 Different Densities of Built-up and their Area

Category	Area in sq. km	Percentage
Low density	30 099	64 11 %
Medium density	10.711	22.81 %
High density	6 138	13 08 %

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 found built-up. The percentage of high-density built-up area was only 13.08 % as against 22.81 % of medium density and as much as 64.11 % of low density built-up (Table 3). This revealed that more compact or highly 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 towns and cities. The medium density was also found mostly along the city periphery and on the highways. The distribution of the low density was the maximum in the study area and this could be inferred as 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 dispersion of the built-up theme in the study area.

7.2 Study Area 2: Tiruchirapalli – Tanjavore – Kumbakonam – Thiruvarur Highway

7.2.1 Image Analyses

The built-up area for 1972 was extracted from the digitised toposheets and is shown in Figure 10. 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, namely, Band 2 (green), Band 3 (red) and Band 4 (near infrared), were used to create a False

Colour Composite (FCC) as shown in Figure 11. Based on the histogram, corresponding to various peaks, the number of clusters for image classification was done using Guassian Maximum Likelihood Classifier and the built-up theme identified in the classified image is given in Figure 12. The built-up area computed for temporal data indicated that there was 133.93 % increase in the built-up area from the seventies to late nineties (Table 4).

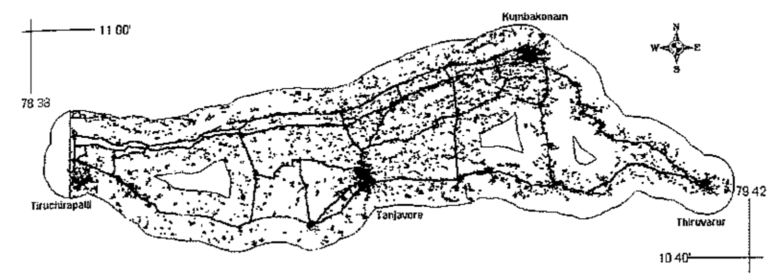

***Figure 10** Built-up Area of the Region along with the Road Network for 1972*

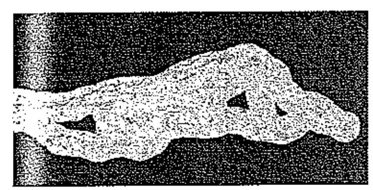

***Figure 11** False Colour Composite of the Region*

Figure 12 *Built-up Area of the Region for 1999*

Table 4 Details of Built-up Area for 1972 and 1999

	Built-up Area 1972 (sq. km)	Built-up Area 1999 (sq km)	Percentage Change in Built-up Area from 1972–1999
Region	82 53	159 49	93 25 %

7.3 Study Area 3: Udupi – Mangalore Highway

7.3.1 Image Analyses for LANDSAT TM Image of 1987

The standard image processing techniques such as, image extraction, rectification, restoration, and classification were applied to the current image. The Landsat TM 5 data supplied by NRSA were extracted into the three bands, namely, Green, Red and Near-infrared. These were used to create a False Colour Composite (FCC) as shown in Figure 13. Training polygons were created along with corresponding attribute data obtained in the field using GPS and verified with the composite image. Based on these signatures, corresponding to various land features, image classification was done using Guassian Maximum Likelihood Classifier. The classified images showing the built-up of 1987 and 1999 are given in Figure 14 and 15.

Figure 13 *False Colour Composite of LANDSAT TM 1987*

Figure 14 *Built-up Area 1987*

Figure 15 *Built-up Area 1999*

7.3.2 Image Analyses for IRS LISS III Image of 1999

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, namely, Band 2 (green), Band 3 (red) and Band 4 (near infrared), were used to create a False Colour Composite (FCC) as shown in Figure 16. 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 Guassian Maximum Likelihood Classifier and the classified image is given in Figure 17.

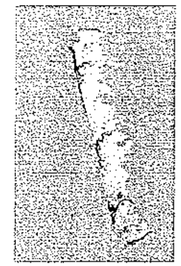

Figure 16 *False Colour Composite – IRS LISS III 1999*

Figure 17 *Classified Image – IRS LISS III 1999*

7.3.3 Population Growth and Built-up Area

The rate of development of land in Udupi – Mangalore region, is far outstripping the rate of population growth. This implies that the land is consumed at excessive rates and probably in unnecessary amounts as well. The built-up area computed for temporal data indicated that there was 107.52 % increase in the built-up area from 1972 to 1987 (Table 5). While the percentage increase from 1987 to 1999 was only 18 %. However the cumulative increase for nearly three decades was 145.68 %. Between 1972 and 1999, population in the region grew by about 54% (Census of India, 1971; 1981; and 1991) while the amount of developed land grew by about 146%, or nearly three times the rate of population growth (Figure 18). This means that the per capita consumption of land has increased markedly over three decades.

Table 5 *Details of Built-up Area for 1972, 1987 and 1999*

Segment	**Built-up Area (sq. km)**		
	1972	**1987**	**1999**
Udupi - Mangalore	25 1383	52 1674	61 7603

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 livelihoods, 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.

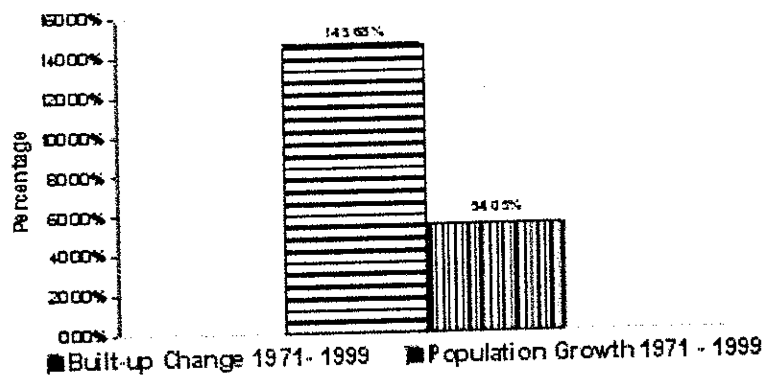

Figure 18 *Rates of Growth in Population and Built-up from 1971–1999*

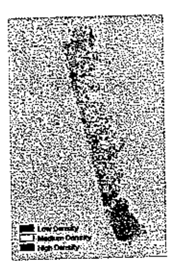

Figure 19 *Patchiness or Number of Different* Classes

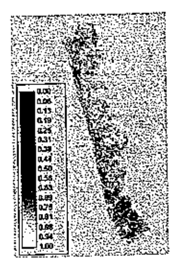

Figure 20 *Map Density*

Figure 21 *Classification of Built-up Densities*

7.3.4 Metrics of Urban Sprawl

Characterising pattern involves its detection, quantifying with appropriate scales and summarising it statistically. There are scores of metrics now available to describe landscape pattern, but there are still only two major components namely, composition and structure, and only a few aspects of each of these. 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. The landscape metrics applied to analyse the built-up theme for the current study is discussed next

i. Shannon's Entropy

The Shannon's entropy (Yeh and Li, 2001) was computed to detect the urban sprawl phenomenon. This value ranges from 0 to log n, indicating very compact distribution for values closer to 0. The values closer to log n indicate that the distribution is very dispersed. Larger value of entropy reveals the occurrence of urban sprawl. Table 5 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 wherein each village was considered as an individual zone (n = total number of villages). From the Shannon's entropy calculation, it revealed 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 or there is the presence of sprawl. The values obtained here being 1.7673 in 1972 and 1.673 in 1999, which are closer to the upper limit of log n, i.e., 1.914, thus showing the degree of dispersion of built-up in the region

Table 6 *Built-up Area, Population and Shannon's Entropy for the Study Area*

Segment	Built-up Area (sq. km)		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

ii. Patchiness

Patchiness or NDC (Number of Different Classes) is the measurement of the density of patches of all types or number of clusters within the n x n window In other words, it is a measure of the number of heterogeneous polygons over a particular area. Greater the patchiness more heterogeneous is the landscape (Murphy, 1985). In this case the density of patches among different categories was computed for a 3 × 3 window

The computation of patchiness using 3x3 moving window, revealed that 2 heterogeneous classes category was maximum (57.15%) and 5 heterogeneous classes was the least (0.02%) in the study area (Table 7). This reveals that about 20.7 % of the study area is homogeneous while the rest are heterogeneous with patch class ranging from 2 to 5 (Figure 19, *see* p 40).

Table 7 *Percentage Distribution of Patchiness*

Number of Classes	Percentage Distribution
1	20.7
2	57 15
3	20 18
4	1.95
5	0.02

iii. 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 Figure 20 (*see* p. 40) Depending on the density levels, it could be further grouped as low, medium and high density (Figure 21, *see* p 40). Based on this, relative share of each categories were computed (area and percentage). This enabled the identifying of 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 found built-up 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 (Table 8) This revealed that more compact or highly 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, the medium density was also found mostly along the city periphery and on the highways. The distribution of the 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 8 *Different densities of built-up and their area*

Category	Area in sq. km	Percentage
Low density	93 88	61 66 %
Medium density	39 08	25 67 %
High density	19.29	12.67 %

8 Dynamics of Urban Sprawl

In the recent years, a lot of thrust in this field has been to understand and analyse the urban sprawl pattern. Various analysts have made considerable progress in quantifying the urban sprawl pattern (Theobald, 2001; Lata et al., 2001; Torrens and Alberti, 2000; Batty et al., 1999; Barnes et al., 2001). However, all these studies have come up with different methodologies in quantifying sprawl. The common approach is to consider the behaviour of built-up area and population density over the spatial and temporal changes taking place and in most cases the pattern of such sprawls is identified by visual interpretation methods.

Defining this dynamic phenomenon with relative precision and accuracy for predicting the future sprawl is indeed a great challenge to all working in this arena. One of the basic and major challenges is quantification of such sprawl. Although different sprawl types were identified and defined there has been an inadequacy with respect to developing mathematical relationships to define them. Further as if aggravating this problem, much of the work related to studying dynamics of urban sprawl are not carried out in the developing countries, except a few. Thus, giving very little relevance to correlate the available findings in the context of developing countries. However, the negative impacts of such urban sprawls in developing countries are more severe and intense compared to that of developed countries. Typically, the developing countries are faced with an unprecedented population growth and potentially threaten vast natural resources. In such a scenario, it is definitely an exacting effort to study, characterise and model the urban sprawl phenomenon in the context of developing countries. This study is an attempt in understanding the urban sprawl phenomenon, pattern recognition and modeling studies as well.

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 were considered responsible for sprawl were:

- Population (POP99),
- a Population density (POPADEN) and b Population density (POPBDEN),
- Annual Population Growth Rate (AGR)
- Distance from Mangalore (MANGDIST) and
- Distance from Udupi (UDUPIDIST)

Population has been for long 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 a population density (POPADEN) is the proportion of the population in every village to the built-up area of that village. The b population density (POPBDEN) is the proportion of population in every village to the total area of that village. The b 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, *a* and *b* 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, namely, 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 modeling studies were undertaken.

8.1 Modeling of Urban Sprawl

In order to explore the probable relationship of percentage built-up (dependent variable) with causal factors of sprawl (population, a and b population densities, etc.), regression analyses considering linear, quadratic (order = 2), and logarithmic (power law) were tried and the results are tabulated in Annexure.

The regression analyses revealed that the population shows linear relationship ($y = a * x + b$) and plays a significant role in the sprawl phenomenon. The quadratic regression analyses for second order were undertaken. All the causal factors were considered and the regression was carried out for the square of causative factors (e.g. When y is the dependent variable and x is the independent variable, then a polynomial regression of second order will be of the form, $y = a * x^2 + b * x + c$). The quadratic regression analyses revealed that the population b density and distance from urban centre (Mangalore) have a significant role in the sprawl phenomenon. The logarithmic (power law) regression analyses were also undertaken. The same causal factors were considered and the regression was carried out for the natural logarithmic of the causative factors (e.g. When 'y' is the dependent variable and 'x' is the independent variable, then a logarithmic regression will be of the form, $\log y = \log a + b * \log x$; or $y = a * x^b$). The logarithmic regression analyses revealed that the population b density has significant role in the sprawl phenomenon.

The probable relationships are:

$$PCBUILT = 0.000611 * POP99 + 10.87149 \ (r = 0.5789) \quad (2)$$

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

$$PCBUILT = -1.7953 * (MANGDIST)^2 + 0.02593 * (MANGDIST) + 36.8607 \ (r = 0.60) \quad (4)$$

$$PCBUILT = -0.9027 * (UDUPIDIST)^2 + 0.002242 * (UDUPIDIST) + 15.9731 \ (r = 0.583) \quad (5)$$

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

Multivariable linear regression analysis was done to assess the cumulative effect of causal factors. The multivariate regression analyses reveal that all causal factors have a significant role in the sprawl phenomenon. Probable relationships are,

$$PCBUILT = -27.08 + 0.002496 * POPBDEN + 0.5743 * MANGDIST + 0.8139 * UDUPIDIST \ (r = 0.719) \quad (7)$$

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

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

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

8.2 Predicting Scenarios of Urban Sprawl

Likely increase in the built-up area is predicted using Equation (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 sq. km, which would be nearly 106 % growth in the change in built-up area to the current sprawl of 61.7703 sq. km 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 for 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.

9 Conclusion and Scope for Further Research

The study investigated the urban sprawl phenomenon occurring along the Bangalore - Mysore highway and found that there has been an overall increase in the built-up area by 194%, the Bangalore North - South taluks having the highest percentage (559%) increase and Srirangapatna - Mysore with the lowest percentage (128%) change in built-up area. Further it was also found the change in built-up was high as the distance from Bangalore decreased. With the Shannon's entropy analysis, the study could identify where the sprawl was taking place and its degree as well. The Bangalore North - South taluks showed higher value entropy indicating sprawl, while the Mandya - Maddur taluks showed lower entropy value indicating compactness or less dispersion. Further, it is seen that Bangalore city was sprawling in radial direction (from the city centre) as well as linearly along the major roads.

The investigation along the Tiruchirapalli – Tanjavore – Kumbakonam – Thiruvarur region revealed that the change in built-up area for nearly three decades was 93.25 %. Further it was found that there was highly dispersed growth in the region with the development mostly taking place along the highways apart from the city's periphery and the riverbank.

The study carried out along the Mangalore - Udupi highway to identify and quantify the sprawl found that the percentage change in built-up over the period of nearly thirty years was 145.68 %. By 2050, the built-up area in the region would rise to 127.7 sq. km, which would be nearly 106 % growth in the change in built-up area to the current sprawl of 61.7703 sq. km over the region.

The study demonstrates GIS and remote sensing coupled with statistical analyses, such as arriving at Shannon's entropy help immensely in spatial and temporal analyses for studying the sprawl and for delineating the regions with higher sprawl. Further the thrust being on the modeling studies, the study successfully defines the sprawl phenomenon with respect to

mathematical relationships. From these the possibilities of sprawl in terms of percentage built-up were estimated for 2051 and 2101. The future scope of this work would look into generating the images of further sprawl under different scenarios to understand any threat to natural resources and ecosystem. The study demonstrates that the application of GIS and remote sensing coupled with statistical analyses, such as arriving at Shannon's entropy helps in studying the sprawl and identifying regions having potential for subsequent sprawl.

With the development and infrastructure initiatives mostly around the urban centres, the impacts of urban sprawl would be on the natural resources and ecology. The wisdom lies in how effectively we plan the urban growth without hampering the natural resources and disturbing the rural set-up. Planning should also focus on a dispersed economic structure and aim at creation of balanced ecological, social, and economic system.

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Appendix

APPENDIX A *Coefficients of causal factors and percentage built-up by linear regression analyses*

Dependent Variable (y)	Independent Variables (x)	Equation ($y = a * x + b$)	Standard Error of y Estimate	Correlation Coefficient, r
PCBUILT	POP99	$y = 0.000611\ x + 10.87149$	13.0163	0.5327
PCBUILT	POPADEN	$y = -0.0004\ x + 19.5719$	11.2594	0.2070
PCBUILT	POPBDEN	$y = 0.005774\ x + 7.849476$	10.1397	0.6474
PCBUILT	AGR	$y = 0.635301\ x + 13.0499$	13.2391	0.0990
PCBUILT	MANGDIST	$y = -0.31149\ x + 22.93755$	12.2142	0.3965
PCBUILT	UDUPIDIST	$y = 0.315763\ x + 5.584017$	12.1528	0.4070

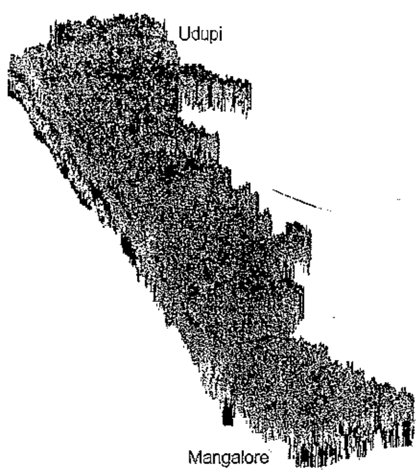
APPENDIX B *Coefficients of causal factors and percentage built-up by polynomial (order = 2) regression analyses*

Dependent Variable (y)	Independent Variables (x)	Equation ($y = a * x^2 + b * x + c$)	Standard Error of y Estimate	Correlation Coefficient, r
PCBUILT	POP99	$y = 0.0006 * x^2 - 1.5 * 10^{-9} * x + 9.7776$	10.9210	0.5784
PCBUILT	POPADEN	$y = -0.00037 * x^2 - 2.7 * 10^{-9} * x + 18.555$	13.0577	0.2208
PCBUILT	POPBDEN	$y = 0.005651 * x^2 - 1.2 * 10^{-7} * x + 6.8950$	9.7880	0.6823
PCBUILT	AGR	$y = 0.66679 * x^2 + 0.05754 * x + 13.3308$	13.3190	0.1017
PCBUILT	MANGDIST	$y = -1.7953 * x^2 + 0.02593 * x + 36.8607$	10.6784	0.6032
PCBUILT	UDUPIDIST	$y = -0.9027 * x^2 + 0.002242 * x + 15.9731$	10.8729	0.5835

APPENDIX C *Coefficients of causal factors and percentage built-up by logarithmic regression analyses*

Dependent Variable (*y*)	Independent Variables (*x*)	Equation (log *y* = log (*a*) + *b* * log *x*)	Standard Error of *y* Estimate	Correlation Coefficient, *r*
LNPCBUILT	LNPOP99	$y = -0.429 + 0.331 * x$	0.7656	0.3835
LNPCBUILT	LNPOPADEN	$y = -1.308 + 0.527 * x$	0.7282	0.4779
LNPCBUILT	LNPOPBDEN	$y = +7.796 - 0.593 * x$	0.6754	0.3363
LNPCBUILT	LNAGR	$y = +2.275 + 0.104 * x$	0.8263	0.0799
LNPCBUILT	LNMANGDIST	$y = +3.718 - 0.456 * x$	0.7208	0.4939
LNPCBUILT	LNUDUPIDIST	$y = +2.008 + 0.114 * x$	0.8192	0.1527

Urbanisation has evinced interest from a wide section of the society including experts, amateurs, and novices. The multidisciplinary scope of the subject invokes the interest from ecologists, to urban planners and civil engineers, to sociologists, to administrators and policy makers, students and finally the common man. With the development and infrastructure initiatives mostly around the urban centres, the impacts of urbanisation and sprawl would be on the environment and the natural resources. The wisdom lies in how effectively we plan the urban growth without—hampering the environment, excessively harnessing the natural resources and eventually disturbing the natural set-up. The research on these help urban residents and policymakers make informed decisions and take action to restore these resources before they are lost. Ultimately the power to balance the urban ecosystems rests with regional awareness, policies, administration practices, management issues and operational problems. This publication on urban systems is aimed at helping scientists, policy makers, engineers, urban planners and ultimately the common man to visualise how towns and cities grow over a period of time based on investigations in the regions around the highway and cities. Two important highways in Karnataka, South India, namely, Bangalore Mysore highway and the Mangalore Udupi highway, in Karnataka and the Tiruchirapalli Tanjavore Kumba-konam triangular road network in Tamil Nadu, South India, were considered in this investigation.



Geographic Information System and Remote Sensing data were used to analyse the pattern of urbanisation. This was coupled with the spatial and temporal data from the Survey of India toposheets (for 1972), satellite imageries procured from National Remote Sensing Agency (NRSA) (LANDSAT TM for 1987 and IRS LISS III for 1999), demographic details from the Census of India (1971, 1981, 1991 and 2001) and the village maps from the Directorate of Survey Settlements and Land Records, Government of Karna-taka. All this enabled in quantifying the increase in the built-up area for nearly three decades. With intent of identifying the potential sprawl zones, this could be modelled and projected for the future decades. Apart from these the study could quantify some of the metrics that could be used in the study of urban sprawl.

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