STUDIES ON URBAN SPRAWL AND SPATIAL PLANNING SUPPORT SYSTEM FOR BANGALORE, INDIA

A Thesis

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By

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Declaration

I hereby declare that I am the sole author of this thesis. I authorize Indian Institute of Science to lend this thesis to other institutions or individuals for the purpose of scholarly research.

Contents

Table of Contents Page No.

List of Tables

List of Figures

List of Maps

List of Abbreviations

ABM	Agent-based Model / Agent-based Modelling
ADB	Asian Development Bank
BATF	Bangalore Agenda Task Force
BCE	Before Common Era
BDA	Bangalore Development Authority
BESCOM	Bangalore Electricity Supply Company Ltd.
BMP	Bangalore Mahanagara Palike
BBMP	Bruhat Bangalore Mahanagara Palike
BMA	Bangalore Metropolitan Area
BMR	Bangalore Metropolitan Region
BMRC	Bangalore Metro Rail Corporation
BMLTA	Bangalore Metropolitan Land Transport Authority
BMRDA	Bangalore Metropolitan Region Development Authority
BMTC	Bangalore Metropolitan Transport Corporation
BSUP	Basic Services to Urban Poor
BWSSB	Bangalore Water Supply and Sewerage Board
CA	Cellular Automata
CASA	Centre for Advanced Spatial Analysis
CDB	Cities Data Book
CDI	City Development Index
CDP	Comprehensive Development Plan
CDSP	City Development Strategic Plan
CE	Common Era
CLD	Causal Loop Diagram
CMC	City Municipal Council

DoT	Department of Transport
DGSS	Dynamic Geo-Spatial Simulation
D-P-S-I-R	Driving forces Pressure State Implications Response
DULT	Directorate of Urban Land Transport
ETM+	Extended Thematic Mapper
EU	European Union
EUMM	Extended Urban Metabolism Model
FAR	Floor Area Ratio
FCC	False Colour Composite
FSI	Floor Space Index
GAS	Geographic Automata Systems
GDP	Gross Domestic Product
GIS	Geographic Information System
GISci	Geographic Information Science
GLCF	Global Land Cover Facility
GoI	Government of India
GoK	Government of Karnataka
GNP	Gross National Product
GPS	Global Positioning System
GSA	Geo-Spatial Analyser
HDI	Human Development Index
HLA	High Level Architecture
IDIP	Infrastructure Development and Investment Plan
IISc	Indian Institute of Science
iDeCK	Infrastructure Development Corporation of Karnataka
IRS	Indian Remote Sensing Satellite
IT	Information Technology
JnNURM	Jawaharlal Nehru National Urban Renewal Mission
KIADB	Karnataka Industrial Area Development Board
KSCB	Karnataka State Slum Clearance Board
KSPCB	Karnataka State Pollution Control Board
KUID&FC	Karnataka Urban Infrastructure Development and Finance Corporation
LDA	Lake Development Authority
LPG	Liquefied Petroleum Gas
MAS	Multi-Agent Systems
MDS	Multi-Dimensional Scaling
MoUD	Ministry of Urban Development
MLD	Million Litres per Day
MPC	Metropolitan Planning Committee
MW	Mega-watt
MUEPA	Ministry of Urban Employment and Poverty Alleviation

NDC	Number of Different Classes
NGO	Non-Governmental Organisation
NIUA	National Institute of Urban Affairs
NUIS	National Urban Information System
NUTP	National Urban Transport Policy
OBEUS	Object-Based Environment for Urban Systems
OECD	Organisation for Economic Cooperation and Development
OO	Object Oriented
OPUS	Open Platform for Urban Simulation
OR	Operations Research
PCoA	Principal Coordinate Analysis
P-S-R	Pressure State Response
PSS	Planning Support System
RAMCO	Rapid Assessment Model for COastal Management
RCC	Reinforced Cement Concrete
RTO	Regional Transport Office
SCATTER	Sprawling Cities And TransporT: from Evaluation to Recommendations
SD	System Dynamics
SFD	Stock and Flow Diagram
SME	Small and Medium Enterprises
SPSS	Spatial Planning Support System
SRTM	Shuttle Radar Topographic Mission
TCPO	Town and Country Planning Organisation
TM	Thematic Mapper
TMC	Town Municipal Council
TRB	Transportation Research Board
UDD	Urban Development Department, Govt. of Karnataka
UIG	Urban Infrastructure and Governance
UK	United Kingdom
ULB	Urban Local Body
USA	United States of America
USET	Urban Sprawl Exploratory Tool

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Abstract

Urban sprawl is the uncontrolled and uncoordinated outgrowth of towns and cities. Noting the various studies, the pattern of urban sprawl is characterised by using spatial metrics based on the extent of paved surface or built-up areas. The process of urban sprawl can be described by change in pattern over time, like proportional increase in built-up surface to population leading to rapid urban spatial expansion. With an understanding of the patterns, processes and causes of urban sprawl, the consequences of sprawl can be explored which are reflected by the patterns, thus eventually aiding in the design of spatial planning support system. Following the sequence of patterns, process, causes and consequence, sets the research agenda as the framework for this research.

The current research addresses the issue of urban sprawl in the context of Bangalore, India. We propose a theoretical framework to analyse the interaction of planning and governance on the extent of outgrowth and level of services. Reviewing the different indicator frameworks, we also propose urban sprawl indicators and operationalise the same for Bangalore. The indicators comprise spatial metrics (derived from temporal satellite remote sensing data) and other metrics obtained from a house-hold survey. The interaction of different indicators with respect to the core city and the outgrowth is determined by multi-dimensional scaling. The analyses reveal the underlying patterns - similarities (and dissimilarities) that relate with the different governance structures that prevail here. Subsequently, we attempt to understand the process of sprawl. This might help one to understand the dynamics that lead to such outgrowths. An attempt was made to capture the dynamics using systems approach and finally the insights gained were translated into agent-based land-use model. Noting the evolution of spatial planning support system (SPSS), the consequences of sprawl are explored. The SPSS developed on an agent-based modelling environment, is essentially a process-based land-use model. We highlight the need for an integrated SPSS, illustrating its development and evaluation. The policy analysis carried out using the SPSS offers insights into areas of concern. It is concluded by noting the drawbacks and challenges for future research for managing urban sprawl. In the present context, with the escalating problem of urban sprawl, the evolution of a SPSS in the form of the BangaloreSim model is the first step in this direction. The SPSS aids in undertaking policy analysis for certain policy measures and its consequences on urban land-use. The research concludes outlining the challenges in addressing urban sprawl while ensuring adequate level of services that planning and governance have to ensure towards achieving sustainable urbanisation.

Papers based on this Thesis

Book Chapter, Peer Reviewed Journals and Conference Proceedings

1. **Sudhira H. S.** and Ramachandra T. V., 2008. Understanding Urban Sprawl: Implications of Planning and Governance on the Level of Services in Bangalore, India. *Urban Affairs Review.* (To be communicated)
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I. The Concept of Urban Sprawl

1.1 Introduction

The concepts of urban sprawl establish the distinction between urban sprawl, urban growth and urbanisation, wherein the purposes for the study on urban sprawl are iterated. The research agenda is founded upon the variety of ascribed definitions of urban sprawl, including the corresponding studies, which emphasise the sequence of patterns, processes, causes and consequences. The present chapter proposes the hypothesis for investigation and hitherto finishes with the research objectives and the scope of the study.

1.1.1 Urban Areas and Urban Growth

The definition of an urban area is normally based upon the number of residents, population density, percent of people dependent upon non-agricultural income and provision of public utilities and services. The term ‘urban’ has its origin from the Roman word *Urbanus,* which adopted the meaning ‘city dweller’ in Latin. The precise definition of an urban area can vary from country to country. Some countries define an urban area as any place with a population of 2,500 or more while some other countries set a minimum population of 20,000 as a criterion. In general, there are no universal standards and therefore each country develops its own set of criteria for recognising urban areas. In India, an area is designated as urban if the population is more than 5000 with a population density of more than 400 persons per sq. km and at least 75 percent of the population is involved in non-agricultural occupations (Shashidhar, H., 2001).

India’s urban population grew at an average rate of 2.35 percent per annum during 2000 to 2005 (United Nations Population Division, 2007). It is projected that the country’s urban population would increase from 28.3 percent in 2003 to about 41.4 percent by 2030 (United Nations, 2004). By 2001, there were 35 urban agglomerations (cities having a population of more than one million), as compared to 25 urban agglomerations of 1991. This increased urban population and growth in urban areas is inadvertent due to an unpremeditated population growth and migration. Urban growth, as such is a continuously evolving natural process due to growth of population (birth and death). The number of urban agglomerations and towns has increased from 3697 in 1991 to 4369 in 2001 (Census of India, 2001a). Among the 4000 plus urban agglomerations, about 38 percent of its population reside in just 35 urban areas. This clearly indicates the magnitude of concentrated growth and urban primacy due to urbanisation.

1.1.2 Urbanisation and Urban Sprawl

Urbanisation is a form of metropolitan growth that is a response to often less understood implications of technological, economic, social, and political forces and to the physical geography of an area. Currently, the Indian economy is experiencing a strange transformation from chiefly agrarian (with about 70 percent of the population in rural areas contributing to about 28 percent of GDP) to services based economy (with about 30 percent of the population in urban areas contributing a significant proportion of the services sector contribution to GDP). With significant economic and livelihood opportunities in the urban areas, an expansion for accommodating the immigrants (or immigrating populations) is resulting in greater urbanisation. Urbanisation, as such, is not seen as a threat to the environment and development but it is the unplanned urbanisation and dynamic urban growth, or the sprawl that affects the land-use of any region that becomes a matter of concern through its affectation in the loss of prime agricultural lands. It is thus imperative to study and bring out the intricacies and implications associated with the problem of unplanned urban growth ensuing into sprawl.

Towns and cities are expanding in certain pockets with a change in the land-use along the highways and in the immediate vicinity of the cities due to ad hoc approaches in regional planning, governance and decision-making. This outgrowth along highways and roads connecting a city and in the periphery of the cities is caused by the uncontrolled and uncoordinated urban growth. This dispersed development outside compact urban and rural centres that is along highways and in rural countryside is referred to as sprawl. Sprawl generally refers to some type of development with impacts such as losses of agricultural lands, open spaces, and ecologically sensitive habitats in and around the urban areas. These regions lack basic amenities due to the unplanned growth and lack of prior information and forecasts of such growth during policy, planning and decision-making.

Sprawl results in the engulfing of villages into peri-urban areas, peri-urban areas into towns and towns into cities. However, in such a phenomenon of development to have basic infrastructure, regional planning requires an understanding of the sprawl dynamics. Nevertheless, in a majority of the cases there are inadequacies to ascertain the nature of uncontrolled growth. Due to lack of prior planning, coordinated decision-making and visualisation of the outgrowths, the regions remain devoid of basic amenities like water, electricity, sanitation, etc. and result in inefficient and drastic changes in land-use, affecting the ecosystem and thus threatening the sustainable development of the region.

1.1.3 Urbanisation and Development - Towards Sustainable Urbanisation

An imminent urbanisation coupled with economic development has transformed societies and cultures apart from the landscapes, and the natural environment. A key challenge faced by most nations today is to ‘sustain’ the economic growth rate— development along with minimal impact on the environment. In the recent years, ‘development’ and ‘urbanisation’ have almost become synonymous especially in developing countries. Further ‘development’ *per se* is mostly associated with economic development, which most nation states promise to deliver to its citizens. Urbanisation is also a common phenomenon, which most of the developing nations are experiencing that has led to the rise of large metros along with its slums and squatters. At the same time, an alarming concern is also about the depleting natural resources, increasing pollution levels and associated environmental hazards apart from the rising urban-rural and rich-poor divisions; a host of environmental and socio-economic factors that have become important challenges of the recent times.

In this regard, it is essential for authorities concerned with administration and management of urban areas and urban development to adopt integrated approaches in regional planning while addressing the needs of its stakeholders and managing the resources sustainably. This also necessitates proper planning along with effective governance to manage the urban growth and to mitigate the pressures on natural resources and environment while catering to the needs of the economy that sustains these urban areas. It is this philosophy that drives sustainable development essentially to balance both economic development and environment, not only for the present but also for the future generations.

In recent years ‘sustainable development’ is a commonly used terminology among various regional, national and international agencies subsequent to the publication of Brundtland report in 1987. The Agenda 21 of Rio 1992 has endorsed the need for sustainable development. Highlighting the tenets for sustainable development, Reddy (2004) emphasised the need for strategies addressing ‘equity, economic efficiency, environmental soundness, long-term viability, self-reliance and peace’ for regional and the nation’s sustainable development. 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 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 need to be taken care of. Land is essential because our food and raw materials originate from them and it is also a habitat for flora and fauna. Similar to other resources, it is a scarce commodity. Any disturbance to this resource through the change in land-use e.g. conversion of forestland, 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.

Urban growth patterns resulting in sprawl are ‘unsustainable’, with the current consumption surging ahead of regions’ carrying capacity and leading to depletion of natural resources for future generations. The need for managing urban sprawl also arises out of the global concerns of achieving sustainable urbanisation. Sustainable urbanisation is a dynamic, multi-dimensional process covering environmental as well as social, economic and political-institutional sustainability (United Nations, 2004). Besides this, the adoption of the Millennium Declaration and the Millennium Development Goals by all the member states of the United Nations to promote equitable and sustainable development across nations, in pursuit of shared future for all, poses significant challenges. This has also set a universal framework for development by targeting the achievement of eight significant goals. Specifically, the seventh goal on ensuring environmental sustainability addresses the concern of improving the lives of millions of slum dwellers living in rapidly expanding cities (United Nations, 2007).

1.2 Urban Governance, Planning and Policies in India: An Overview

1.2.1 Urban Governance and Planning

The key organisational structure responsible and representing the citizens in urban areas are the elected local bodies. Technically for all towns and cities in India, there exists an urban local body. For the metropolitan cities, there exists the City Corporation surrounded by neighbouring municipal councils, which are generally a part of the larger urban agglomeration. The 73rd and 74th Constitutional Amendment Acts passed in 1993 mandates the urban local bodies for administering, managing and preparing master / development plans. Instead, planning in the form of land-use zoning is undertaken for the metropolitan region while their regulation is vested with a parastatal agency. Significant administration and decision-making in these areas with regard to delivery of various services rests with other parastatal organisations. Apart from the urban local bodies represented by the local elected representatives, all other organisations responsible for essential services are parastatal bodies controlled by the State governments. Thus, there exist striking contrasts with respect to devolving powers to the respective urban local bodies by the State governments much against the policies of Central government.

A critical aspect in the regulated development of urban areas is through proper implementation of master plans / development plans. Although 1200 master plans / development plans for towns and cities have been prepared so far in India, their implementation has not been satisfactory due to a variety of reasons, which in turn have resulted in mushrooming of slums and squatters, unauthorised and haphazard development and above all environmental degradation and transportation problems within and around the urban areas. Further, the development plans / master plans are mostly documents prepared with limited forecasting capabilities without capturing the entire dynamics and are generally not responsive to dynamic problems and responsive to policy changes. Besides this, these plans mostly restrict to demarcate only land-use zones with little or no effective regulation for the same. Further, with planning authorities restricting to mostly land-uses, there is hardly any coordinated effort to involve or integrate transport, water and sanitation, etc. in the planning process. This results in, organisations involved or catering to different services (transport, health, water, energy, etc.), work in disintegration to address basic amenities. Lack of coordination among many agencies has led to unsustainable use of land and other resources and also uncoordinated urban growth.

From the observation and analysis of the practices in urban governance, the operation plans drawn are ineffective in addressing smooth coordination with other agencies concerned with delivery of services. Essentially much of the chaos is contributed due to the disengagement with the planning organisation and the organisation involved with daily operations. A stark contrasting fact with the planning organisation is its lack of acknowledgement of any city functions: mobility, jobs, economy, energy, etc. The planning organisation on the one hand is focussed on land-use plans and its regulation alone, accepting supplements of integrating land-use with transportation for enhancing mobility. On the other hand, the local administration has to resolve overnight about daily operations management with little realisation on the implications of the planning organisation ignoring the city functions.

With numerous organisations responsible for addressing various city functions, it is imperative that these organisations acknowledge their interdependencies formally through appropriate mechanisms. Thus, the possible way out to break the gridlock, is facilitating systems and practices that ensures feedback and coordination effectively. Essentially the interplay of these organisations involved with different city functions has to be acknowledged and bridged from short-to-medium (5 to 10 years) time frame planning undertaken by development authorities to near-to-short term operations undertaken by City Corporations. Thus, it is essential to link the daily-operations with the planning of 10 year time period so that future chaos is arrested. In this perspective, planning and governance have to be responsive to local and regional issues while ensuring requisite infrastructure and delivery of basic services.

Much of the urban growth is normally attributed to migration of people from other places. Migration takes place mainly due to uncertain employment in rural areas where the majority relies on agriculture, which is dependent on unpredictable monsoons. In the absence of effective rural-employment guarantee schemes and prevalent macro-economic initiatives, catering to urban areas further fuel rural-urban migration with some formal or informal employment in the offing. Thus, for certain critical issues planning and governance cannot confine itself even to limited boundaries of the urban area, but acknowledge conditions and factors to address and plan effectively at a regional level.

1.2.2 Policies and Programs for Urban Areas

Traditionally, the policies of urban development have been focussed on addressing the lack of housing and delivery of basic services due to the rise in urban population. A premise while pursuing urban policies was also that the country was predominantly agrarian and largely supported by the rural economy. These are further evident from the plan outlays under housing and urban development sector in the Five Year Plans of the Planning Commission of India. Until recently, the positive aspects of cities as engines of economic growth in the context of national economic policies were not much appreciated and, therefore, the problems of urban areas were treated more as welfare problems and sectors of residual investment rather than as issues of national economic importance (Ministry of Urban Development, 2005).

Addressing the urban areas in the initial years, focus was on land policies, later on towards delivery of basic services to urban poor, and curently on urban infrastructure and governance. Ravindra (1989) has attempted to delineate the urban land policy in the country. Accordingly he has examined the instruments of land policy employed by the State for interventions broadly as: legal measures, fiscal measures and direct interventions. There have been intense debates and some large-scale initiatives to systematically tackle urbanisation. The first major attempt to address the urban land problems was by the Committee on Urban Land Policy. The other initiatives were through: the Task Force on Housing and Urban Development in 1985, the National Housing Policy in 1985, the National Commission on Urbanisation in 1988, the Mega City Scheme during 1993-1998, the Jawaharlal Nehru National Urban Renewal Mission (*JnNURM*) from 2005 to 2012 and the National Urban Transport Policy (Ministry of Urban Development, 2006).

The Ministry of Urban Development, Government of India, launched the *JnNURM* in 2005. This countrywide programme addresses renewal of urban areas for 63 cities encompassing nearly 70% of total urban population, its primary aim being to link the revitalisation of urban infrastructure with a specific agenda of institutional reforms. The total investments envisaged under *JnNURM* over the mission period (2005-2012) is pegged at Rs. 12,05,360 million. The key mission of this programme is to support reforms-driven, fast track, planned development with focus on improving efficiency in urban infrastructure and service delivery mechanisms, through community participation and ensuring accountability of urban local bodies and parastatals towards citizens. *JnNURM* is made operational with two sub-missions:

- Urban Infrastructure and Governance (UIG)
- Basic Services to Urban Poor (BSUP)

The sub-mission on UIG focuses on major infrastructure projects for water supply, sanitation, sewerage, solid waste management, road network, urban transport and redevelopment of inner (old) city areas with a view to upgrading infrastructure therein, shifting industrial and commercial establishments to conforming areas, etc. The sub-mission on BSUP focuses on integrated redevelopment of slums combining housing, water supply, drainage, storm water drains, solid waste management, street lighting, and community halls.

Realising the growing concerns of mobility and more specifically the acknowledgement of linkages of land-use planning and transportation planning, the Ministry of Urban Development, Government of India, approved the National Urban Transport Policy (NUTP) in June 2006. Based on the NUTP and the recommendations of National Working Group on Urban Transport for the 11th Five Year Plan, the Government of Karnataka has constituted the Directorate of Urban Land Transport (DULT) through a government order on 8th March 2007. The creation of DULT in Karnataka is perhaps the first of its kind in the country. The functions of DULT as envisaged are:

- Periodic assessment of travel demand
- Determination of the level of public transport required in different corridors and the type of transport systems required
- Assessment & recommendation of the new investments needed creation of infrastructure
- Procurement of public transport service from private operators
- Policy guidelines for development of total network in urban areas / new layouts
- Designing and developing integrated policies and plans for city level transportation

Furthermore, in order to facilitate and expedite these activities for Bangalore, the Government of Karnataka has created the Bangalore Metropolitan Land Transport Authority (BMLTA) also through an order with the following functions:

- To co-ordinate all land transport matters in the Bangalore Metropolitan Region (BMR)
- To prepare detailed Master Plan for Transport Infrastructure based on the comprehensive Traffic and Transport Study for Bangalore
- To oversee implementation of all transportation projects
- To appraise and recommend transportation and infrastructure projects for bilateral Central assistance
- To function as empowered Committee for all Urban Transportation Projects

- To initiate action for a regulatory framework for all land transport systems in BMR
- To initiate steps, where feasible, for common ticketing system
- Take any other decision for the integrated urban transport and land-use planning and implementation of the projects

Understandably, the acknowledgement of the forces of urbanisation by the highest planning body in the country coming in recently, quite obviously, the perception and problem of sprawl has been conveniently overlooked until now. Thus, this study gains importance in studying urban sprawl with an outlook for policy implications. Understanding the sprawl processes, its dynamics and modelling provide an insight of future growth trends, which is useful for effective resource utilisation and infrastructure planning. The efficiency of urban settlements largely depends on how well they are planned; how well they are developed economically and how efficiently they are managed. Management of urban sprawl entails quantifying the pattern of sprawl and capturing the processes requires analysis of causal driving factors. This requires understanding and visualisation of the consequences of policies, local planning and administration on sprawl, like lack of effective public transport system with varying work-home distances, giving rise to independent motor vehicles and the resultant congestion and spatial expansion. This necessitates integrated spatial planning support systems for managing sprawl. It is thus essential to undertake a study to understand the dynamics of sprawl and evolve a dynamic spatial planning support system.

1.3 Background and Literature Review

1.3.1 Origin and Evolution of Towns and Cities

Introspection on the origin of towns and cities has to be traced back to the human evolution about 3 million years back. Our distant ancestors lived a very hard existence as hunters and gatherers until the early civilisations started around 8000 years ago. Sjoberg (1965) notes that the different levels of human organisation characterised by technological, economic, social and political patterns are the factors that aided the origin and evolution of cities before the modern epoch of urbanisation.

In the first level, the pre-urban and pre-literate human society was mostly hunters and gatherers with little or no surplus food. Consequently, the society had little or no specialisation of labour or distinction of class. Slowly through the advances in technology and organisational structure, human societies evolved into slightly complex societies through settlements in villages. Humans learnt to cultivate and subsequently communities evolved that could support more people with food as the time progressed. With the knowledge of cultivating plants, lighting fire, inventing wheel, making tools, humans advanced by leaps and bounds. This second level of human organisation is attributed to the knowledge of humans to cultivate thereby creating a surplus of food. This pre-industrial civilised society is also characterised by the art of writing to make inscriptions, maintain and record law, literature, and religious beliefs and the ability to harness energy from wind and water sources for sailing in seas to grinding grains to make use of water power. By around 2500 years BCE (before Common Era) there were towns and cities like Harappa and Mohenjo-daro. Within the last 500 years BCE, kingdoms and cities emerged worldwide where most of the civilisations originated mostly in the river valleys. This included the cities of India, Mesopotamia, Egypt, China, etc. During the next one millennium the world saw a host of religions that came up to have a significant impact on human evolution. Meanwhile, cities expanded, kingdoms rose and fell, wars were fought, and the humans learnt to harness the natural resources incessantly and mercilessly. The post-industrial revolution cities was characterised by mass literacy, a fluid class system and the tremendous technological breakthrough to new sources of inanimate energy that sustained the industrial revolution from the third level of complexity in the human organisation (Sjoberg, 1965).

The industrial revolution during eighteenth and nineteenth century was seen as a major cause for the current growth and sustenance of towns and cities. The developments during the industrial revolution between 1750 and 1830 CE transformed most of north-western Europe from a largely rural and agrarian population to a town-centric society engaged increasingly in factory manufacture, trade and commerce. The post industrial revolution era also saw the enormous upsurge in people moving from rural to urban settlements.

As most of the north-western Europe became industrialised, the faster was the urbanisation. In the more advanced countries, urbanisation seemed as a consequence of industrialisation, although as more of these countries urbanised, industrialisation and technological innovations were also enhanced significantly. A strong positive reinforcing feedback emerged with the industrialisation and urbanisation in the advanced countries alone.

Contrastingly enough, the industrialisation and subsequent urbanisation did not catch up in the developing and under-developed countries as in the developed countries until the mid-nineties. Of late, the developing countries have seen tremendous upsurge in their urbanisation and urban population growth rates, especially with the number of cities and urban agglomerations having a population of more than a million has increased significantly over the recent decades. This upsurge has not been solely as a consequence of industrialisation alone in these countries but also due to the falling agriculture produce and other factors in rural areas like livelihood inducing migration of large populations into urban areas in search of better livelihoods (Harris, 2005).

In industrialised countries the growth of urban population is comparatively modest as population growth rates are low and over 80 percent of their population already live in urban areas. Conversely, developing countries with higher growth rates are in the middle of a transition. 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). Unlike in developed countries where the problem of sprawl has to be addressed in terms of transport, energy, land-use, and environment, developing countries are faced with additional problems of increasing urban poverty levels, higher population growth rates and rising numbers of slums or squatters resulting out of sprawl. It is in this context that the study on urban sprawl gains importance.

1.3.2 Urban Growth, Urbanisation and Urban Sprawl

It is very much apparent that cities had evolved more than a few millenniums ago, while some grew and perished, urban growth was prevalent and not urbanisation. It is essential to clearly distinguish from the growth of cities from the thousands of years to the more recent urbanisation. On the distinction of urbanisation and urban growth, several authors have put forward their viewpoints. Cautioning that attributing simply the growth of cities to urbanisation, Davis (1965) notes that urbanisation refers to the proportion of the total population concentrated in urban settlements, or else the rise in this proportion. It is argued that since urbanisation would account for the total population composed of both urban and rural, the proportion of urban is a function of both of them. Accordingly, cities can grow without urbanisation provided the rural population grows at an equal or greater rate. The transformation of human settlements from a spread-out to compact urban centres is a change that can be traced but the growth of cities has no inherent limit and so are the boundaries. Such growth could continue even after everyone was living in cities, as in cities of already urbanised developed countries, through sheer excess of births over deaths (Davis, 1965).

The process of urbanisation is fairly contributed by rural-urban migration leading to the higher proportional population growth of urban-rural and infrastructure initiatives, resulting in the growth of villages into towns, towns into cities and cities into metros. In developed countries of north-western Europe and North America, urbanisation is already at its peak, with little or no further urbanisation possible, as the scope for rural-urban migration is minimal. Furthermore, it is the urban population *per se* that grows and not the proportion of urban to rural population. With the extensive urbanisation followed by industrialisation, the compact and densely populated cities emerged during the last century. Over the last century, these countries saw the emergence of large metropolitan cities. What has been intriguing to the urban planners, researchers, managers and administrators is that in spite of the saturated and stagnated urbanisation, the cities are continuing to spread (Batty, Besussi, and Chin, 2003). As the cities grew in population, transportation got affected. The affluent aided by individual transportation, moved towards the outskirts thereby minimising costs at the central business districts, inducing the spread of cities (Marathe, 2001). At times, the city authorities provided better transportation from the core to the outskirts and along the periphery, which encouraged people to move outskirts also inducing sprawl. In other words, be it either better transportation or the population growth, the cities expanded consuming neighbouring agricultural lands and affecting ecologically sensitive habitats. This phenomenon of urban sprawl is being witnessed, studied and documented in several cities of north-western Europe and North America even after reaching the stagnation and saturation levels of urbanisation. The problem of sprawl is now being addressed through extensive studies and policy recommendations in the European Union (Gayda *et al.*, 2005) and United States of America (Transportation Research Board, 2002).

In 1800, only 3 percent of the world’s population lived in urban areas. By 1900, almost 14 percent were living in urban centres, and only 12 cities had 1 million or more inhabitants. In 1950, 30 percent of the world’s population resided in urban centres and the number of cities with over 1 million people had grown to 83. The world has experienced unprecedented urban growth in the recent decades. In 2000, about 47 percent of the world’s population lived in urban areas. Now, there are 411 cities over 1 million population. The prevalently developed nations are about 76 percent urban, while 40 percent of residents of less developed countries live in urban areas. However, urbanisation is occurring rapidly in many less developing countries. According to Population Research Bureau (2005), it is expected that 60 percent of the world population will be urban by 2030, and that most urban growth will occur in less developed countries.

The implications of sprawl are not only on the surrounding neighbourhood with loss of agricultural lands or ecological habitats but also on the access to basic amenities and infrastructure like health care, water supply and sanitation, transportation, energy, etc. within the inner core of the city. As sprawl advances, the city notifies overtime these areas as a part of the extended city itself, thus it will become the onus of the city administration to cater for the rising travel demands, water supply and sanitation, energy needs, etc.

The magnitude and nature of urban sprawl is quite different in the developed countries than to that of a rapidly developing and largely rural-agrarian populated country like India. The problem of sprawl is magnified in the developed countries after reaching saturation levels of urbanisation. Conversely, most of the developing and under-developed countries are now urbanising rapidly and already prone to the problem of sprawl at an even worse magnitude. A significant difference in the urbanisation patterns of developed and developing countries is that of population densities. The developed countries embraced urbanisation after industrialisation wherein the population growth rates and densities were lower, with a prosperous economy and technology to support. Conversely, developing countries are having high population growth rates and densities, in the midst of economic development, with lack of basic amenities and urbanisation taking place at a rapid rate. In India, already 28 percent of the population live in urban areas and these cities are expanding like never before, with inadequacies in facilities for transportation, water supply and sanitation, energy demands, etc. With a booming economic activity on the one side and large population in unorganised sectors of employment with inadequate housing on the other, rise of slums and squatters in urban areas seems inevitable.

1.3.3 Studies on Urban Sprawl

Until 1960s, the problem of urban sprawl was not studied / documented in already urbanised economically advanced countries. Although, Davis (1962) notes the ‘deconcentration of cities as they become more urbanised’, this was not formally termed as sprawl then. The

Transportation Research Board (TRB) of the United States of America (USA), in one of the recent and authoritative definitions, ascribe sprawl to exhibit 'deconcentrated centres' and grow in the neighbourhood (Transportation Research Board, 2002). The problem gained importance only in late 60s and early 70s, mostly in the USA and north-western Europe. And since then there has been significant research and debates on this topic.

Several authors: Batty, Xie, and Sun (1999); Batty, Chin, and Besussi (2002); Torrens and Alberti (2000); and Transportation Research Board (2002) and other organisations have attempted to define 'sprawl' since the problem of urban sprawl has been acknowledged for nearly fifty years. Sierra Club (1998) defines sprawl as a low-density development beyond the edge of service and employment, which separates where people live from where they shop, work, recreate, and educate— thus requiring cars to move between zones. This definition ascribes sprawl as induced directly by the location of work-home and aided by individual transportation (cars), and this phenomenon is more prevalent in the United States of America.

Batty, Xie, and Sun (1999) consider urban sprawl in relation to the contemporary urban growth consisting of three interrelated problems of spatial dynamics: the decline of central or core cities which usually mark the historical origins of growth; the emergence of edge cities which compete with and complement the functions of the core; and the rapid suburbanisation of the periphery of cities - core and edge - which represent the spatially most extensive indicator of such growth.

Further, Torrens and Alberti (2000) note that sprawl is characterised by uniform low-density development, which is often uncoordinated and extends along the fringes of the metropolitan areas invading prime agricultural and resource lands. Also, they indicate that such areas are over reliant on the automobiles for access to resource and community facilities with these areas regarded as aesthetically displeasing.

The study of urban sprawl and its implications have been addressed by Transportation Research Board (1998; 2002) and Sierra Club (1998). TRB (Transportation Research Board, 2002) explains sprawl as the spread-out development that consumes significant amounts of natural and man-made resources, including land and public works infrastructure of various types. Sprawl also adds to overall travel costs due to increasing use of the automobile to access work and residence locations more widely spaced due to the sprawl phenomenon.

Furthermore, sprawl appears to deconcentrate centres and takes away from the multiplicity of purpose that neighbourhoods once delivered. Yet sprawl has benefits. It offers access to less-expensive housing and opportunities for homeownership at the periphery of metropolitan areas. It provides congestion management in automobile-dominated metropolitan areas by creating the suburban-to-suburban trip and by better equalising the percentages of the commuting population involved in reverse and forward commutes.

Ciscel (2001) examined sprawl by quantifying three components: the jobs, business and housing; commuting; and government infrastructure capital costs. He notes that sprawl raises the costs of operating urban infrastructure and hence leads to economic inefficiency. Brueckner (2001) attributes the spatial growth in the USA to: rise in population, rise in incomes and falling commuting costs. It is further argued that urban growth is in response to these fundamental forces and hence urban growth is not socially undesirable. Any market failures distorting the fundamental forces, can lead to improper allocation of land between agricultural and urban uses.

Recently Batty, Besussi, and Chin (2003) termed sprawl as 'uncoordinated growth', the unplanned incremental urban growth, which is unsustainable. Noting that sprawl is a consequence of simultaneous population growth and better transportation from the core to edge, they question it as a typical chicken and egg conundrum of what comes first: better transportation or population growth; or population growth followed by better transportation? Obviously, it is a difficult paradigm to ascertain whether it is population growth or transportation that leads to sprawl. In an already urbanised and developed country like England, the sprawl can be thought of chicken or egg problem. However, in the context of a rapidly urbanising and developing country like India wherein the population is largely agrarian with high urban population growth rates and a booming economic activity, sprawl is not only a chicken and egg problem but there are a host of factors that are contributing to the complexity for sprawling towns and cities.

Review of various studies concerning urban sprawl indicates that sprawl has been attributed in various contexts, while characterising / quantifying sprawl has always been a contentious issue. Noting the same, Galster *et al.* (2001) have observed that literature on sprawl is 'lost in semantic wilderness', and hence they categorise sprawl as being ascribed under six broad categories:

a) By example that embodies characteristics of sprawl, such as Los Angeles

b) Aesthetic judgement and general development pattern

c) Cause of an externality

d) Consequence or effect independent variables

e) Pattern of development

f) Process of development

Extending Torrens and Alberti (2000)'s notion of urban sprawl, Galster *et al.* (2001) define sprawl as a pattern of land-use in an urban agglomeration that exhibits low levels of some combination of eight distinct dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity. Ascribing sprawl as a pattern of land-use alone would not throw light on the underlying processes, causal mechanisms and hence consequences. In a developing country like India, where population density is high with significant urbanisation rates, urban sprawl obviously cannot be characterised by pattern alone but processes, causes and their consequences. Hence, we suggest a modification to the definition of urban sprawl as the pattern of outgrowth emergent during the process of urban spatial expansion over time caused by certain externalities and a consequence of inadequate regional planning and governance. The sequence of patterns, processes, causes and consequences sets the research agenda in the current thesis.

In India, several studies have addressed urbanisation and urban growth in relation to transportation linking energy (Reddy B. S., 2000), land-use (Srinivasan, 2002) and vehicular emissions (Rama Krishna and Reddy 2001; Sikdar, 2001), etc. However, not many studies have addressed the problem of urban sprawl (Behera, *et al.*, 1985; Jothimani, 1997; Lata *et al.*, 2001; Subudhi and Maithani, 2001; Sudhira *et al.*, 2003). Furthermore, there are fewer studies on modelling urban sprawl in India (Subudhi and Maithani, 2001; Sudhira *et al.*, 2004b). Similar to trends in research on urban sprawl in advanced countries, the problem of sprawl has been largely addressed in isolation in India. Of late, there have been concerns of integrative modelling by synchronising different domains concerned with urban issues and making planning more effective for taking policy decisions. For undertaking the public transport planning, Mohan (2001) has attempted to integrate safety, environment and economic issues. Padam and Singh (2001) highlight the need for an urban transport policy in the wake of rapid urbanisation owing to transportation problems, while taking into account of the economic contributions of the urban areas. Gakenheimer (2002) notes that currently land-use planning and transportation planning are not synchronous although well undertaken individually, thus leading to significant concerns and problems in urban areas. However, the need for integrative approach linking land-use and transportation planning is now being suggested (Gakenheimer, 2002). Subsequently, as with the studies and definitions on urban sprawl, the metrics and methods to quantify sprawl are still vague. This necessitates arriving at appropriate metrics to address the problem of urban sprawl considering the rates of urbanisation and population densities apart from the spatial extents amassed by urban areas.

Considering the various studies and prevailing conditions of urban fabric in India, it is found that lack of effective urban governance have resulted in unplanned and uncoordinated urban outgrowth. Urban governance requires keeping track of various processes, activities, services and functions of the urban local body, which is possible through an information system. In the absence of any such system, at the basic level, there is a strong and pressing need for an information system to cater to all these. In the next level, it becomes essential to build models based on the information systems involving simulation and analysis for specific urban contexts. The subsequent level involves evolving different strategy and policy options using the models and information systems. Thus, at the outset, there are three essential steps to address the problem of sprawl and to strengthen planning and decision-making, namely, information systems, models and policies.

i. Metrics of Urban Sprawl

Evolving appropriate measures to quantify urban sprawl is a prerequisite to undertake modelling of urban sprawl dynamics. Often, there is a lack of appropriate indicators and information concerning the cities or its status, from a holistic perspective that captures not only the economic aspects but also ecological and socio-economic aspects including livelihood of people. Given the problem of urban sprawl and its inadequate understanding to precisely determine its nature, pattern and rate of growth, there is an urgent need to characterise urban sprawl, more so from the perspective of achieving sustainable urbanisation in developing countries. Thus, a significant challenge is to understand the processes that cause such growth, for which, there is a pressing need to identify the appropriate indicators towards achieving sustainable urbanisation.

Torrens and Alberti (2000) note that despite the level of importance given to the problem of sprawl, there remains little understanding of its determinants and its constituents, since sprawl is most often confused with sub-urbanisation. However, some researchers in the recent past have attempted to characterise urban sprawl (Barnes *et al.*, 2001; Hurd *et al.*, 2001; Epstein, Payne, and Kramer, 2002; Sudhira *et al.*, 2004b) using spatial metrics.

Essentially, the urban sprawl metrics aid in quantifying the process, monitoring the extent of urban sprawl and also become useful as indicators for measuring the implications of policy decisions. Although some of the indicators for achieving sustainable development have been evolved by Meadows (1998), still there is not any broad consensus on the appropriate indices representing all of the factors and disciplines. For managing urban sprawl in north-western European cities, Gayda *et al.* (2003) have evolved metrics, adopted as indicators to achieve sustainable development. Furthermore, on the lines of sustainable development framework, there also exists quantification of metrics based on the carrying capacity approach. In this case, the carrying capacity of an urban system is evaluated based on the different functions and activities of the urban systems and accordingly a certain threshold for development is set, beyond which it is detrimental to the entire system itself. The concept of carrying capacity has been in news since the seminal work by Meadows *et al.* (1972) on the notion of 'Limits to growth'. In India, the NIUA (National Institute of Urban Affairs, 1996) has evolved a framework for the carrying capacity based regional planning. The essence of carrying capacity based approach on the lines of achieving sustainable development lies in the fact that a host of factors (such as assimilative and supportive capacities) are under consideration in the planning processes.

Some of the existing works on sprawl ascribe spatial extent of built-up areas derived from remote sensing data or other geospatial data as the measure of sprawl. On the spatial metrics for sprawl, entropy, patchiness and built-up density have been suggested (Yeh and Li, 2001; Sudhira *et al.* 2004b; Torrens and Alberti, 2000). In addition to this, the percentage of population residing over the built-up area to arrive at population-built-up density was considered metric for sprawl (Gayda *et al.*, 2005; Sudhira *et al.*, 2003). However, it still remains largely unanswered as to how and what are the appropriate metrics or indicators of urban sprawl that are sufficient to represent the process of sprawl. Although some attempts are made to capture sprawl in its spatial dimensions, still they fail to capture sprawl in other dimensions (like travel times, pollution, resource usage, etc.) and neither do they indicate their intensity (density metrics). It is thus imperative for research to address intensity of sprawl through appropriate metrics or indicators for effective regional planning.

ii. Capturing the Dynamics of Urban Sprawl

a. Approaches to Model the Dynamics of Urban Sprawl

The urban sprawl phenomenon is very dynamic in nature. Although it is often considered endemic, the phenomenon has impacts on the structure and growth of any city or town. Development of suburbs because of increased population growth and infrastructure facilities around cities is a well-established reasoning for urban sprawl. Several approaches and methods originating from the disciplines of urban planning, engineering, management, geography and artificial intelligence have been used for modelling urban systems. The key approaches include operations research (OR) methods, system dynamics (SD) framework, geospatial modelling using the tools of GIS and more recently the use of agent-based models in conjunction with geospatial models to capture the dynamics and modelling of urban sprawl.

A review of different OR methods were done by (Catanese, 1972). Among the predominantly used methods for operational planning and decision-making are probabilistic models, optimisation techniques, linear, non-linear, dynamic and stochastic programming methods. More recently, simulation tools are being used extensively to capture and emulate urban system and its dynamics. These simulations are based on the concepts of discrete-event system simulation approaches. With the emergence of multi-agent systems from artificial intelligence domain, these are now being used to aid in simulation of urban systems. The SD framework captures the system based on complexity involving dynamic relations represented by stocks and flows determined by various activity volumes in the city, which were synthesised from casual knowledge and observations. Although OR approaches and SD framework have been applied quite rigorously in urban systems, but in the recent times, geospatial modelling aided by visualisation has been very effective. The origins of GIS date back to the late 1960s with the creation of a spatial database for urban areas. Mapping urban sprawl provides a “picture” of the location and extent of growth that helps to identify the environmental and natural resources threatened by such sprawls. Analysing the sprawl over a period of time will help in understanding the nature and growth of this phenomenon, which helps to suggest the likely future directions and patterns of growth. Availability of spatio-temporal data with GIS are very useful to study sprawl. The spatial patterns of urban sprawl on temporal scale can be analysed and monitored using the remotely sensed satellite imageries. They can be used in identifying urban growth pattern from spatial and temporal data. These help in delineating the growth patterns of urban sprawl such as linear growth and radial growth patterns.

b. Modelling Urban Sprawl

Modelling urban sprawl dynamics has closely followed traditional urban growth modelling approaches. Subsequently, with the need to manage urban sprawl, modelling urban sprawl by relating to nature of growth and its implications has been undertaken since sixties. Urban development models were developed much earlier, however modelling dynamics of urban sprawl has been undertaken only recently (Batty, Xie, and Sun, 1999; Torrens and Alberti, 2000). The key initial studies in the developed countries on urban growth and urban development models (Lowry, 1967, In: Batty and Torrens, 2001; Helly, 1975; Allen and Sanglier, 1979; and Pumain *et al.*, 1986). Most of these studies followed the traditional approaches of urban model building. The traditional approach of model building involved linking independent to dependent variables, which were statistically significant, additive as in a linear model or a non-linear model but tractable in a mathematical way. However, these models were used mostly for policy purposes, but they could not be useful when processes involved rule-based systems, which in practice cannot be tractable mathematical operations (Benenson and Torrens, Geosimulation: Automata-based modeling of urban phenomena, 2004).

Among the path-breaking models developed to capture urban systems, Forrester (1969) attempted to model urban dynamics based on complexity involving dynamic relations represented by stocks and flows that determined the various activity volumes in the city, which were synthesised from knowledge and observation of causal factors. A key distinction of this model was its ability to represent emergent behaviour of the system originating out of complexity. However, this model could not be represented spatially.

Batty *et al.* (1999) provided spatially aggregate model for the urban sprawl phenomenon. Cheng and Masser (2003) report spatial logistic regression techniques for analysing urban growth pattern, which was applied for a city in China. This study also includes extensive exploratory data analyses considering the causal factors. Later, Sudhira *et al.* (2004b) attempted modelling urban sprawl in a non-spatial domain. In an interesting analysis on regional industrialisation in a province in China, Huang and Leung (2002) have employed geographically weighted regression to identify spatial interaction between level of regional industrialisation and various factors affecting industrialisation. It is argued that conventional regression analysis would only produce the 'average' and 'global' parameter estimates, which vary over space depending on the respective spatial systems. Thus, they suggest using the geographic weighted regression technique for analysing spatial non-stationarity of different factors affecting regional industrialisation.

Allen *et al.* (1986), Couclelis (1987) and Engelen (1988) assert modelling urban systems as complex systems, while acknowledging the self-organisation in urban systems. Capturing urban systems as discrete models gained further momentum with the popularity of the cellular automata (CA) based techniques. Ulam developed CA in the 1940s, and it was later used by von Neumann to investigate the logical nature of self-reproducible systems (White and Engelen, 1993; Li and Yeh, 2000) and extensive experiments were done by Wolfram (2002). The most pioneering work in simulating urban growth using CA was done by Couclelis (1987) and Batty and Xie (1994). Now, most models of spatial dynamics rests with land cover and land-use change studies (Yang and Lo, 2003), urban growth models (Batty, 1998; Batty and Xie, 1994; Clarke and Gaydos, 1998; Clarke, Hoppen, and Gaydos, 1996; Couclelis, 1997; Jianquan and Masser, 2002; White and Engelen, 1993; White and Engelen, 1997) and in urban simulation (Li and Yeh, 2000; Torrens and O'Sullivan, 2001; Torrens, 2000; Waddell, 2002). Urban growth modelling considering the spatial and temporal analyses of land-use / land cover changes like LUCAS (Land Use Change Analysis System) model (Berry, Flamm, Hazen, and MacIntyre, 1996), GIGALOPOLIS (Clarke, Hoppen, and Gaydos, 1996), and California Urban Futures (CUF-II) model (Landis and Zhang, 1997). Li and Yeh (2000) develop and demonstrate the constrained CA model for sustainable urban development modelling. Some of these models conceptualise the causal factors, such as the availability of land and proximity to city centres and highway, driving the sprawl.

CA has been used for simulating urban growth quite successfully, mostly considering various driving forces that are responsible for sprawl. However, some issues like the impact on ecology, energy, environment and economy for taking policy decisions have not been addressed effectively. To counter the shortcomings of CA, different approaches are being suggested. Among them is the integration of agent-based models and CA models, where agent-based models are used to capture the externalities driving the processes.

Models developed using CA and agent-based models would prove beneficial to pinpoint where sprawl takes place, which would help in effective visualisation and understanding of the impacts of urban sprawl. Further to achieve an efficient simulation of urban sprawl, modelling has to be attempted in both spatial and non-spatial domains. Modelling urban sprawl in non-spatial domain is mainly done by the application of statistical techniques while CA models and agent-based modelling are known to complement modelling in the spatial domain. For achieving the integration of CA and agent-based models to simulate urban sprawl phenomenon, Benenson and Torrens (2004) have evolved the Geographic Automata Systems (GAS) framework, while Sudhira *et al.* (2005) have developed the Dynamic Geo-Spatial Simulation (DGSS) framework. Although research in geospatial modelling has matured towards arriving at simulation frameworks, this is yet to be graduated into an effective spatial planning support system.

iii. The Integrated Spatial Planning Support System

For effectively managing, testing of different hypothesis, building and visualising scenarios, it is imperative to have a robust Spatial Planning Support Systems (SPSS) for addressing the problem of urban sprawl. An ideal SPSS would not only aid in managing but also in planning, organising, coordinating, monitoring and evaluation of the system in question. These systems include instruments relating to geoinformation technology that have been primarily developed to support different aspects of the planning process, including problem diagnosis, data collection, mining and extraction, spatial and temporal analysis, data modelling, visualisation and display, scenario-building and projection, plan formulation and evaluation, report preparation, enhanced participation and collaborative decision-making (Geertman and Stillwell, 2004). Integration of different processes associated with the dynamics of sprawl phenomenon is required for addressing the problem of urban sprawl. Moreover, a key challenge for technology is to facilitate collaborative decision-making for evaluating different policy options through participatory simulations by different stakeholders.

Most of the existing simulation framework allows simulations only on stand-alone systems, wherein each stakeholder has to choose / decide the options on the same system / platform. This would suggest that all the stakeholders have to meet physically to evaluate and decide. Moreover, such initiatives are not normal and very difficult to moderate. In this context, it becomes necessary for a distributed simulation framework to support SPSS, so that all the stakeholders and managers / administrators are able to interact, organise, plan, evaluate and decide through a network. Then the challenges are twofold: one, to integrate different models that are required to carry out the simulations and secondly, to synchronise the model's inputs, feedbacks and outputs over space and time.

Currently, there are a few popular frameworks that try to emulate SPSS with an objective to make planning interactive and participatory. Among such existing SPSS are *What-If?* (Klosterman, 1999), RAMCO (Uljee, Engelen, and White, 1999) etc. *What-If?* (Klosterman, 1999) is an interactive GIS-based planning support system that responds directly to both achieving the ideals of communicative rationality and traditional comprehensive land-use planning. It uses geographic data sets to support community-based efforts to evaluate the likely implications of alternative public policy choices. The package can be customised to a community's existing geographic data, concerns, and desires that provides outputs in easy to understand maps and reports which can be used to support community-based collaborative planning efforts. The system requires that, given a set of factors and factor weights for determining the suitability, projections for future land-use and subsequent allocation can be based on user requirements. Although this system is claimed to be interactive, the dynamics of the factors and hence their interactions are less captured with only a final land-use scenario obtained as output, which does not support a distributed (simulation) framework.

The RAMCO (Rapid Assessment for Management of COastal zones) is a prototype information system for regional planning in a generic decision support environment for the management of coastal zones through the rapid assessment of problems (Uljee, Engelen, and White, 1999). The system was developed integrating GIS, CA and system dynamics. Subsequently, White and Engelen (2000), the developers of RAMCO, also supported the integration of GIS, CA and system dynamics with the usage of multi-agent systems for a high-resolution integrated modelling of spatial dynamics of urban and regional systems. This has currently set the standard of technology that can be used for achieving an integrated spatial planning support system. However, this also does not support a distributed framework.

UrbanSim and OBEUS are two other established frameworks and supporting packages for integrated modelling of urban systems. UrbanSim is implemented as a set of packages under Open Platform for Urban Simulation (OPUS) (Center for Urban Simulation and Policy Analysis, 2006). This is fairly comprehensive in the sense that the framework integrates land-use, transportation, economic, demographics and environmental variables. However, this framework does not support participatory simulations. The OBEUS (Object-

Based Environment for Urban Systems) is more robust and is an emerging trend to integrate various processes as agent-based models to simulate them spatially and hence it is termed as geosimulation (Benenson and Torrens, 2004). The notion of GAS (Geographic Automata Systems), formalising the fusion of agent-based models and cellular automata models in a spatial framework is demonstrated here. However, again the key drawback here is that this does not support participatory simulations. Also, if one may wish to consider each agent-based model as an individual discrete-event simulation model, then OBEUS addresses it using synchronous or asynchronous updating. It may well be a good frame of reference to build a distributed simulation framework for enabling participatory decision-making possible.

Typically the planning machinery and administrators are less equipped to address the issues of sprawl. Concentrated economic developmental activities in a few localities have implications of rural-urban migrations that lead to skewed growth. The city planning is mostly addressed at catering to the future projected population and the facilities that the civic authorities need to cater for that forecast of population, which are normally static master plans or development plans. These plans are also less equipped to review and evaluate any policy decisions dynamically so as to visualise the potential implications of a policy directive and also the regions of potential sprawl. It is in this context that the planning machinery and administrators need to be informed of the possible areas of sprawl to take corrective actions to mitigate the implications. In this regard, the present thesis attempts to contribute towards a deeper understanding of the urban sprawl phenomenon, capturing the dynamics, modelling it and designing a spatial planning support system to visualise, review and evaluate the various policy options so as to have effective methods and tools to mitigate the problem of sprawl.

1.4 Research Agenda

1.4.1 Patterns, Processes, Causes and Consequences

Considering the various studies, the pattern of urban sprawl is characterised by using spatial metrics based on the extent of paved surface or built-up areas. The process of urban sprawl can be described by change in pattern over time, like proportional increase in built-up surface to population leading to rapid urban spatial expansion. Analysing the causes of urban spatial expansion, the externalities are modelled as agents in a geospatial environment like location of jobs, housing, access to services, level of economic activity, etc. With an understanding of the patterns, processes and causes of urban sprawl, the consequences of sprawl can be explored which are reflected by the patterns, thus eventually aiding in the design of spatial planning support system. Following the sequence of patterns, process, causes and consequence, sets the framework / agenda for this research (Figure 1-1).

The phenomenon of urban sprawl is potentially observed as a threat for achieving sustainable urbanisation. It is very essential that effective understanding on the phenomenon of urban sprawl especially with the perspective of a developing country should be gained. This would eventually aid in evolving any policy and management options for effectively addressing the problem of urban sprawl.

Based on the proposed research framework it is important to address each of the research questions systematically. It is now generally accepted that patterns can be mapped based on satellite remote sensing data, however, it is still not clear whether they are alone sufficient to distinguish the level of services in the outgrowths. Further, there have also been studies to assess the level of services in different urban areas missing the spatial aspects. Thus, it should be possible to comprehensively develop indicators based on level of services that complement the spatial metrics. Accordingly, the sprawl regions identified by the spatial metrics should be supported by the assessment of level of services. In this context, it will be interesting to explore as to how the level of services are affected with the outgrowth of the city?

The characterisation of sprawl based on both level of services and spatial metrics would throw light on the effectiveness of planning and governance. Governance itself determines the level of services in the outgrowth, while planning addresses the forecasts of such future outgrowth. It is in this outlook that understanding the sprawl process gains importance. Certainly, sprawl process is driven by a multitude of activities involving planning policies and regulation, governance structures, population dynamics, economic activities, ongoing and future development prospects, etc. In these circumstances, the dynamics manifested by the interaction of these entities would result in non-linear dynamics. Hence, capturing the dynamics would require different methods that are capable of synthesising the non-linearities in the system. However, it will be certainly interesting to address whether development of outgrowths follow planning or vice versa.

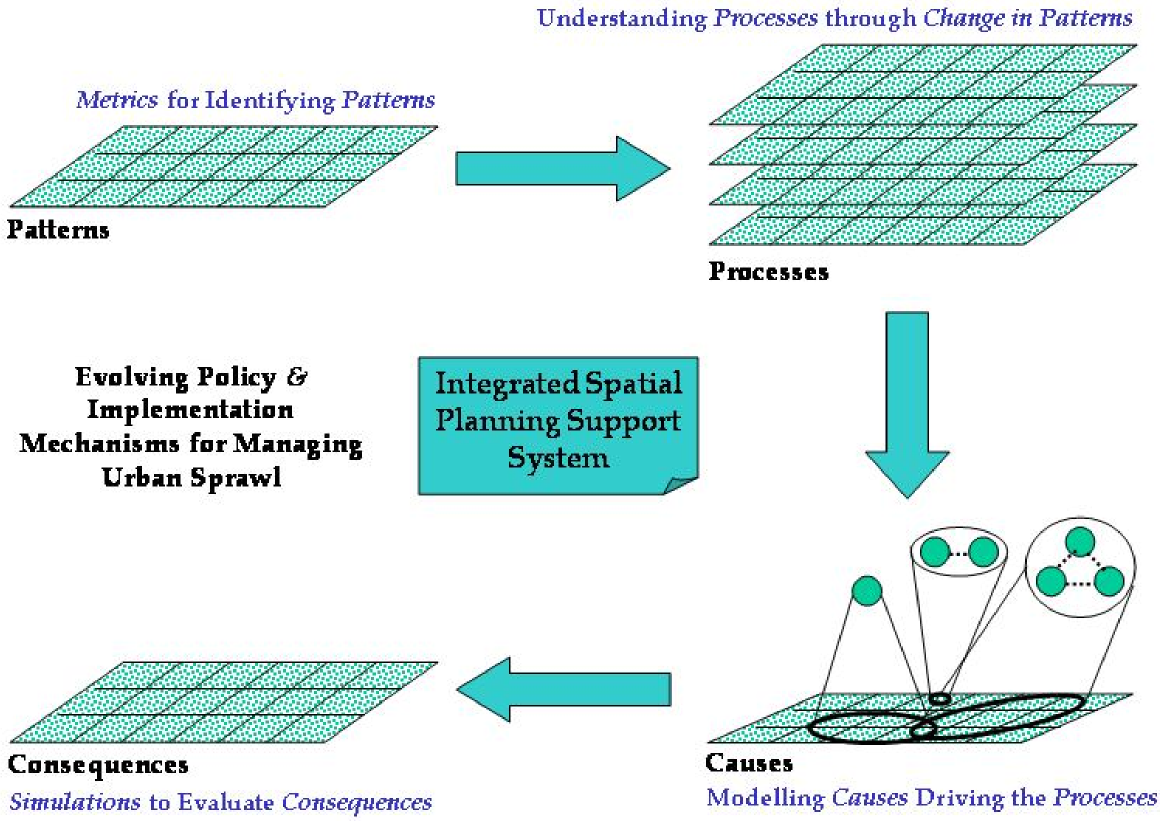

Figure 1-1: Research framework

However, with the challenges for sustainable urbanisation, urban planning and governance needs insights on the policy levers that can aid in addressing them. From the integrated study based on characterising sprawl, understanding of the process and causes, it is envisaged that the dynamic land-use model can facilitate as a spatial planning support system that can aid in choosing, evaluating, testing and visualising different scenarios based on the policy options. Thus, aiding in outlining the policy options for enhancing the level of services and managing the outgrowth in urban areas.

Based on the above discussions, there are five major emerging research questions:

1. How to characterise urban sprawl?
2. What are the processes involved and causes responsible for urban sprawl?
3. How do we design a spatial planning support system?
4. What will be the consequences of urban sprawl?
5. What are the policy options for managing urban sprawl?

1.5 Research Objectives

The main objective of this research is to investigate the dynamics responsible for causing urban sprawl so that this knowledge will aid in managing and mitigating urban sprawl with the larger objective of designing a spatial planning support system for achieving sustainable urbanisation. A key requirement to understand these dynamics is to identify the sprawl through appropriate metrics or indicators. The subsequent objective of this research is to develop an integrated spatial planning support system, which would aid in visualisation of urban sprawl by capturing the dynamics of causal factors through investigations of the nature and pattern of the urban sprawl on temporal and spatial scales. This would aid as a policy tool and aid in management for mitigating impacts of urban sprawl. In order to realise this, the specific objectives are:

1. To evolve appropriate metrics to characterise the urban sprawl.

2. To determine the different drivers and causal factors responsible for sprawl and establish the linkages (model) for Bangalore city.

3. To design an SPSS (Spatial Planning Support System) to evaluate and review policy options in order to recommend appropriate policy and management solutions.

1.6 Scope of the Study

The present thesis aims to address the problem of urban sprawl in the perspective of a developing country with Bangalore city as the case under investigation. In the recent years, Bangalore has seen unprecedented growth spatially and economically leading to sprawl. It is in this setting that the present study aims to address the problem of sprawl in Bangalore.

1.7 Structure of the Thesis

The thesis addresses the problem of urban sprawl with an interdisciplinary perspective. In the second chapter, a theoretical framework is presented. The subsequent chapter presents the urban setting of Bangalore and provides an overview of the urban fabric, discussing various prospects related to infrastructure and governance while outlining the challenges in planning and governance for the city. In the next chapter, the pattern of urban sprawl is discussed by presenting the spatial metrics and indicators for quantifying urban sprawl. The fifth chapter on process and causes capture the dynamics of urban sprawl using system dynamics and agent-based models. With an understanding of patterns, processes and causes, the design of spatial planning support system is evolved in the sixth chapter to evaluate the consequences. This chapter also evaluates for certain policy options and analyses to arrive at appropriate policy recommendations for managing urban sprawl. The final chapter concludes with the summary of the research and recommendations for future work while outlining the remaining challenges in managing urban sprawl.

1.8 Summary

This chapter presented the concept of urban sprawl, where the aspects of urban growth and urbanisation were distinguished. Considering the origin of towns and cities, the chapter reviewed literature concerning urban studies in general and sprawl in particular carried out in developed countries and in India as well. The need for characterising sprawl through patterns, capturing the dynamics to understand processes and causes, and the need for an integrated spatial planning support system to evaluate the consequences were discussed.

II. Dynamics of Urban Sprawl: A Theoretical Framework

2.1 Understanding the Dynamics

The interactions among numerous entities and sub-systems in the urban systems generate complex dynamics that can be often intractable in comprehension and too terse as a system of equations. At an aggregate level, the effects of the dynamics are evident from the growth of urban centres by the rise in city size and its spatial extent. At the level of a particular urban centre, the dynamics are evident from the varying socio-political settings, economic activities and resource usages. It is of special interest to study these dynamics to understand if they depict any underlying pattern and process in the course of their evolution. At least three time scales have to be considered for describing the main processes of evolution of urban systems (Pumain, 2004):

1. the short time process of innovation and competition, as it may be seen at the actor level,

2. the mean time – usually a few decades – process of specialisation as related to economic cycles at the level of each town and city, and

3. the long time process of the emergence and slow transformation of the urban hierarchy – in general, several centuries – at the level of the whole system of cities.

The study on dynamics of urban systems is attempted by acknowledging the effect of scale. In the short time process, the interactions of actors and the activities in urban areas generate dynamics within the city, influencing travel times, market dynamics, etc. At the actor level, the choice and allocation of requisite proportion of resources especially in urban governance evolves as a consequence of these interactions. In the mean time (near to short-term), the consequences of the dynamics are evident by change in land-uses, like reduction in open spaces and green-cover, change in pollution levels, etc. Further, the evolution of towns and cities are studied in the mean time scale over years ranging from decades to a century. The rise in size of towns and cities in terms of population and its spatial extent are important determinants of urban growth in this scale. The analysis in the long-time process is not attempted due to unavailability of appropriate data ranging over several centuries.

In this chapter, we first put forward the proposition of organic urbanisation as an evolutionary process. This is studied and empirically supported by analysis of urban evolution in Karnataka State over the last century. Subsequently, we present a theoretical framework for explaining sprawl (spatial expansion) through the process of land-use change in the mean time scale. A simple model to describe the process of land-use change considering the drivers is presented. The theoretical framework sets the context for analysing the interaction of level of services on the one hand and the extent of outgrowth on the other influenced by planning. It is hypothesised that planning and governance affects the evolution of city.

2.2 The Concept of Organic Urbanisation

The concept of organic urbanisation is ascribed to the natural increase in the proportion of urban population to that of the total population, chiefly induced by migration complimented by unplanned development of outgrowth of urban areas. It is also referred as the organic growth of cities and its outgrowth lacking any planned delivery of urban services along with requisite infrastructure and amenities. In the developing economies, it is an immense challenge to manage the organic growth of cities experiencing rapid urbanisation. For the developed economies, as noted earlier in chapter 1.3.1, urbanisation followed after industrialisation thus paving scope for managing the urban areas better. However, in the developing economies, where urbanisation is taking place prior to industrialisation, planning for urbanisation has compounded the task due to several problems arising in densely populated urban areas from lack of adequate housing and access to basic services. If governments plan for urbanisation, the organic growth of urban areas can be managed better.

However, it can be noted that the process of urbanisation without industrialisation need not be confused with organic urbanisation. Even without industrialisation there can be planned urbanisation by way of provision of services and infrastructure to accommodate the influx of population to these urban centres. Yet, the larger challenge for improving the level of services in organically grown urban areas remains.

In the process of urbanisation, many villages get absorbed into towns and cities or certain villages grow into towns and emerge as cities. In this context, the evolution of towns and cities can be explained in the backdrop of two contrasting schools of thought: one that contends that villages evolved gradually into the emergence of towns and cities whereas the other argues that cities gradually emerged by engulfing nearby villages. Whatever the case may be, it is an important question to understand how and why only certain towns evolve into larger cities.

Initiating this debate in a more authoritative and assertive manner, Jacobs (1969) put forth two propositions: one in the field of archaeology and the other in economics. Traditional archaeologists had always presumed that a city could only appear where there was enough food for a great number of inhabitants not producing food exclusively to exist. Hence, agriculture logically preceded the city. Jacobs argued that the opposite is true. It is through trade in wild animals and grains that people in cities discovered agriculture and then exported it (like modern factory towns) to the outskirts of the city itself. While the argument is debatable, a key aspect that drives it is that the city's economy supports agriculture in the neighbourhood and agriculture does not drive the city's economy. With the evolution and growth of cities and their economies, the city’s economies aid and sustain the other sectors interlinked with its mainstream. The mainstream urban economy sustains on trade, commerce, manufacturing or any other services. Jacobs also tackles the question of economic booms noting that flourishing economies have had one of these economic booms. She asserts that it is through import replacement that cities have such economic growth. It is argued that cities are at the root of all economic growth (agricultural, manufacturing, technology, information, etc.) and therefore import replacement is the cause to all economic growth. A classical example cited in this context is that that innovation and creativity for better farm equipments (tractors, machinery, etc.) and fertilisers all happened in cities than in villages!

2.2.1 Organic Urbanisation as an Evolutionary Process

The proposition put forward here is that towns and cities have evolved due to organic urbanisation than planned urbanisation. In the organic urbanisation cities engulf neighbouring villages and small towns, resulting in the formation of larger urban agglomerations due to urbanisation. Urbanisation in India has been never as rapid as it is in the recent times. In India, urban population is currently growing at around 2.3 percent per annum. The number of urban agglomerations and towns in India has increased from 3697 in 1991 to 4369 in 2001. It is projected that the country’s urban population would increase from 28.3 percent in 2003 to about 41.4 percent by 2030 (United Nations, 2004). An increased urban population and growth in urban areas is inadvertent with population growth and migration. By 2001, there were 35 urban agglomerations / cities having a population of more than one million from 25 urban agglomerations in 1991. Of the 4000 plus urban agglomerations, about 38 percent reside in just 35 urban areas, thus indicating the magnitude of urbanisation prevailing in the country. In India, the towns and cities are classified based on their sizes as depicted in Table 2-1.

Table 2-1: Classification of towns by size class

Class	Population size
I	100,000 & above
II	50,000 to 99,999
III	20,000 to 49,999
IV	10,000 to 19,999
V	5,000 to 9,999
VI	Less than 5,000

Analysis on the growth of number of towns (Figure 2-1) and the percentage of urban population (Figure 2-2) in these, based on size classes, reveals the nature of urbanisation taking place in the country (Table 2-2). In 1901, there were only 24 towns in class I and by 1951 it increased to 76— a little more than three times. However, by 2001 the number of class I towns rose to 393. Among the different size classes, the towns within class III and IV saw the highest growth from 130 and 391 in 1901 to 1151 and 1344 in 2001 respectively. The decline in size classes was found in class V and VI. The decreasing trend of number of towns in class V and VI suggests that perhaps only fewer new small towns emerged. The shift in numbers is also evident by the swelling in numbers of larger towns with class III and IV. Interestingly the number of towns with class I and II have only grown moderately.

The growth in number of towns across different size classes depicts the evolution of urban settlements in the country. However, the percentage of urban population in these towns represents their distribution. Figure 2-2 depicts the growth in percentage of urban population by different size classes. It reveals that as much as 68.6 percent of urban population lived only in class I towns by 2001 as against 26 percent in 1901. This suggests the concentration of urbanisation in a few cities than other larger towns. In spite of the marked growth in the number of class III and IV towns, they harboured only 19 percent of the urban population. The evolution of towns across different size classes and the concentration of population in class I towns alone characterises organic urbanisation prevailing in the country. The rise in concentrations by engulfing of neighbouring towns and villages, and outgrowths has indeed spurred the concentration in the top 20 cities / urban agglomerations of the country. It is this rise in concentration accommodating the in-migrant population and engulfing neighbouring towns and villages, which are driving the city's expansion leading to agglomerations (Figure 2-3).

Table 2-2: Growth in number of towns and percentage of urban population by size class

	Number of Towns by size class										
Class	1901	1911	1921	1931	1941	1951	1961	1971	1981	1991	2001
I	24	23	29	35	49	76	102	148	218	300	393
II	43	40	45	56	74	91	129	173	270	345	401
III	130	135	145	183	242	327	437	558	743	947	1151
IV	391	364	370	434	498	608	719	827	1059	1167	1344
V	744	707	734	800	920	1124	711	623	758	740	888
VI	479	485	571	509	407	569	172	147	253	197	191
Total	1811	1754	1894	2017	2190	2795	2270	2476	3301	3696	4368
Class	Percentage of urban population by size class										
I	26	27.4	29.7	31.2	38.2	44.6	51.4	57.2	60.3	65.2	68.6
II	11.2	10.5	10.3	11.6	11.4	9.9	11.2	10.9	11.6	10.9	9.67
III	15.60	16.4	15.9	16.8	16.3	15.7	16.9	16	14.3	13.1	12.2
IV	20.8	19.7	18.2	18	15.7	13.6	12.7	10.9	9.5	7.7	6.8
V	20.1	19.3	18.6	17.1	15	12.9	6.8	4.4	3.5	2.6	2.3
VI	6.1	6.5	7	5.2	3.1	3.1	0.7	0.4	0.5	0.3	0.2

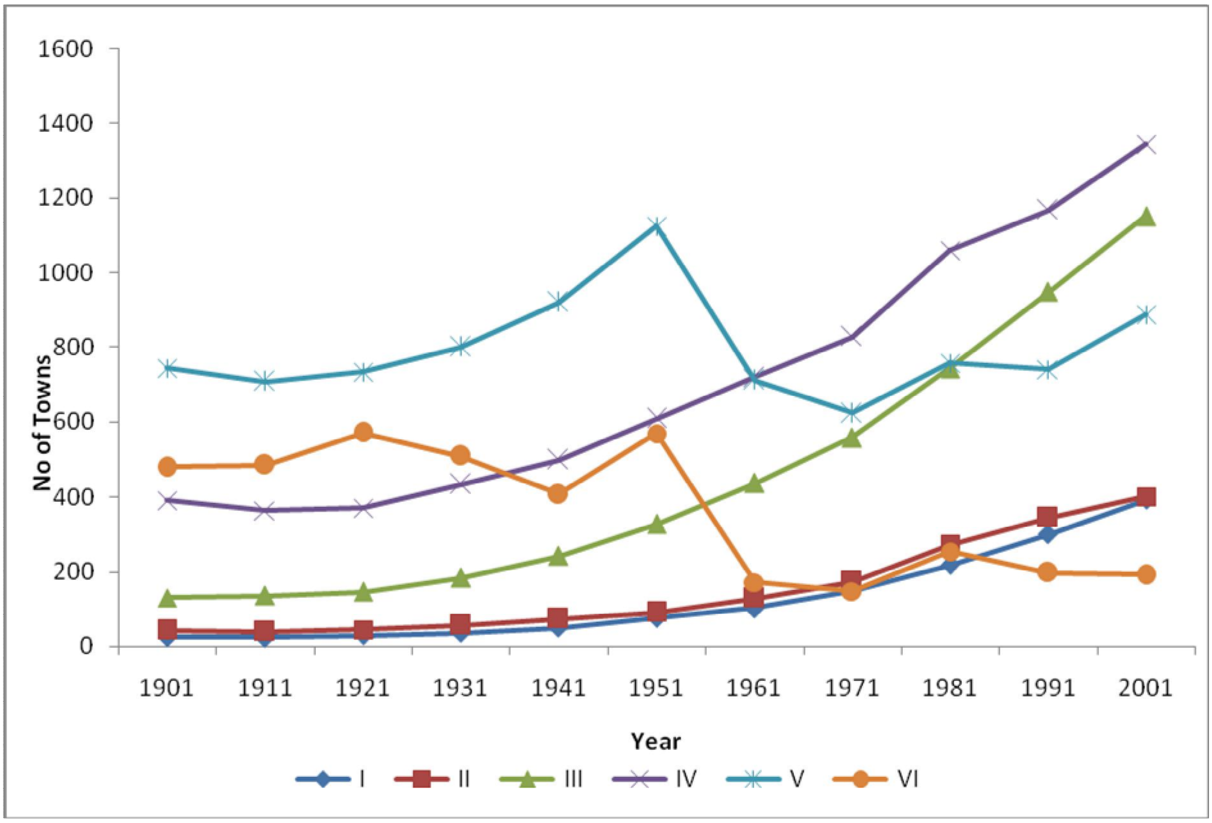

Figure 2-1: Growth in number of towns by size class

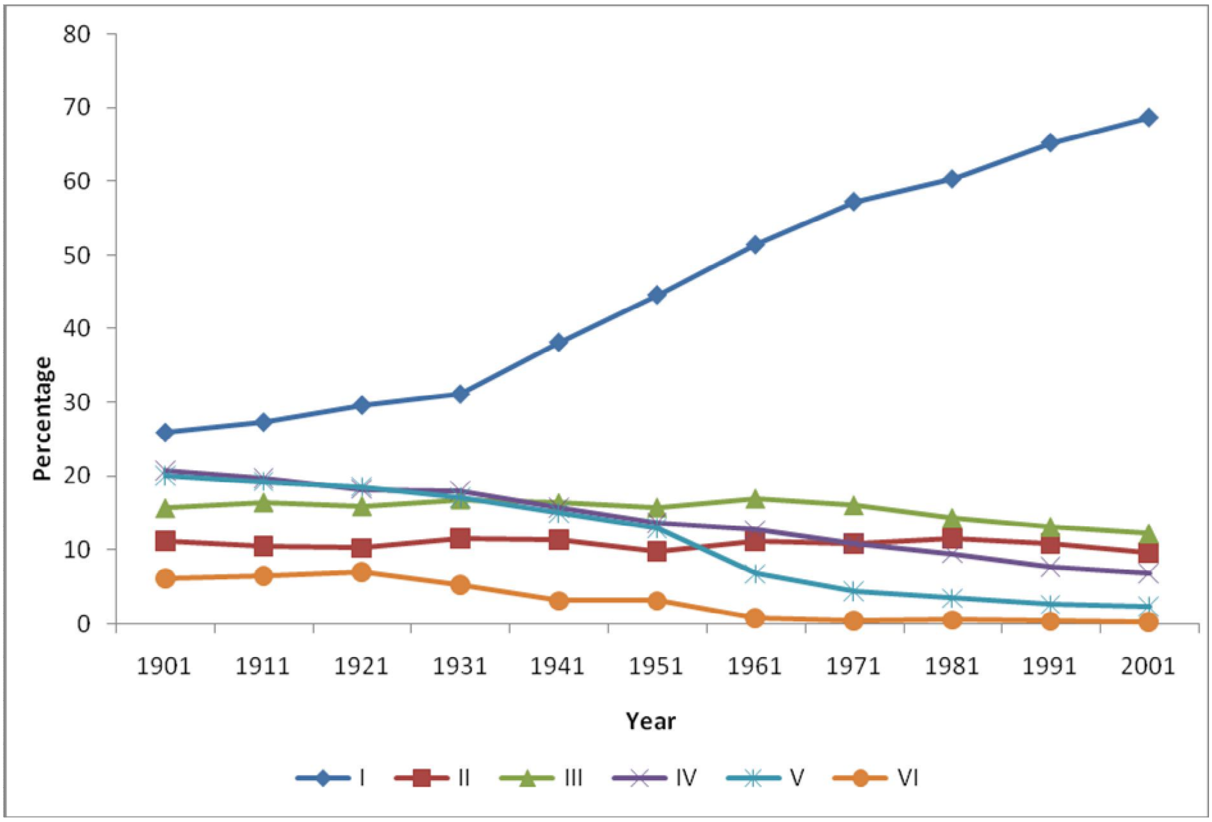

Figure 2-2: Growth in percentage of urban population by size class

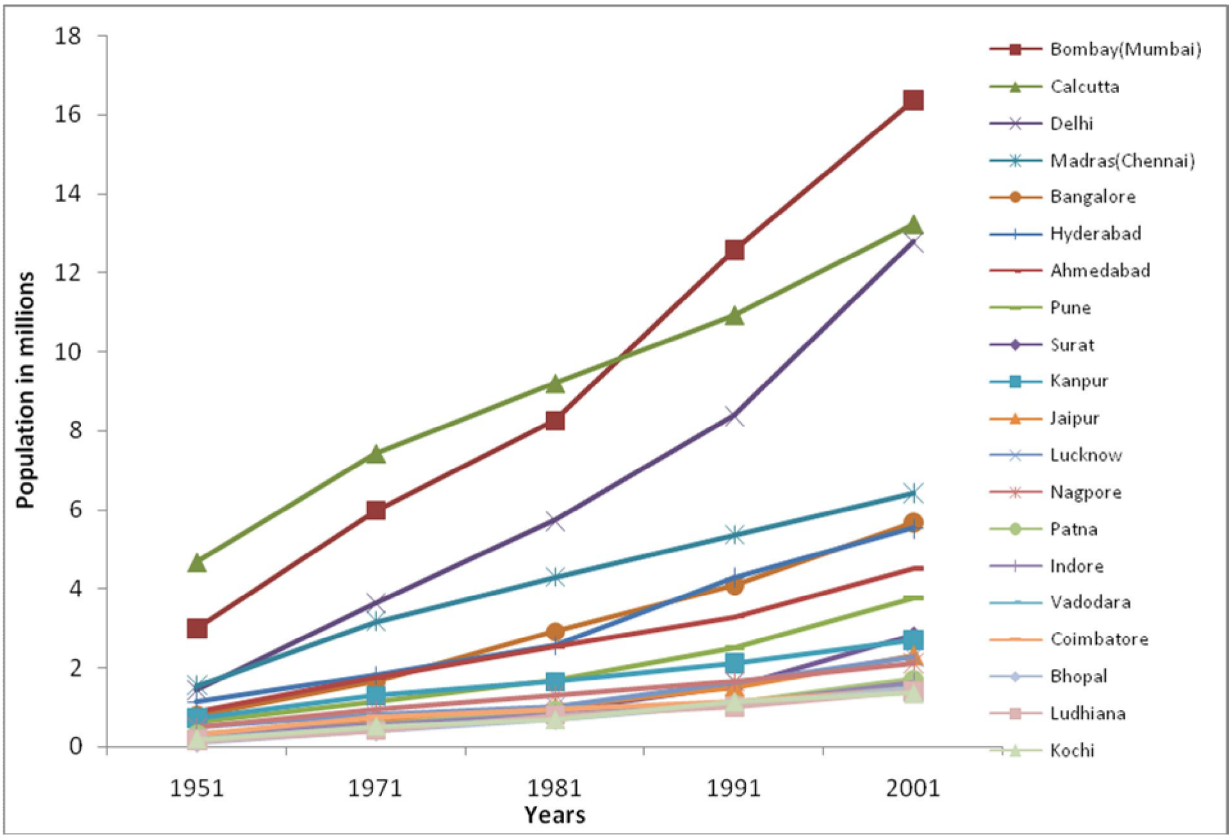

Figure 2-3: Growth in population among top 20 cities and urban agglomerations based on 2001 census

2.2.2 Dynamics of City-Size Distributions

The evolution of towns into cities and urban agglomerations raises interest in exploring any possible underlying pattern in the course of organic urbanisation. The hierarchical organisation of societies (towns and cities) by their city-size distributions confirming to some of the scaling laws as in biological systems, has been well studied. There is already considerable treatment on the applicability of scaling laws in urban systems and ranking of the organisation of societies (Fujita *et al.*, 1999; Gabaix, 1999; Gabaix and Ioannides, 2003; Batty, 2004; Pumain, 2004; Batty 2007).

i. Zipf's Law

One of the intriguing empirical facts in social sciences and economics is Zipf's law for cities. Zipf had noted the regularity as an inverse geometric progression between the population P_i of a city and its rank R_i in a national set of towns and cities, giving an approximate size of one half of the largest city population for the population of the second city and one third for the third one, and so on. This "rank size-rule" formulated as $P_i = P_1 / R_i$ has been generalised as a

Pareto-type distribution of the number of cities according to their size, $P_i = K / R_i \alpha$, where the parameter K has a value close to P_1 and α is around 1.

From the available literature, it is now evident that this model has been fitted many times to more or less correctly measured population series of towns and cities. Typically, the estimated values for the parameter ranges between 0.7 and 1.3 for the population of the urban agglomerations (towns and cities over 10,000 inhabitants) of each state in the world. Pumain (2004) remarks on the ill-founded conclusions based on Zipf's law mainly due to small samples of observations and a lack of accuracy in empirical data. However, Fletscher (1986, In: Pumain, 2004) has demonstrated based on the data for early settlements that whatever the part of the world and the period of observation, since the 10,000 years when towns first emerged, the model of settlement size distribution have always been reasonably well approximated by a Pareto or log-normal distribution.

Pumain (2004) further notes that often, the upper part of the size distribution, corresponding to the largest urban settlements, does not fit very well to any model. These cases of urban primacy (one to up to eight cities per state whose size exceeds the expected values) seem to be a generality rather than an exception. When this 'primacy index' is computed, as the ratio between the population of the largest and second largest city, it is found that in most states of the world it is much larger than the value of two, which would correspond to Zipf's rank size rule and the mean value for all countries of the world taken together is 5.2. The confirmation to the rank-size model (Zipf's law) is also true for the top cities in India, almost mysteriously, similar to most other nations of the world (Pumain, 2004).

The Zipf's law or the rank-size rule states that when logarithm of ranks and corresponding city sizes are plotted on a log-log plot, they would fit a straight line. In other words,

$$\mathbf{ln\ (rank) = P_k - \alpha\ ln\ (city\ size)} \qquad \textbf{…Equation 1}$$

with high R^2, where P_k is the population of the city with highest population (Gabaix, 1999).

An attempt to analyse the city-size distribution of towns and cities in Karnataka was made to validate the Zipf's law. The State of Karnataka is one of the most urbanised states in India with 34 percent urban population. The analysis was carried out for the duration of 1901-2001, decadal census data. The model is estimated through the least squares method.

Accordingly, the model was estimated in the form of Equation 1, which indeed revealed a high R^2 and increasing α (Table 2-3).

The analysis conforms to the Zipf's law, similar to other empirical studies pertaining to other nations and verifies the prevalence of characteristic scaling behaviour in urban systems (Gabaix, 1999). Gabaix (1999) and Pumain (2004) have separately offered explanations for the presence of scaling effects in urban systems, yet, the implications from scaling behaviour with respect to the organisation of human societies in structurally similar pattern as observed in different places irrespective of their geographic boundaries, political boundaries and political economies raises many questions.

Table 2-3: Estimates for rank-size distribution model to towns and cities of Karnataka

Year	α	R^2	P_k	P_1
1901	0.83	0.93	177976	163091
1911	0.85	0.92	181396	189485
1921	0.85	0.95	209419	240054
1931	0.85	0.96	243477	309785
1941	0.88	0.95	333558	410967
1951	0.87	0.97	462989	786343
1961	0.90	0.97	619737	1206961
1971	0.92	0.94	895520	1664208
1981	0.93	0.98	1294733	2921751
1991	0.96	0.98	1812023	4130288
2001	1.04	0.94	3002970	5686844

Note: P_k is the estimate of the population for the city with rank 1 (P_1)

Pumain (2004) asserts that the general structure of urban systems, including scaling effects is the result of social evolutionary processes: as in biological sciences, but in this case the evolution is also partly driven by a cognitive activity of inventing technical and social artefacts. However, the action of this organizing principle on the spatial structure of the urban systems is almost always indirect: especially at the level of the system of cities, as there is neither conscious will nor responsible institution for organising and adapting the system to ensure this increasing power of accessibility. The global structure and its more or less continuous adaptation are emerging from the interurban competition.

It is intriguing to note that Bangalore (5,686,844) which emerged as the largest city had taken the lead by almost 8 times from its nearest contenders (Hubli-Dharwad with 786,018 and Mysore with 785,800). The evolving primacy index (Figure 2-4) is a cause of concern in the State of Karnataka indicating the increasing urban hierarchy. Despite this indicating the magnitude of concentrated growth and urban primacy (since $\alpha > 1$), a consequence of such a process has led to urban sprawl. In the context of organic urbanisation, the presence of scaling effect and the rise in urban primacy as a social evolutionary process also suggests the probable trend in this direction. While the analysis on organic urbanisation is presented in the mean-time scale, we also present the framework for land-use change in the mean-time scale considering certain actors with the extent of city's outgrowth. An imminent urban sprawl driven by the forces of urbanisation and globalisation also throws significant challenges in governance and sustainability.

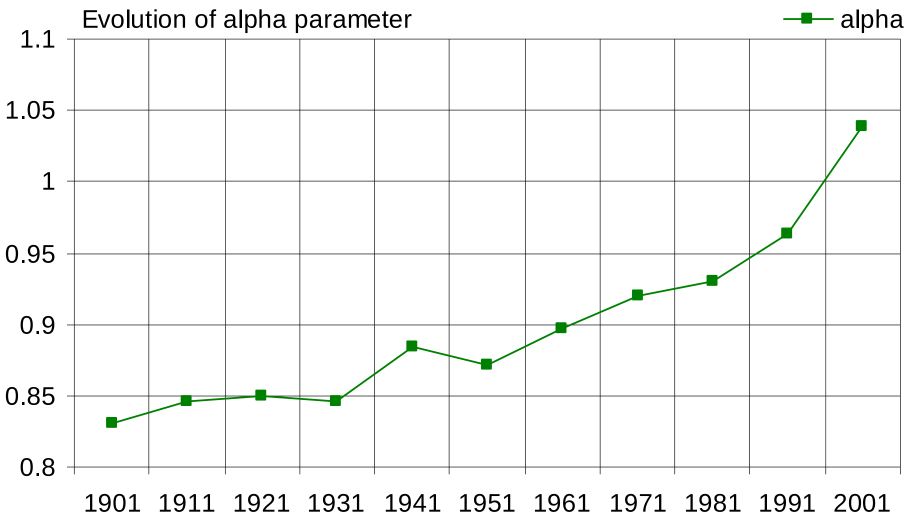

Figure 2-4: Evolution of alpha parameter for towns and cities in Karnataka

2.3 Urban Sprawl as a Process of Land-use Change

With the background on evolution of towns and cities especially in the context of organic urbanisation, we explore the linkages with actors like governance and planning, and its influence on the extent of outgrowth. In India, urban areas contribute significantly to the national economy (about 50 to 60 percent of gross domestic product), while facing critical challenges in ensuring access to basic services and necessary infrastructure, both social and economic. The overall rise in population of urban poor or increase in travel times owing to congestion in road networks are indicators of the performance of planning and governance in assessing and catering to the demand. Agencies of governance at all levels: local bodies, State and Central governments are facing the brunt of this rapid urban growth. It is imperative for planning and governance to systematically facilitate, augment and service the requisite infrastructure over time. Provision of infrastructure and ensuring delivery of basic services cannot happen overnight and hence planning has to facilitate in forecasting and provisioning these services with appropriate mechanisms.

2.3.1 Governance Structures

The urban governance is characterised by an urban local body and numerous parastatal agencies responsible for delivery of services and ensuring access to basic amenities and infrastructure. On the supply side, the urban local body along with the parastatal agencies is responsible for allocating resources to the residents and create a favourable ecosystem for conducting the businesses. In a typical case, the urban local body being the elected body has the greater onus and powers to administer, plan and regulate the delivery of services and allocation of resources. Chapter 1.2.1 has also dealt on prevailing urban governance structures in the country.

However, a strange paradigm that exists in the country is the presence of a large number of *Parastatal* organisations. Although the *Parastatal* are primarily responsible for the delivery of services and ensuring access to resources, they are not directly answerable to the citizens, but only to the State government. Since, they are managed by the State government the urban local bodies have little say in the function of these bodies while the actions of the *Parastatal* directly affect other stakeholders of the city.

Constitutionally, the urban local bodies are supposed to be vested with adequate powers and mechanisms to carry out all the functions and activities the parastatal organisations are currently undertaking. In most large urban local bodies, the State has not devolved adequate powers to these bodies and thus manages the activities through creation of parastatal organisations. In certain cities, with the dissolution of the body of elected representatives, the State government is wresting control over the same. Eventually, the State government assumes the role of planning and governing the city. Although the governance by the locally elected body is absent, nevertheless, the urban local body has the primary responsibility to deliver basic amenities and ensure access to resources and infrastructure.

The level of service assesses the access to essential services and amenities. This also comprises provision of certain infrastructure like outer ring roads, residential development, etc. The level of service, access to infrastructure and other amenities are measured based on a household survey across the region discussed in the fourth chapter.

2.3.2 Planning Matters

Planning refers to the process of formulating the roadmap towards achieving the objectives for promoting development. The specifics of planning vary with the desired goals of separate nation states. Normally, planning refers to the prevalent land-use planning or spatial planning as practiced by the State. However, planning also concerns the formulation of policies and programs towards economic development, apart from land-use planning for promoting sustainable urban development. In the context of sprawl, land-use planning plays a very important role in limiting the extent of outgrowth by zoning and notifying areas for future growth. The forecast and allocation of land-uses to the expected demand for housing, industrial, commercial, and retaining open spaces are considered in land-use zoning. Thus, planning here restricts to land-use planning only. However, the effectiveness of land-use planning in its effort to manage urban sprawl rests on the goals of planning and policies therein. Noting the importance of land-use planning, the State or city governments either own planning functions or facilitate appropriate organisation structure to oversee that. The performance of planning can be measured by the presence of formal structures (with or without State capture), publication of master plans (process of preparation, periodicity of publication and its enforcement) and community participation in planning.

With the presence of parastatal planning agencies formally called as Development Authorities, planning function too is in a situation of State-capture. However, in certain cities, the functions of water supply and sanitation rests with the urban local body, but for the rest, they are with parastatal agencies.

2.3.3 Extent of Outgrowth (Sprawl)

The extent of outgrowth or the sprawl is measured primarily through the amount of paved surface extending beyond the municipal boundaries. There are now various metrics to characterise sprawl, which are discussed in the next chapter. In the recent times, the extent of outgrowth has been also fuelled by speculative land market dynamics in the periphery of the city. The outgrowth beyond the municipal limits are also aided by minimal or no restrictions on building guidelines. Thus, the outgrowths are marked by the process of land-use changes. However, it is important to characterise these outgrowth and forecast such outgrowth by the local governments to systematically ensure the delivery of services and attempt planned development in these regions.

2.4 Framework for Process of Land-use Change

Development of suburbs because of increased population growth and infrastructure facilities around the cities is a well-established reasoning for urban sprawl. The key aspect surrounding urban sprawl is the extent of outgrowth around the periphery of the city or along the highways, which is factored by land-use change, the level of services and access to basic services and amenities in these areas. We analyse three important variables: planning, governance (level of service) and extent of outgrowth.

We categorise these different aspects in order to emphasise the role of planning and governance in addressing urban sprawl (Figure 2-5). In this diagram, two are outcomes (level of service and extent of outgrowth) while the key input is planning, depicted along the diagonal. With this diagram, we define testable hypothesis on the effectiveness of planning and governance to either contain the outgrowth or deliver the requisite level of services to the citizens through provision for basic amenities and infrastructure. The hypotheses to be tested are as follows:

- Planning and Governance are critical: Is it possible for a city without effective planning to deliver desirable level of services and contain the outgrowth? Importantly, would a compact city necessarily require good planning for delivery of desirable level of services? We hypothesise that city's planning and governance are critical for ensuring the delivery of desirable level of services and containing outgrowth.

- Extent of outgrowth and level of services interact: With a sound planning the city should be able to limit the outgrowth and ensure desirable level of services. However, good planning can accommodate phased growth, which would in turn facilitate good level of governance. Does the level of services either by provision of amenities or infrastructure (like outer ring road) with limited planning capabilities fuel more sprawl? With provision of outer ring road and poor planning and governance, the city would spread beyond the periphery of these ring roads.

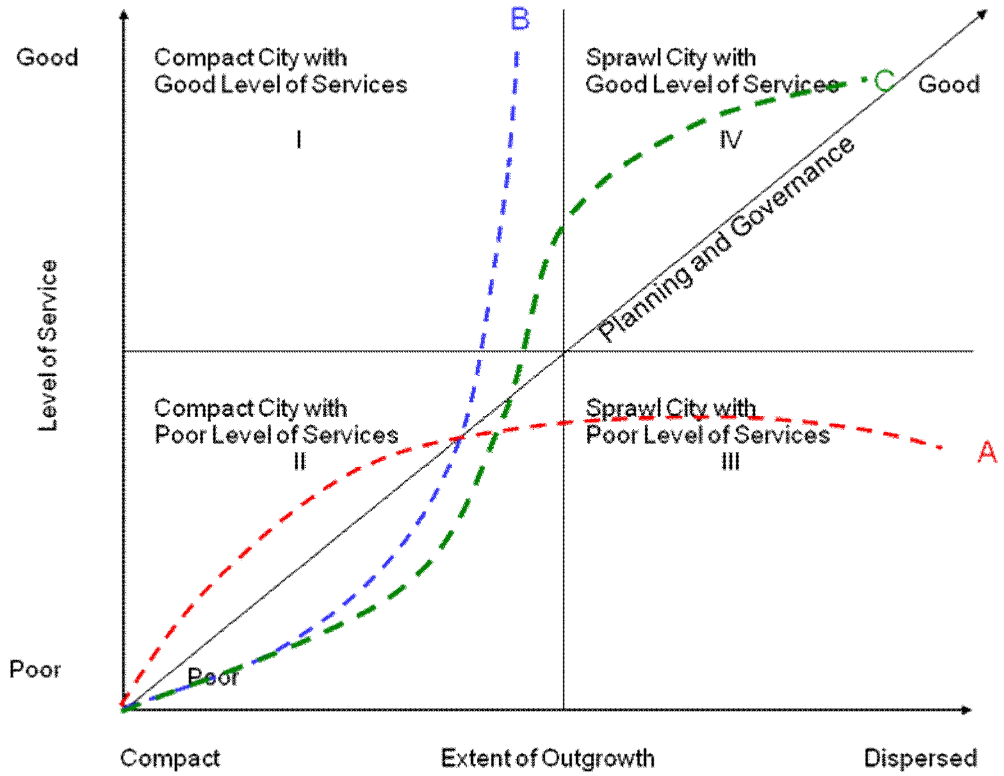

Figure 2-5: Extent of outgrowth and level of service as outcome of planning and governance

2.4.1 Trajectories of Possible Urban Evolution

In the framework presented in Figure 2-5, there can be four possible states for cities:

I. Compact city with good level of services

II. Compact city with poor level of services

III. Sprawl city with poor level of services

IV. Sprawl city with good level of services

It is obvious to note that most cities would fall in any one of the four states. Accordingly, during the evolution of cities, cities may target reaching the states I or IV. There can also be three possible trajectories of urban evolution: A, B and C, as depicted in Figure 2-5. In trajectory A, a city would evolve with dispersed growth, which can lead to poor level of services with limited planning and governance. The city would have managed to grow with limited planning capabilities resulting in the delivery of services lesser than the desirable levels. A city can evolve with compact growth while ensuring desired level of services aided by sound planning and governance as seen in trajectory B. A city can also evolve according to trajectory C, allowing for outgrowth with delivery of desirable services augmented by planning for the new developed regions. Balachandran and Haran (2008) have pointed the distinction of planning following development for cities of Bangalore and Hyderabad, while development followed by planning is evinced in Ahmedabad.

2.5 Summary

The extent of outgrowth (or the sprawl) is factored by the process of land-use change. Hence, the model specified above for land-use change corresponds to the evolution of city. This chapter first presented the concept of organic urbanisation from a macro perspective. This was supported by the analysis confirming the characteristic scaling behaviour demonstrated by towns and cities in Karnataka due to scaling. Then the theoretical framework for explaining sprawl (spatial expansion) through the process of land-use change as a function of planning and governance is presented. The theoretical framework sets the context for analysing the interaction of level of services on the one hand and the extent of outgrowth on the other. The key argument put forward is how planning and governance affect the evolution of a city.

III. Study Area: Bangalore, India

3.1 General

Bangalore[1] is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka. Greater Bangalore[2], an area of 741 square kilometres agglomerating the city, neighbouring municipal councils and outgrowths, was 'notified' (established) in December 2006 (Map 1). A tiny village in the 12th century, it grew to become one of the fastest growing cities in the world by the 21st century and to figure among the million-plus (in population) cities in India[3]. Bangalore has grown spatially to more than ten times since 1949 (Table 3-1). The city enjoys a pleasant and salubrious climate throughout the year. Its tree-lined streets, numerous parks and abundant greenery have led to it being called the 'Garden City' of India. It has also been identified as the country's 'Silicon Valley' and it is one of the technological innovation hubs with a score of 13 out of a maximum of 16[4] (United Nations Development Programme, 2001). However, with all the hype about growth in IT and IT based industries, Bangalore also houses numerous other leading commercial and educational institutions, and industries like textiles, aviation, space, biotechnology, etc. As an immediate consequence of this growth in the last decade, apart from creating a ripple effect in the local economy, there has also been great pressure on infrastructure and resources like water supply, energy, public transportation, land, etc. The local body and other parastatal agencies responsible for delivery of basic services are facing stiff challenges in catering to this demand.

Quite recently there have been serious attempts by sociologists and urban planners to characterise the city. Heitzman (2004) has analysed the nature of growth that the city experienced with the emergence of the information society, while bringing out the ingredients that led to the transformation of planning methodologies and spatial planning tools for the city.

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[1] The name, Bangalore has been proposed for renaming to 'Bengalooru' by the State government following suit of Bombay to Mumbai, Madras to Chennai and Calcutta to Kolkota. However, 'Bangalore' will be used all through.

[2] The Urban Development Department, Government of Karnataka has issued gazette notification vide No. UDD/92/MNY/2006, dated 2.11.2006 for constituting the Bruhat Bangalore Mahanagara Palike (Greater Bangalore City Corporation) merging the existing area of Bangalore City Corporation, 8 Urban Local Bodies (ULBs) and 111 Villages of Bangalore Urban District.

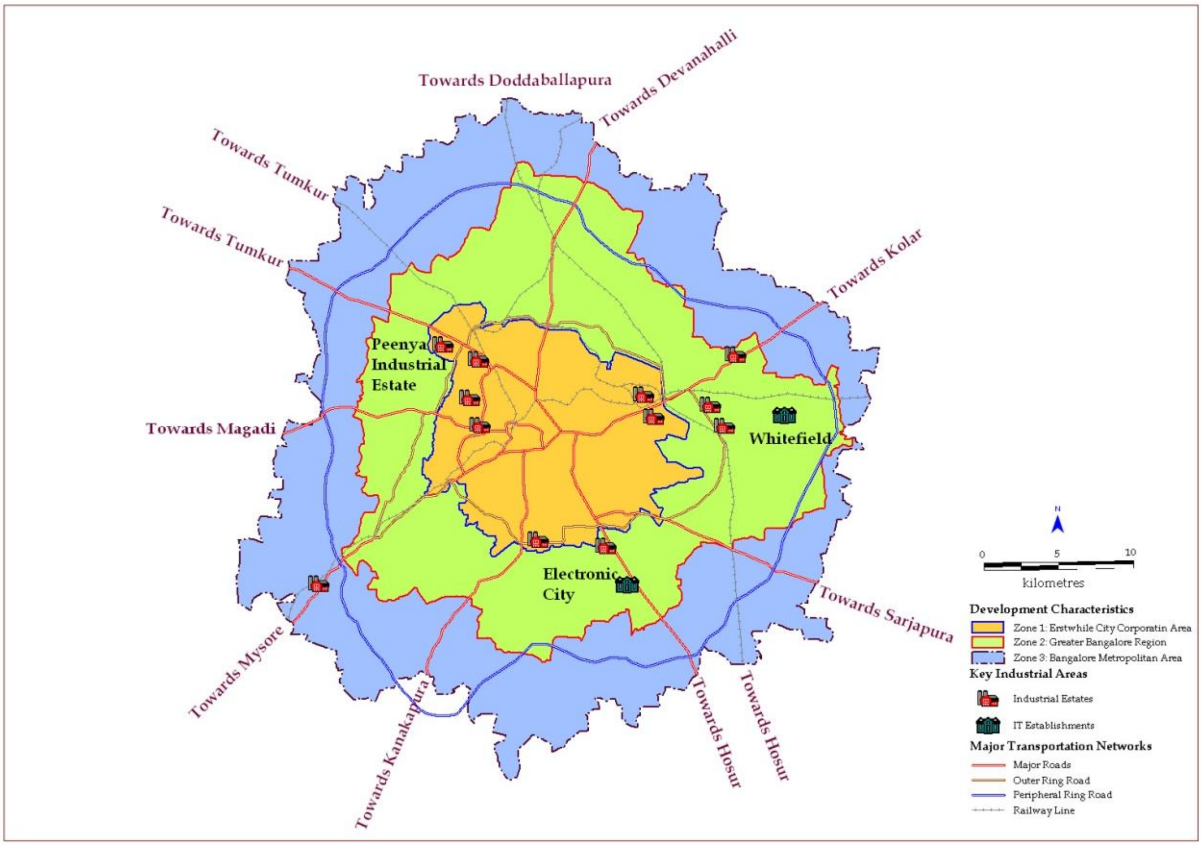
[3] Bangalore is the fifth largest metropolis in India currently with a population of about 7 million.

[4] Almost on par with San Francisco (USA), while Silicon Valley (USA) is number 1 with a score of 16.

Nair (2005) has exemplified Bangalore as ‘the promise of the metropolis’ while illustrating the urban fabric of Bangalore over the last century. In this chapter, an attempt is made to bring out the status of current infrastructure and various facets of planning and governance.

Table 3-1: Bangalore City Corporation limits over the years

Year	Area (sq. km)
1949	69
1963-64	112
1969	134
1979	161
1995	226
2007	741



Map 1: Map depicts development characteristic over Bangalore with the erstwhile City Corporation limits, Greater Bangalore region and Bangalore Metropolitan Area and noting some of the prominent industrial areas

The next section deals with the origin and history of the city followed by a description of climate, geography and environment. The subsequent section considers culture, demography and economics. Lastly, the urban agenda addressing governance and infrastructure discussing the stakeholders involved, challenges in managing urban infrastructure and issues in planning and development are elaborated.

3.2 History and Culture

The earliest reference to the name, in the form '*Bengalooru*', is seen in a ninth century Ganga inscription (hero-stone) from Begur, referring to a battle that was fought in that place. The present name of the city, Bangalore is an anglicised form of *Bengalooru,* which according to the popular belief is derived from *Bengaalu* - synonymous of *Benda kaalu* or boiled beans and *ooru* meaning a town. Tradition associates Hoysala King Vira Ballala (12^{th} Century) with the origin of this name. Vira Ballala, during one of his hunting expeditions in this region, lost his way and after hours of wandering reached the hut of an old woman. This woman is believed to have offered cooked beans to the king. Pleased with her hospitality, the king named the place as 'benda kaala ooru' (town of boiled beans). But it is interesting to note that there was already evidence for name of the place much before Hoysalas. Kamath (1990) notes that Bangalore is said to have got its name from benga, the local Kannada language term for Pterocarpus marsupium, a species of dry and moist deciduous tree, and ooru, meaning town. However, the founding of modern Bangalore is attributed to Kempe Gowda, a scion of the Yelahanka line of chiefs, in 1537 (Kamath, 1990). Kempe Gowda is also credited with the construction of four towers (Figure 3-1) along four directions from Petta, the central part of the city, to demarcate the extent of city growth. By the 1960's the city had sprawled beyond these boundaries (Asian Development Bank, 2003).

Figure 3-1: The Kempe Gowda tower at Lalbagh – one of the four towers Kempe Gowda built to demarcate the extent of city growth in four directions. [Photo: H. S. Sudhira]

Later on, the city was administered by the Wodeyars, rulers of Mysore, until it was given as Jagir (with rights for general administration and collection of taxes) to Hyder Ali during late 18th Century. Hyder Ali and later, his son, Tippu Sultan, were responsible for the growth and development of Bangalore in a significant way with the construction of summer palace and Lalbagh. Indeed, Bangalore was already the commercial capital during Tippu's time and the second important city after 'Srirangapatna', Tippu's capital. During the early nineteenth century, the city was known to have almost all coins in circulation from different places and kingdoms, thus evidencing a flourishing trade and commerce (Buchanan, 1870). The fall of Bangalore in the Second Mysore War of 1792, may also have led to the fall of Tippu Sultan in Third Mysore War of 1799, after which Bangalore became a base for the British troops and saw the establishment of the Cantonment in 1802. British control over Bangalore was initially established indirectly through the Maharaja of Mysore. By 1831 the administration of the city was taken over by the British, and in 1862 two independent municipal boards were established: Bangalore City Municipality (in the older areas), and Bangalore Civil and Military Station Municipality. After Independence, Bangalore was notified as the capital of Mysore (now Karnataka) State. In 1949, the two municipalities were merged and the Bangalore City Corporation was formed. Subsequently, to keep up with the pace of growth and development, there have been reorganisations with respect to the zones and wards within the corporation, rising from 50 divisions in 1949 to 95 wards in 1980s, 100 wards in 1995 and now about 145 wards. With the 2006-07 notification, the Bangalore City Corporation is now reorganised as Greater Bangalore City Corporation (footnote # 2, pg. 44).

Bangalore, in spite of the buzz around IT-based and related commercial activities, has retained much of its unique cultural ties keeping its date with its history, culture and tradition. The city is known for historical temples such as the Someshwara temple in Halasuru (neighbourhood of Bangalore) built during 12th – 13th century by Cholas, Basavanagudi (Bull Temple) built by Kempe Gowda during 16th century, Kaadu Malleshwara temple built during 17th century in Dravidian architecture, and Gavi Gangadhareshwara temple, all nestled in the middle of the city. Apart from the numerous temples that have mushroomed around the city, Bangalore also has one of the six basilicas in the country, built during the 17th century, St. Mark's Cathedral built during 1808, the oldest mosque, Sangeen Jamia Masjid built by the Moghuls during the 17th century, and the popular Jamia Masjid near the City Market built during the 1940s. The 'Bengalooru Karaga' is a major annual fair associated with the Dharamaraya temple, is considered to be the actual fair of the erstwhile city, and is still persistent in the older central parts of the city. Karaga, a five-day festival of Tigalas, a community who migrated from Tamil Nadu, has many unique features such as intense religious fervour, strict rituals, unchanged traditions over centuries, a fixed route and stops for the procession, welcome and respect shown at all the temples on route. The annual groundnut fair, '*Kadalekai Parishe*' takes place in a part of old city, Basavanagudi (Figure 3-2), during November-December. More recently, an annual cultural fest called '*Bengalooru Habba*' ('*habba*' in Kannada means festival) is held during the first week of December hosting various cultural programmes like music, dance and drama. The involvement of all sections of people and the unique communal harmony displayed by the special prayer at Tawakkal Mastan Darga (mosque) are also remarkable (Chandramouli, 2002).

Figure 3-2: Groundnut Fair – an annual event, colloquially called “Kadelekai Parishe”, has helped Bangalore retain its cultural flavour. [Photo: N. Akash]

3.3 Geography and Environment

Bangalore is located at 12º 59’ north latitude and 77º 57’ east longitude, almost equidistant from both eastern and western coast of the South Indian peninsula, and is situated at an altitude of 920 metres above mean sea level. The mean annual total rainfall is about 880 mm with about 60 rainy days in a year considering the last ten years. The summer temperature ranges from 18° C to 38° C, while the winter temperature ranges from 12° C to 25° C. Thus, Bangalore enjoys a salubrious climate all round the year.

Bangalore is located over ridges delineating four watersheds, viz. Hebbal, Koramangala, Challaghatta and Vrishabhavathi. The undulating terrain in the region has facilitated creation of a large number of tanks providing for the traditional uses of irrigation, drinking, fishing and washing. Their creation is mainly attributed to the vision of Kempe Gowda and, later, to the Wodeyar dynasty. This led to Bangalore having hundreds of such water bodies through the centuries. Even in early second half of the 20th century, in 1961, the number of lakes and tanks in the city stood at 262. However, these tanks and open spaces were seriously affected with the enhanced demand for real estate and infrastructure consequent to urbanisation. Official figures for the current number of lakes and tanks vary from 117 to 81[5]. With the city's unprecedented growth, the large number of public open spaces diminished over the years. Much of the loss in green cover is due to the rapid change in land-use. As the city grew over space and time, inner areas got more crowded and congested. Initiatives to ease congestion on road networks have led to axing numerous road-side trees. Many lakes have been converted into residential layouts, bus stands, playgrounds and stadiums, etc. (Figure 3-3). The built-up area in the metropolitan was 16 % in 2000 and it is currently estimated to be around 23-24 %. The rest of the area is occupied either by agriculture lands, quarries or other vacant land.

In the aspect of nurturing flora and fauna, the situation in Bangalore is quite complex. With prominent green spaces like Lalbagh and Cubbon Park being situated almost at the city's centre, and a few water bodies such as Ulsoor, Sankey, Lalbagh, Yediyur and Madiwala lakes scattered across the city's landscape, the remaining green spaces in the periphery harbour a great number of species. In a compilation of fauna present in and around Bangalore within a radius of 40 km from the city centre (Karthikeyan, 1999), about 40 species of mammals, more than 340 species of birds, 38 species of reptiles, 16 species of amphibians, 41 species of fishes and 160 species of butterflies have been recorded. A new 'ant' species, *Dilobocondyla bangalorica*, was discovered in Bangalore recently (Varghese, 2006). In another study, Sudha and Ravidranath (2000) have investigated the floral assemblage in different land-use categories and the changes in vegetation over Bangalore City. 164 species were identified in different residential areas, of which 149 were recorded within compounds and 87 were avenue trees. The rich diversity speaks for the volume of life still persisting in spite of rapid urban growth.

In recent times, the increase in vehicular traffic (see section on Urban Agenda addressing Infrastructure) has increased the release of suspended particulate matter and other oxides of carbon, nitrogen and sulphur in the environment. Air pollution and the reduction in tree cover have induced the urban heat island effect causing variations in local temperature and sudden unanticipated showers during late afternoons.

[5] IDIP Report, prepared by STEM for KUIDFC, pp 2, Chapter 8

Figure 3-3: High-rise buildings sprouting across Bellandur lake. [Photo: H. S. Sudhira]

3.4 Demography and Economy

The state of Karnataka was carved out in 1956 based on linguistic boundaries, with regions dominated by Kannada speaking people. Bangalore was retained as the capital of the state, with Kannada as the official language while being true to its cosmopolitan status it has accommodated other languages like Tamil, Telugu, Malayalam, English and Hindi. The population census in Bangalore has been recorded for every decade since 1871, the most recent census being carried out in 2001. Figure 3-4 shows the growth of population in Bangalore from 1871 to 2001 (5.7 million), along with an estimate for 2007 (7 million). It is notable that since the first census, Bangalore was already the most populous city in Karnataka. This urban primacy has been retained consistently for more than a century now. After Independence, Bangalore, as a State capital, saw an influx of population through migration, although it should be noted that the steep population rise in the decade 1941-1951 was partly due to this migration but also exclusively through the amalgamation of Bangalore Civil and Military Station Municipality with the then Bangalore City Corporation. Population growth during the 1970s could be ascribed to numerous public sector industries and other defence establishments that came up during the period and fuelled significant immigration. By this time, incidentally, Bangalore had lost its tag of 'Pensioners Paradise', gained before Independence. Although the advent of IT is attributed to the late 1980s, nevertheless, the major growth and expansion of this industry happened only during the late 1990s. Still, population growth in Bangalore in the last census decade, 1991-2001 (38%), was substantially less than that in 1971-1981 (76%). Nevertheless, the physical growth of the city has been phenomenal over the last few years, and the glaring evidence of this is increased travel-times and the escalating real-estate prices.

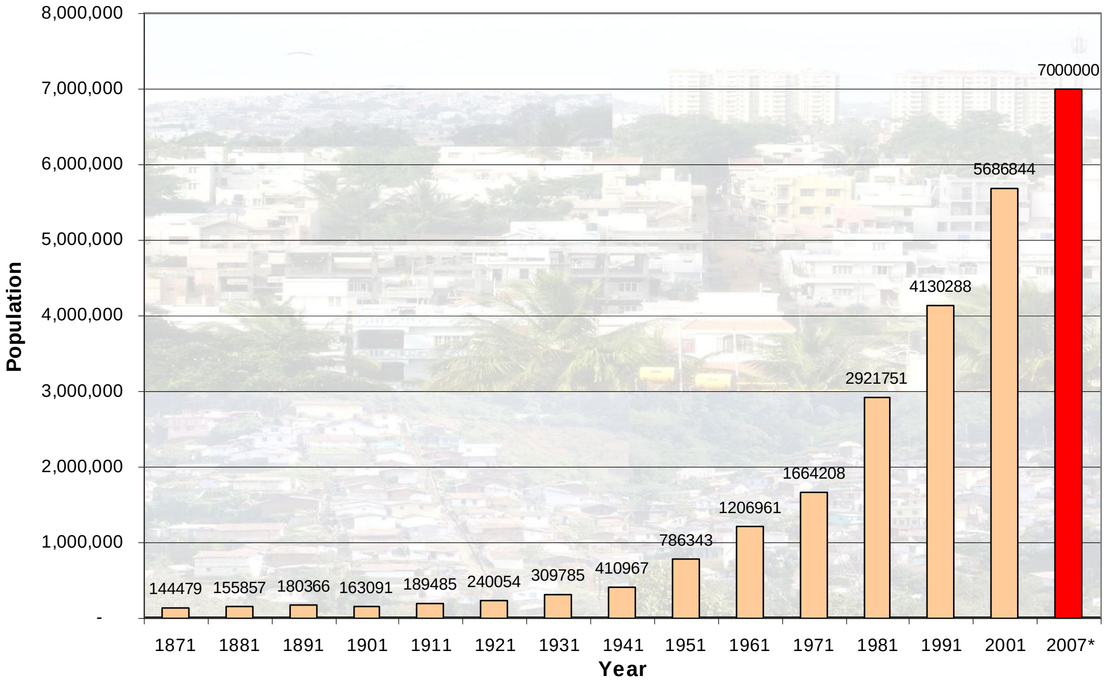


Figure 3-4: Population growth of Bangalore City during 1871 – 2007*

(* The population for 2007 is an estimate), Source: Census of India (2001a)

According to the latest census (Census of India, 2001a), the urban agglomeration had an overall population of 5.7 million within an area of 560 sq. km in 2001, which included a workforce of 2.2 million, , and a literacy rate of 75.10 %. The hype over the IT industry is attributed to Bangalore having about 30 % of all IT workforce in the country and a personal disposable income greater than the Indian city average. This has also resulted in a trickledown effect within the urban economy. Further, investments in industries (not only IT), infrastructure and other services, have significantly increased purchasing power among the people and have nurtured real estate with consequent land market dynamics, apart from creating numerous secondary employment in services. Interestingly enough, of the 5.7 million population in the urban agglomeration in 2001, about 2 million were migrants (Census of India, 2001b). About 1.2 million of these were from Karnataka state, mainly from the rural parts, while the remaining 0.8 million were from outside the state; the majority of these were from urban areas. It is further noted that people have migrated chiefly for employment or moved with household or for education. The large number of migrant population from other parts of India explains the multitude of languages spoken and understood in Bangalore.

Bangalore is home to numerous institutes of higher learning and research, which is evident from the establishment of premier centres like Indian Institute of Science (IISc), Indian Institute of Management (IIM), Institute for Social and Economic Change (ISEC), Indian Institute of Information Technology (IIIT), National Institute of Advanced Studies (NIAS), Tata Institute for Fundamental Research (TIFR), Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Indian Space Research Organisation (ISRO), National Aerospace Laboratories (NAL), Central Power Research Institute (CPRI), Central Manufacturing Technology Institute (CMTI), various research centres of Defence Research and Development Organisation (DRDO), and several professional engineering and medical colleges at undergraduate and graduate levels. In tune with recent trends, Bangalore now has numerous malls and multiplexes that are swarmed during weekends. With an active nightlife and Bangaloreans penchant for fast-food, a large number of restaurants, pubs and 'eat-outs' throng the city.

The economic fabric of the city, although at times masked by the IT-based industries is varied, being also characterised by textile, automobile, machine tool, aviation, space, defence, and biotechnology based industries. In addition to these, numerous services, trade and banking activities mark the city's economic landscape. An important feature of the economic activities of Bangalore is the huge concentration of Small & Medium Enterprises (SMEs) in diversified sectors across the city. Bangalore has more than 20 industrial estates / areas comprising large, medium and small enterprises. Of these, Peenya Industrial Estate, located in the northern part of the city comprises about 4000 SMEs and is considered the largest industrial estate in South and South East Asia (Peenya Industries Association, 2003). Among others, a majority of the SMEs function as ancillaries / subcontractors to large enterprises in the field of engineering and electronics industries. The industrial estates sprung up mostly in the periphery of the erstwhile city and gradually as the city grew became part of its sprawl. Notable among these are the Peenya Industrial Estate just mentioned, Electronic City and Whitefield (Map 1). The proliferation of SMEs in residential and commercial areas, in addition to the industrial areas, has added to the chaos and congestion in the city. Thus, the thriving economy of the city has resulted with a net district[6] income of Rs. 262,592 million (approx. US $ 5.8 billion) and a per capita income of Rs. 39,420, a little more than twice the State's average per capita income of Rs. 18,360 (Government of Karnataka, 2005).

Despite higher per capita income within the urban district relative to the rest of the State, and with significant migrant population, the number of urban poor has been on the rise and the slum settlements in the city have not been restrained. The escalating costs of land prices coupled with rise in cost of living has pushed the urban poor to reside in squatter settlements with inadequate amenities and services (Figure 3-5). Some of these settlements have speckled the city's landscape garnering immediate action from civic authorities. According to Bangalore Mahanagara Palike (2006), the number of households in the urban agglomeration defined as poor was 0.22 million, housing approximately 1.1 million people out of a 5.7 million population (Table 3-2). Considering the importance of the matter, the State Government has set up a special agency, Karnataka Slum Clearance Board (KSCB)[7] specifically to address the redevelopment of slums in partnership with various stakeholders like the Housing Board, Local Bodies, Water Supply Boards, etc. The initiatives taken up by the local body addressing redevelopment of slums are noted in the section on Issues in Planning and Development.

Table 3-2: Distribution of slums across Greater Bangalore (BMP, 2006)

Agency / Authority	No of slums	No of Households	Remarks
Karnataka Slum Clearance Board (KSCB)	218	106,266	Declared
Greater Bangalore City Corporation	324	110,991	310 Undeclared & 14 Declared
Grand Total	**542**	**217,257**	

Note: Estimates are based on 2001 Census

[6] In the Indian federal system, each state is divided into districts (which are further divided into taluks) for administrative purposes, including decentralised implementation of developmental programmes. The State of Karnataka has 27 districts, of which Bangalore Urban is one, comprising Bangalore East, Bangalore South and Anekal Taluks. Taluk boundaries dissect the city and extend beyond the Bangalore Metropolitan Area. Thus the 'net district income' refers to the entire district and not to the city alone.

[7] Karnataka Slum Clearance Board is responsible for slum improvement, clearance and rehabilitation of the slum dwellers.

Figure 3-5: The plight of urban poor in Jayanagar 9th Block, a locality in Bangalore [Photo: BBMP]

3.5 Urban Agenda: Governance and Infrastructure

An important aspect of a city is how well it is planned, managed and administered, that are activities which form the core part of an urban agenda – governance. However, appropriate state mechanisms through organisational structures, procedures and policies are needed to enable these. Also, apart from the formal administrative structures, the presence and involvement of civil society significantly drive the urban agenda.

3.5.1 Organisations and Stakeholders

Greater Bangalore City Corporation (Bruhat Bangalore Mahanagara Palike) is now the key 'urban local body' (ULB), that is, the local governmental structure representing and responsible to the citizens for the city and outlying areas. Notified in December 2006, the new Corporation replaced the erstwhile local bodies, Bangalore City Corporation (Bangalore Mahanagara Palike), 8 neighbouring councils (7 City Municipal Councils and one Town Municipal Council) and 111 outlying villages. Independent of the Corporation[8], which is

[8] 'Corporation' refers to the recently notified Greater Bangalore City Corporation unless otherwise stated.

governed by locally elected representatives, parastatal bodies controlled by the State government are responsible for many essential services (see Table 3-3).

Table 3-3: Organisations concerned with Bangalore

Organisations	Functional Areas (Scope of Work)
Greater Bangalore City Corporation [*Bruhat Bangalore Mahanagara Palike* (BBMP)]	Urban local body responsible for overall delivery of services — Roads and road maintenance including asphalting, pavements and street lighting; solid waste management, education and health in all wards, storm water drains, construction of few Ring roads, flyovers and grade separators
Bangalore Development Authority (BDA)	Land-use zoning, planning and regulation within Bangalore Metropolitan Area; Construction of few Ring roads, flyovers and grade separators
Bangalore Metropolitan Region Development Authority (BMRDA)	Planning, co-ordinating and supervising the proper and orderly development of the areas within the Bangalore Metropolitan Region, which comprises Bangalore urban district and parts of Bangalore rural district. BDA's boundary is a subset of BMRDA's boundary
Bangalore Water Supply and Sewerage Board (BWSSB)	Drinking water – pumping and distribution, sewerage collection, water and waste water treatment and disposal
Bangalore City Police	Enforcement of overall law and order; Traffic Police: Manning of traffic islands; Enforcement of traffic laws; Regulation on Right of Ways (One-ways)
Bangalore Metropolitan Transport Corporation (BMTC)	Public transport system – Bus-based
Bangalore Metro Rail Corporation Ltd (BMRC)	Public transport system – Rail-based (Proposed)
Regional Transport Office (RTO)	Motor vehicle tax; Issue of licenses to vehicles
Bangalore Electricity Supply Company (BESCOM)	Responsible for power distribution
Lake Development Authority (LDA)	Regeneration and conservation of lakes in Bangalore urban district

Planning in the form of land-use zoning and regulation are vested with Bangalore Development Authority (BDA), a parastatal agency, in spite of the 74th Constitutional Amendment Act, passed by the National Parliament in 1993. This Act requires that the planning function be vested with the (elected) urban local body and not with any parastatal agency. But, in the case of Bangalore, the Corporation has not been granted adequate powers by the State to plan, decide and administer their city! Furthermore, the State has created numerous other organisations of its own to manage various services such as water supply, law and order, energy, etc, The result is the existence of many parastatal organisations, each acting in its own jurisdiction area, leading to complication and confusion in coordinating different activities. Apart from the issue of a common jurisdiction and the lack of coordinated effort, even basic information related to different sectors is extremely difficult to collect, collate and to correlate. For effective planning it is imperative that all the basic information is gathered across a common jurisdiction with the effect of creating a robust city information system.

In addition to the official bodies, civil society of Bangalore is known for its vibrant community participation. The spectrum of their activities ranges from literacy and green brigades to urban governance, ensuring continuous interactions with the local administration.

Notable spheres of activity of these non-governmental organisations (NGOs) include: improving urban governance by Public Affairs Centre (PAC), Citizens Voluntary Initiative for the City (CIVIC) and Janaagraha; improving living conditions in slums by AWAS, APSA, Paraspara, etc.; addressing child literacy by Prerana, Dream School Foundation, India Literacy Project and Akshara Foundation; taking on environmental issues by the Environment Support Group, Hasiru Usiru, etc. Apart from the NGOs, there are numerous resident welfare associations, trade and commercial organisations, and professional organisations that have played a major role in some of the important activities of local bodies and influencing their decision-making. Civil society has contributed considerably in shaping the policies and governance structures and has always intervened whenever there has been any apathy on the part of the administration towards activities of interest to society at large. An experiment to promote public private partnership and to bring together citizens, NGOs, industry representatives and the erstwhile local bodies established the “Bangalore Agenda Task Force (BATF)”. This experiment was about to be benchmarked as one of the ‘best practices’ in urban local governance, when it faced strong criticisms from several civil society groups for setting aside priorities favouring the urban poor and was accused of making a back door entry towards policy making (Ghosh, 2005). In the event, the activities of BATF came to a standstill with the change of guard at the State government few years ago and it is currently dormant. Another instance of strong action by civil society groups, was seen when the local government started tree felling and pruning for road widening. Members of the green brigade, Hasiru Usiru, staged protests, held an all night vigil, stormed the Commissioner’s office and also moved to High Court and finally got the actions stayed. The High Court also ruled later that Hasiru Usiru members should inspect the trees along with the designated Tree Officer from the Forest Department before any tree felling and pruning of branches begun.

3.5.2 Challenges in Managing Urban Infrastructure

Urban activities require the support of infrastructure. Broadly, urban infrastructure can be divided into social and economic infrastructure. Social infrastructure encompasses facilities like healthcare, education, housing, commercial (shops, markets and hotels), sports, recreation and entertainment. With mixed land-use being practiced in most parts of Bangalore, shops and markets are the most commonly found amenities (approximately 1 shop per 100 persons) in the urban agglomeration[9] (Karnataka Urban Infrastructure Development and Finance Corporation, 2006). The provision and maintenance of primary healthcare, elementary education, sports, recreation and entertainment are administered mostly by the Corporation, while BDA also facilitates some of the social infrastructure like shopping complexes, with provisions for private participation. Economic infrastructure encompasses water supply, wastewater treatment, storm water drainage system, solid waste management, telecommunication network, and transportation network.

Bangalore Water Supply and Sewerage Board (BWSSB) is the parastatal agency responsible for drinking water supply, and wastewater collection and treatment in the city. Bangalore is on a ridge and does not have its own year-round sources of water. Drinking water is pumped from the river Cauvery, located at a distance of about 100 km over an elevation of 500 m with an energy expenditure of 75 MW for approximately 900 million litres per day (MLD). Apart from the supply from River Cauvery, groundwater and water from the River Arkavathy are also tapped. However, while water supply distribution is 100 percent in the former Bangalore City Corporation limits, only about 20 % of the Municipal Council households are serviced. In view of rapid growth of the city, and recent notification of Greater Bangalore, it remains a challenge to service the remaining areas.

Regarding collection and treatment of wastewater, the sewerage system is based on the city's four natural river valleys that are already noted earlier with BWSSB as the nodal agency. There are three major treatment plants with a total capacity of about 450 MLD (the outlets of Koramangala and Challaghatta valleys are combined to form the K&C Valley Treatment Plant

[9] The urban agglomeration refers to the area formally administered by Bangalore City Corporation and the 8 councils.

at Bellandur). Wastewater stress on natural water bodies is evident from the fact that the present wastewater treatment capacity in the city is around 450 MLD as against an estimated generation of domestic wastewater of 700 MLD. Although more secondary wastewater treatment plants are in progress, they are yet to be completed. Another problem is the frequent clogging of storm water drains, resulting in pollution of natural water bodies. Hence it is now proposed to rehabilitate and remodel all the major trunk sewers to prevent any discharge into the storm water drains.

Addressing mobility in Bangalore city, an overview of transportation and traffic reveals the following facts. Bangalore city is estimated to have vehicle population of about 2.6 million while the current city population is about 7 million. The vehicle to person ratio is far higher than any other city in India. This has led to increased congestion in road networks across the city and frequent traffic jams. Manning signals at traffic islands has also become unmanageable with the amount of traffic plying across junctions. Again, in this sector different components related to mobility are vested with different parastatal bodies.

Public transportation forms one of the key functionalities for mobility in any urban area. In Bangalore where the working population is around 2 million, the Bangalore Metropolitan Transport Corporation (BMTC) operates on any given day with 4,144 schedules, 4,262 buses, 60,475 trips, and carries 3.5 million passengers. It earns Rs. 20.5 million per day and pays Rs. 0.955 million to the government as taxes (Bangalore Metropolitan Transport Corporation, 2006). Further, according to recent estimates, there are about 1.6 million two-wheelers, 0.32 million motor-cars, 80,000 auto-rickshaws, and 0.17 million other vehicles totalling around 2.2 million vehicles on road (Regional Transport Authority, 2006).

The onus of maintaining and improving road networks lies with the Corporation. Although a study for the City by consultants' iDeCK and RITES (2005) identified 52 high and medium traffic intensity corridors requiring various interventions by different organisations, the former City Corporation proposed only to widen some of these roads. A key aspect ignored while addressing mobility is the role of land-use in generating traffic demand. Failure by the city to acknowledge this, and in particular the implications of changes in land-use from residential to commercial or industrial, has led to stereotypical approaches in addressing mobility such as road widening, creation of new flyovers and underpasses, or conversion into 'one-ways'. With the City's compartmentalised approaches to widening of roads or construction of flyovers and grade separators, the problem of mobility is far from being solved.

3.5.3 Issues in Planning and Development

To understand the development characteristics of the Bangalore metropolitan area, it may help to distinguish three concentric zones – zones, which correspond closely with previous current local authority areas. The first zone would comprise the erstwhile city corporation area of 226 sq. km. The second zone would include the areas of the former 8 neighbouring municipal councils and 111 villages, which together form the peri-urban areas and are now incorporated into the Greater Bangalore City Corporation. The third zone would include other villages extending up to the Bangalore Metropolitan Area limits as proposed by Bangalore Development Authority. The development characteristics and agencies across these zones are summarised in Table 3-4 and depicted in Map 1.

Table 3-4: Development Characteristics across Bangalore

Characteristics	**Development Zones**		
	Zone 1	**Zone 2**	**Zone 3**
Authority	Greater Bangalore City Corporation (formerly Bangalore City Corporation).	Greater Bangalore City Corporation (formerly 8 municipal councils) and 111 Villages).	Development Authorities and other Town and Village Municipal Councils.
Urban Status	Core city.	Outgrowth.	Potential areas for future outgrowth.
Infrastructure Services	Present, but nearly choked, needs augmenting of existing infrastructure.	Not fully present, with new growth, requires planning and augmentation of infrastructure.	Farmlands and scattered settlements with minimal to no infrastructure.
Impact of growth	No scope for new growth but calls for urban renewal to ease congestion, etc.	High potential for growth due to its present status of being a peri-urban area and emergence of new residential layouts and other developments.	Mostly rural, with minimal growth currently, but potential for future growth.
Planning, Development and Regulation Controls	Corporation operates building controls. Planning vested with BDA.	Corporation operates minimal building controls. Planning vested with BDA.	Planning vested with parastatal agencies: BDA and BMRDA and not other local bodies. No regulation on building / construction.

Traditionally, planning has been restricted to land-use planning, being vested with BDA for the region under Bangalore urban agglomeration, and with Bangalore Metropolitan Region Development Authority (BMRDA) for the larger peripheral area comprising the rest of Bangalore Urban District (See footnote 6). BDA obtains land, develops it as residential layouts, which eventually are handed over to the city corporation, often involving the extension of city limits. Land-use plans are formalised through the Comprehensive Development Plans (CDP) prepared for every 10 years. Accordingly, the last CDP, prepared in 1995 for the period up to 2011, was revised in 2005-06 for the period up to 2015 (Bangalore Development Authority, 2007). A key aspect of these CDPs are that they indicate the amount and location of land-use allocated for various uses (like residential, commercial, industrial, etc.) as well as restricting development in specific areas demarcated as Green Belt and Valley Zones. However, another organisation similar to BDA, the Karnataka Industrial Area Development Board (KIADB), is responsible for development of industrial areas. These industrial estates are situated for the most part in the outskirts of the city and KIADB has powers under the law to take over tracts of agricultural land for the purpose.

Generally, however, the regulation and enforcement of land-use zoning regulations are dismal, leading to a large number of illegal developments and encroachments on public land – problems which have led Karnataka State to constitute a legislative committee to look into irregularities in and around the city. In the particular case of growth occurring around outer industrial areas, the urban local bodies are generally unable to provide basic infrastructure and services, thus further aggravating inefficient utilisation of land and other natural resources. With such instances prevailing especially in the areas of the former Municipal Councils, the new Corporation faces a great challenge to deliver basic infrastructure and services.

Bangalore is one of the beneficiaries under the Government of India’s Jawaharlal Nehru National Urban Renewal Mission (*JnNURM*) with an estimated outlay of US $ 1.7 billion over the next six years. In accordance with the *JnNURM* guidelines, the erstwhile Bangalore City Corporation prepared the City Development Strategy Plan (CDSP) for both UIG and BSUP (Bangalore Mahanagara Palike, 2006). The CDSP outlines only an investment plan and financial strategy for taking up various initiatives envisaged in the mission. Under BSUP, 218 declared slums in the former City Corporation limits would be taken up by KSCB for redevelopment. Further, there are 169 slums under the erstwhile City Corporation jurisdiction that remain undeclared, which would be redeveloped by the new Corporation. There are, in addition, 155 slums in the neighbouring former municipal council areas that would be redeveloped by the new Corporation and KSCB. However, a draft community participation law has not been enacted and in Karnataka State, most of the infrastructure projects and redevelopment plans have been administered by ULBs and parastatal agencies and not through community participation as envisioned by the mission. The result is a continuation of top-down rather than bottom-up modes of planning and delivering infrastructure and services. This calls for introspection on the implementation and achievement of the mission objectives. However, with various initiatives under *JnNURM* being underway, it does offer hope, and perhaps promise in improving the essential urban infrastructure and services in the city.

3.6 Summary

Bangalore, with all due respect to its status as 'Silicon Valley' and 'Garden City', faces real challenges in terms of addressing and delivery of basic infrastructure and services to all its stakeholders. In spite of numerous initiatives and activities envisaged by the urban local bodies, past and present, and by parastatal bodies, the rationalisation of jurisdictions for these activities could mark the beginning of a coordinated effort in addressing the needs of the city. In the wake of recent notification of Greater Bangalore City Corporation and initiatives under *JnNURM*, Bangalore is currently experiencing a strange transformation. Bangalore also stands out as a beacon of the globalising world and to sustain this, it needs to systematically address the key challenges that the city is facing in terms of governance and infrastructure.

IV. Patterns

If we could first know where we are, and whither we are tending, we could better judge what to do, and how to do it.

- Abraham Lincoln

4.1 Indicators and Spatial Information Systems

Indicators, as it means explicitly are measures of some phenomenon of interest. This is typically measured through appropriate metrics, for example, to know how hot or warm the day is going to be, the ‘temperature’ is measured. To measure economic growth of a nation, a common metric used is the growth of gross domestic product (GDP) or Gross National Product (GNP). Similarly, there are scores of metrics or indicators that report the status of a phenomenon of interest. These indicators serve multiple purposes; they serve as benchmarks, as measures to plan, evaluate, review and communicate. Indicators are classified typically based on performance indicators, issue-based indicators and need-based indicators. Further, the choice of indicators depends upon the framework upon which these indicators are evolved. Among the major approaches for developing indicators are: policy-based approach, thematic / index approach and systems approach (Asian Development Bank, 2003). Thus, there are different indicators that have been evolved with different approaches and frameworks: policy-driven, theme-or-index driven, systems, performance, needs-based allocation and benchmarking. Realising the need for appropriate indicators, worldwide scores of researchers, academicians and administrators have, at times come up with a host of indicators on various themes.

Given the problem of urban sprawl and its inadequate understanding to precisely determine its pattern, processes and causes there is a need to characterise urban sprawl. Often, there is a lack of appropriate indicators and information concerning a city or its status, from a holistic perspective, that captures not only the economic aspects but also the ecological and living conditions of the people. In all, there is definitely a dearth of such information that the city administrators, managers and planners would like to have from time to time. Thus, a significant challenge is to understand the processes that cause such growth, which necessitates identification and development of appropriate indicators towards achieving sustainable urbanisation in developing countries.

Alongside the need for indicators, urban governance requires a robust spatial information system to keep track of various activities and aid in operational management. Broadening the scope of such spatial information systems in urban planning and management, Singh *et al.* (2004), suggest a planning system, which is dynamic, flexible and efficient and is backed by an information system. In India, there have been efforts to evolve such a robust information system for urban areas as envisaged by the Town and Country Planning Organisation (TCPO), Government of India. Accordingly, TCPO has arrived at the National Urban Information System (NUIS) framework, establishing the guidelines and requisite standards for developing such a system (Town and Country Planning Organisation, 2006) through all urban local bodies ranging from large metropolitan corporations to municipal councils. In spite of such initiatives, still, they have not yet been realised by the various urban local bodies. This necessitates a faster development and implementation of such an urban information system.

In the foregoing section, we first briefly discuss the need for indicators in the context of addressing urban sprawl. We then review some of the important indicators of urban systems (cities, sustainability indicators and sprawl indicators) and then propose the indicators for urban sprawl in India. We operationalise the indicator framework for Bangalore towards achieving sustainable urbanisation.

4.1.1 The Systems Approach

The systems approach attempts to capture the interactions through feedback amongst the entities defined within a system or a model. The entities form the indicators while the linkages and the causalities are established based on the interactions. Among the popular framework within the systems approach is Pressure-State-Response (P-S-R) framework developed and popularised by the Organisation for Economic Cooperation and Development (OECD) (1993) for environmental reporting. The P-S-R framework has also been revised and extended as DPSIR (Driving forces-Pressure-State-Implications-Response) model (Asian Development Bank, 2003).

Newman (1999) developed the Extended Urban Metabolism Model (EUMM) based on systems approach, which forms the basis for most recent urban indicators. This model maps the inputs while capturing the mediating processes and the resulting outputs. The EUMM views cities as systems that require inputs of key resources (stocks) which are drawn into their resident domestic, industrial, and governmental urban processes to produce two key sets of outputs. One of these is a 'liveability' dimension of a human-orientated built environment, which can be characterised through a range of indicators that range from adequacy of infrastructure, to environmental, health, and social well-being of the inhabitants. The second set of outputs relates to emissions and waste flows. The goals for this dimension are to diminish flows over time (Asian Development Bank, 2003).

Noting the importance of indicators and achieving sustainability, and thus the 'sustainability indicators', Meadows (1998) argued earlier that an environmental indicator becomes a sustainability indicator (or unsustainability indicator) with the inclusion of time, a threshold (limit), or target, wherein the central questions of sustainability posed are: How long can these activities last? How long do we have to respond before we run into trouble? Where are we with respect to our limits? Therefore, sustainability indicators are ideally expressed in time units (Meadows, 1998). If the cities continue to spread at the ongoing rate, how many years will the supporting resources such as land and water bodies last? Unless they are not expressed in units of time, sustainability indicators should be related to carrying capacity or to threshold of danger or to targets.

Meadows (1998), further argues that development indicators should include efficiency, sufficiency, equity, and quality of life than just growth indicators. Arguing that development can easily be confused with growth, it is noted that growth simply means getting larger - not necessarily getting better, while most of the economic indicators are defined around growth, with the GDP per capita as the most glaring example. This is in consonance with Reddy's (2004) concept of sustainable development. Therefore, it is imperative that the focus for development has to be from material gains / growth to improving the quality of life through an appropriate measure for development index. The sustainability indicators suggested by Meadows (1998) have the hierarchy from ultimate means to ultimate ends (Figure 4-1) based on four themes.

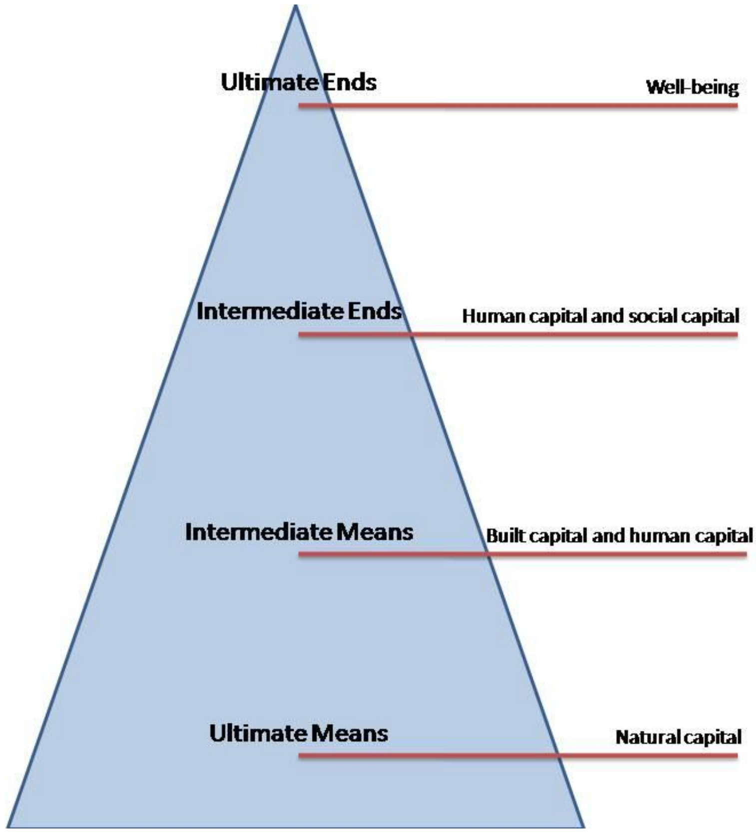


Figure 4-1: The hierarchy from ultimate means to ultimate ends

In spite of having a holistic approach towards achieving sustainable development based on the systems and theme-based approach, Meadows (1998) notes that there is still no consensus among the different indicators. However, it is found that this attempt outlines a good framework for developing indicators for sustainable development. Another important aspect noted by Meadows (1998) is that while developing indicators, it is also imperative to have a robust information system that can be used to document, monitor, plan, evaluate and communicate. Despite suggesting an information system coupled indicators for sustainable development, this framework will be more effective with a spatially enabled information systems and indicators. This will add more values, as it can be easily used to identify and visualise the areas of concerns by planners and administrators.

4.1.2 Carrying Capacity based Regional Planning - NIUA

Carrying capacity refers intrinsically to the finite capacity or the limitation of the natural environment both as a reservoir of resources to support human consumption and as a sink to assimilate the residuals or wastes. Thus, carrying capacity based planning deals with the management of 'throughput', that is, the size and nature of human activities leading to resource consumption and waste generation, as well as the supportive resource base and the assimilative capacities of the environment (National Institute of Urban Affairs, 1996) with optimisation of human demands in relation to manageable supply of environmental resources. In this regard, indicators for the carrying capacity based regional planning are based on two criteria: Supportive Capacities and Assimilative Capacities. These are further categorised into five modules:

Table 4-1: Modules under supportive capacities and assimilative capacities

Modules	Capacity Type	Domain
Module A	Waste Assimilative Capacities of Urban Environment	Air Environment Water Environment Land / Soil Environment Biological Environment Acoustic Environment
Module B	Supportive Capacities of Urban Land and Shelter Resources	Urban Land Resources Housing Social Amenities
Module C	Supportive Capacities of Urban Transportation and Communication Infrastructure	Regional Accessibility Intra-urban Accessibility Communication Facility
Module D	Supportive Capacities of Urban Utilities	Water Supply Sanitation Energy Non-Conventional Energy Development
Module E	Supportive Capacities of Socio-Economic Resources	Manpower Resource Economic Base Local Institutional Resource

Under these five modules a total of 58 indicators (Appendix A) were suggested for carrying capacity based regional planning. Although the indicators suggested by the NIUA are exhaustive in terms of serving as essential indicators for an urban system, at a certain level, it shadows the very basis of carrying capacity approach. This is because the indicators suggested, 'do not put forward how to estimate the actual thresholds'. Then an imminent task is to arrive at these limiting values based on the local supportive and assimilative capacities. Perhaps employing the systems approach, it would be possible to determine these limiting values for the various resources (through indicators). A consequence of this would entail in capturing the dynamics through the various feedbacks generated / arising out of different interactions in the system. It is interesting to note that this framework has suggested mapping of appropriate and adequate information for timely action with the spatial distribution of infrastructure, services and areas of environmental problems for analysing the problems of the city at both aggregate and disaggregate levels.

4.1.3 Boston Indicators

The biennial reports of the Boston Foundation highlighting the city's activities on various facets are known as Boston Indicators (Kahn, 2007). In the third biennial report, called as '*Thinking globally / acting locally: A regional wake-up call*', brings out the challenges faced by the city. Boston, with a booming economy happens to be one of the prime centres of technological innovation, while facing stiff competition from other cities across the country and a few other cities across the globe, with cities notably in India and China. Boston's competitive advantage over other cities until recently was in terms of culture and practice of technological innovation; institutional and physical infrastructure; and a well-educated, skilled and diverse workforce. The high economic growth rates in countries of India and China, coupled with availability of qualified work-force, and technological competition in these countries are offering tougher challenges to the sustenance of the prevailing growth in Boston (Kahn, 2005). In the recent and fourth biennial report called, '*A time like no other: Charting the course for next revolution*', it finds that Greater Boston's economy has strengthened considerably but that the region faces persistent challenges in high costs, labour shortages, and growing income inequality. The report also emphasises Boston's innovative capacity and its potentially revolutionary role at a time of global economic and climatic change (Kahn, 2007).

The Boston Indicators attempt to capture the city's status through different themes. Accordingly, the indicators based on different themes are: civic health, cultural life and the arts, economy, education, environment, housing, public health, public safety, technology and transportation.

Here again, the enlisting of themes for describing indicators ideally fits in for most cities. However, this does not attempt to link among the indicators and represent spatially. Therefore, it is essential to establish linkages amongst the indicators, and address them from a dynamic perspective than static snapshots. It would also be easier to review and evaluate the implications of one factor on the other, if the interactions amongst them are known.

4.1.4 Urban Indicators for Managing Cities - ADB

Cities Data Book (CDB) project of the Asian Development Bank (ADB) has resulted in the comprehensive, 'Urban indicators for managing cities' (Asian Development Bank, 2003) that has attempted to define what indicators are required in the context of managing urban areas in developing countries of Asia, apart from quantifying it for some of the participating cities in the region. The objectives of the CDB was to assess the situation of individual cities and provide a comparative information from other Asian and Pacific cities keeping in mind the challenges faced by most of these places like, globalisation, urbanisation, new technologies and intercity competitions. This highlights the need for better information about these cities for assessing the situation and prioritising to facilitate monitoring and aid in policy and decision-making.

A key contribution of this effort is the indices of City Development Index (CDI), Congestion Index and Connectivity Index. The CDI has been developed combining the indicators from the themes of infrastructure, health, education, waste, and city product. The congestion index is designed to measure crowding. The connectivity index measures the extent to which the city is connected to the rest of the world, outside of national borders. The indicator framework devised here fall under thirteen prominent themes as given below, while these broad themes also have many sub-themes (Appendix B).

1. Population
2. Equity
3. Health and Education
4. Urban Productivity
5. New Technology
6. Urban Land
7. Housing
8. Municipal Services
9. Urban Environment
10. Urban Transport
11. Cultural

12.Local Government

13. Urban Governance

It is claimed that CDI parallels the Human Development Index (HDI) at the city level, combining the city product with health, education, infrastructure, and waste management components. It is further argued that the CDI better correlates with many of the variables of particular interest in development, better than the national HDI or the city product, and it also gives a meaningful ranking of cities in the development spectrum (Appendix B). While the CDB effort is amongst the most comprehensive enlisting of indicators of urban areas, this also attempts to establish the relationship of CDI with congestion index and connectivity index. However, the feedbacks that may be generated by the indicators are not captured and it is this shortcoming that can be a starting point for future research on urban sprawl to evolve appropriate metrics and capturing the dynamics.

4.1.5 Costs of Sprawl: 2000 - TRB

The phenomenon of urban sprawl has been more prevalent and reported in the developed countries than developing countries. Noting the importance of sprawl, the Transportation Research Bureau (TRB) of the National Research Council, United States of America, has commissioned extensive research on this. The outcomes of this research are two reports; Cost of Sprawl - Revisited (Transportation Research Board, 1998) and Costs of Sprawl - 2000 (Transportation Research Board, 2002). The outlook with which the problem of sprawl is addressed is by evaluating the respective costs and benefits associated with the sprawl (uncontrolled growth) and contained development (compact or ‘smart’ growth). It is argued that both have their own respective advantages and disadvantages. A broad perspective under which the costs (and benefits) of sprawl is addressed are:

1. Impact of sprawl on resources
   - Land conversion
   - Water and sewer infrastructure
   - Local road infrastructure
   - Local public service costs
   - Real estate development costs

2. Personal costs of sprawl
    - Travel miles and costs
    - Quality of life

An important deviation from all other approaches of indicator frameworks in this approach is by the evaluation of respective costs and benefits of having sprawl and smart growth, and finally relating it to the quality of life. By evaluating the quality of life, incorporating the variables as an outcome of both sprawl and smart growth, it is shown that there is not much variation in quality of life but there are definitely higher resource cost incurred in case of sprawl than the compact smart growth development patterns. It is interesting to note that although the report brings about the debate whether sprawl is beneficial or otherwise, sprawl is seen to have impacts on resources, while there could be better quality of life and less expensive housing with the incidence of sprawl. But then, it is concluded that there are more costs than benefits, especially with the level of resource consumption and hence suggests more-compact development that can lead to development savings.

This framework has attempted to link amongst the various indicators of sprawl, to the quality of life. However, in the context of problem of sprawl in a country like India with high rates of urbanisation, some of the indicators used for identifying sprawl and means of computing the quality of life need to be revisited. It is further acknowledged that this framework also makes a good reference for developing indicators for urban sprawl.

4.1.6 Sprawling Cities And TransporT: from Evaluation to Recommendations (SCATTER)

The *Sprawling Cities And TransporT: from Evaluation to Recommendations* (SCATTER) was a European Union funded project that aimed at addressing the issue of urban sprawl in Europe. After the TRB's Costs of Sprawl, this has been another comprehensive study on sprawl. With an explicit focus on reviewing and assessing policy options for setting up recommendations towards tackling sprawl, the SCATTER project studied six cities in the European Union (Gayda *et al.*, 2005). An important aspect of this research is arriving at indicators and statistical methods to measure urban sprawl. Accordingly the statistical framework consisted of:

- A generalised shift-share analysis
- A measure of spatial deconcentration, called *H*-indicator

- The local spatial autocorrelation statistics (e.g. Moran's *I*)
- Traditional indicators like densities, shown on maps

The variables that have been investigated were:

- Total population and total employment
- Income per capita, number of commuters, commuter trip length, house prices, number of dwellings, residential buildings, and number of jobs directly induced by the population

Further, as an outcome of research, an urban sprawl exploratory tool (USET) was developed which is an interactive tool implemented on the internet (http://www.casa.ucl.ac.uk/monitor Last accessed: 7th August 2006), intended for local and planning authorities involved in decision-making to regularly review, plan, monitor and evaluate urban sprawl. It can also serve as a tool to inform and raise awareness apart from exploration and monitoring variables related to sprawl. This essentially provides an overview of definitions and concepts related to urban sprawl; set of relevant indicators to be collected for a city and collected indicators for the study cities; and a policy database referring to the policies evaluated by simulations or by the case studies. The set of city sprawl indicators suggested are:

1. Land use
    - Households in core metropolitan area
    - Households in urban zones
    - Jobs in core metropolitan area
    - Jobs in urban zones
    - H relative measure of population
    - H relative measure of employment
2. Mobility pattern
    - Average home-work travel distance
    - Average travel time (all modes)
3. Public transport
    - Modal share of public transport

   - Passenger-km by public modes

4. Road traffic
   - Private vehicle-km
   - Average road traffic speed
   - Greenhouse gases from transport

5. Accessibilities
   - Accessibility to city centre
   - Accessibility to services
   - Productivity gain from land-use

With a focus on addressing the issue of sprawl from a policy perspective, SCATTER project has attempted for both qualitative and quantitative evaluation of policies aiming to reduce sprawl. This has involved quantitative evaluation and use of simulation models based on integrated land-use-transport models for three cities, with the indicators of this evaluation framework to mainly tackle concentration / deconcentration of population and employment, mobility pattern and CO emissions (Gayda *et al.*, 2005). It is here wherein researchers have attempted to link some of quantitative indicators of sprawl and evaluated for different policy options, quite different from most of the earlier indicator frameworks.

4.2 Sprawl Indicators for Bangalore, India

From an overview of the above-discussed indicators, it is seen that amongst the most relevant sprawl indicator frameworks are that of the Costs of Sprawl (TRB) and SCATTER (EU). It is further noted that the set of indicators suggested above fit very well for countries, wherein the rates of urbanisation are almost stagnant, converse to the situations in countries, with high urbanisation rates. It is with this motivation, the current chapter arrives at the indicators for sprawl on the lines of indicators developed by TRB and SCATTER, with strong relevance to the prevailing local conditions. In this regard, the suggested metrics for quantifying urban sprawl extends the city sprawl indicators of SCATTER (Gayda *et al.*, 2005), to chiefly accommodate migration, population densities and literacy levels amongst others. The sprawl indicators are grouped under four themes:

1. Demography and Economy;
2. Environment and Resources;
3. Mobility; and
4. Planning and Governance.

4.2.1 Demography and Economy

The first set of indicators reflects the demographic and socio-economic characteristics of the city across different zones (core to agglomeration). The basic demographics reflect the population – native and migrant, household size, housing condition, population densities: alpha and beta density, and among the economic aspects are income levels.

4.2.2 Environment and Resources

The second set of indicators capture the environmental variables and the resource consumptions that chiefly include land-use, solid waste generation and collection, water consumption and wastewater generation, and energy: consumption, sources and end uses. The different land-uses considered are: built-up, water bodies (includes tanks and all wetlands), open land (includes barren land, rocky outcrop and dry grassland), and vegetation (includes agriculture plantations, parks, forest cover, and all green cover). For the built-up areas, some of the established sprawl metrics like, density and patchiness were further computed. The solid waste management metrics consider per-capita generation and mode of collection. The water consumption per capita per day and the corresponding wastewater generated and the treatment capacities form the metrics under Water and Wastewater.

4.2.3 Mobility

The third set of indicators about mobility is mode of transport, modal share of public transport, mobility patterns, road traffic, average road traffic speed and travel times. The modal share of public transport, passenger-km by public modes, mobility pattern considering the average home to work travel distance and average travel time (for all modes) are part of the metrics under mobility.

4.2.4 Planning and Governance

The last set of indicators captures the aspect concerning planning and governance. These variables include: preparation and publication of master plans, public participation, and integration of city functions. For measuring the effectiveness of governance, the level of accessibilities to city centre, different amenities, services (including healthcare) and infrastructure are estimated. The presence / absence of elected local body and their participation in planning are also considered.

4.3 Data, Methods and Tools

The planning of resources and provision of amenities are interrelated and requires an understanding of the current consumption patterns and level of access to various services across different socio-economic classes. In the planning perspective, it is important to consider the effect of mobility on sprawl. It is in this context that it attempts to characterise the level of access to services, mobility patterns and consumption patterns of resources across Greater Bangalore.

4.3.1 Data Sources

The data for the current study comprises both primary and secondary sources. In order to characterise the level of accession to services across Bruhat Bangalore Mahanagara Palike (BBMP) jurisdiction, a questionnaire-based household survey was conducted. Further to augment this with the spatial patterns of urban growth, remote sensing data was used. The following sections describe the strategy, size and mode of sampling for household survey and discuss on the satellite remote sensing data collection. The data were analysed by employing several analytical techniques discussed in the subsequent sections.

i. Questionnaire-based Household Survey

In Bangalore, there are numerous agencies concerned with delivery of various services. Accordingly, most of their jurisdiction does not overlap and hence collecting and collating data from these agencies to analyse and interpret are impossible. Thus, it required a questionnaire-based household survey across different zones of Greater Bangalore to determine the level of access to different services from healthcare to amenities and infrastructure.

Method of Sampling: Questionnaire-based Survey

The sampling was carried out based on a structured questionnaire (Appendix C) aimed at capturing the dimensions of:

1. Nativity
2. House ownership, house type & criteria for housing
3. Access to energy sources
4. Access to water, mode of disposal of wastewater and solid waste
5. Mobility patterns
6. Level of access to healthcare, amenities and infrastructure

The questionnaire was initially piloted for a sample size of 20 households and then modified (tuned) appropriately based on the initial feedback.

Sampling Strategy and Sample Size

The entire study area was stratified into two groups: one, the erstwhile city corporation limits-BMP area and two, the newly added regions of BBMP area. Map 2 depicts the regions accordingly.

The sample size was arrived at based on the following formula:

$$S = Z^2 * N * E(1 - E) / [(A^2 * N) + (Z^2 * E(1 - E))]$$

where,

S = Required sample size; Z = Factor for the desired confidence level; N = Population size; E = Expected error rate; A = Precision range.

Eight zones of Bruhat Bangalore comprises: 3 Zones of erstwhile BMP (with population of 4.5 millions) and 5 New Zones from CMCs and TMC (with population of 2.5 millions). For a sample size of 7 millions, with an error rate of 5%, precision range of 3% at 95% confidence level, the requisite sample size is 203. Further, distinguishing the earlier BMP (3 zones) region of 226 sq km and 5 new zones as two separate clusters, the total sample size for the survey were 421 (greater than approx. 203 x 2).

Map 2: Zones under Bruhat Bangalore Mahanagara Palike[10]

Data Collection

Stratified random sampling was undertaken capturing all the socio-economic classes in each zone based on house type. The number of samples in each zone was divided according to the low-income housing, middle-income housing and high income housing as different starting points. Accordingly, in the Bangalore East, Bangalore West and Bangalore South Zones the sample size were 75 each with about 7 starting points and 11 samples per starting point. In the five new zones, the sample size was about 42 each with about 7 starting points and 6 samples per starting point.

ii. Satellite Remote Sensing Data

The remote sensing data for land cover by NASA's Landsat TM for 1992 and Landsat ETM+ for 2000 was obtained from the Global Land Cover Facility (GLCF –

[10] RRNagara corresponds to the Raja Rajeshwari Nagara Zone of the Bruhat Bangalore Mahanagara Palike.

http://www.landcover.org/), Institute for Advanced Computer Studies, University of Maryland, United States of America. The land cover data, IRS LISS-III for 2006 was obtained from the National Remote Sensing Agency, Hyderabad, India.

iii. Secondary Data

The secondary data collected included the demographic details from the primary census abstracts for 1971, 1981, 1991 and 2001 from the Directorate of Census Operations, Census of India. Several other relevant data were obtained from various government departments including the Bruhat Bangalore Mahanagara Palike, Bangalore Development Authority, Bangalore Water Supply and Sewerage Board, Bangalore Metropolitan Transport Corporation, Bangalore City Police, Directorate of Economics and Statistics (Government of Karnataka), Karnataka State Pollution Control Board, Planning Commission of India, and Ministry of Urban Development (Government of India).

4.3.2 Research Method and Tools

i. Analysis of Survey Data

The analysis of the survey data began with their tabulation, sorting and exploratory data analysis. Exploratory data analysis restricted to estimation of averages and percentages for each of the parameter. The section on results presents these findings. The corresponding results were later tabulated according to the respective zones for undertaking further statistical analysis.

Multidimensional Scaling

In order to explore any structural underlying patterns: similarities or dissimilarities in the data, the multivariate statistical analysis using multidimensional scaling (MDS) were employed. MDS is non-parametric version of the principal coordinate analysis (PCoA). Given an association matrix between the units under comparison, the method attempts to find a representation of the units in a given number of dimensions while preserving the pattern / ordering in the association matrix.

MDS pictures the structure of a set of objects from data that approximate the distances between pairs of the objects. The data, which are called similarities, dissimilarities, distances, or proximities, reflect the amount of dissimilarity (between pairs of the objects). The term *similarity* generically refers to both similarities (where large numbers refer to great similarity) and to dissimilarities (where large numbers refer to great dissimilarity). The primary outcome of an MDS analysis is a spatial configuration, in which the objects are represented as points. The points in this spatial representation are arranged in such a way that their distances correspond to the similarities of the objects: similar objects are represented by points that are close to each other, dissimilar objects by points that are far apart. In non-metric MDS, only the ordinal information in the proximities is used for constructing the spatial configuration. A monotonic transformation of the proximities is calculated, which yields scaled proximities. Optimally scaled proximities are sometimes referred to as disparities $d' = f(p)$. The problem of non-metric MDS is how to find a configuration of points that minimises the squared differences between the optimally scaled proximities and the distances between points. More formally, let p denote the vector of proximities (i.e. the upper or lower triangle of the proximity matrix), $f(p)$ a monotonic transformation of p, and d the point distances; then coordinates have to be found, that minimise the so-called stress:

$$\text{Stress} = \sqrt{}\,(\Sigma\ (f(p)\text{-}d^2)/\Sigma(d^2))$$

MDS programs automatically minimise stress in order to obtain the MDS solution, while there exist, many versions of stress.

Judging the Goodness of Fit

The amount of stress may also be used for judging the goodness of fit of an MDS solution: a small stress value indicates a good fitting solution, whereas a high value indicates a bad fit. Kruskal (1964, In: Wickelmaier, 2003) provided some guidelines for the interpretation of the stress value with respect to the goodness of fit of the solution (Table 4-2).

Table 4-2: Stress and goodness of fit

Stress	Goodness of fit
> 0.20	poor
0.10	fair
0.05	good
0.025	excellent
0.00	perfect

Stress decreases as the number of dimensions increases. Thus, a two-dimensional solution always has more stress than a three-dimensional one. Since the absolute amount of stress gives only a vague indication of the goodness of fit, there are two additional techniques commonly used for judging the adequacy of an MDS solution: the scree plot and the Shepard diagram. The Shepard diagram displays the relationship between the proximities and the distances of the point configuration. Less spread in this diagram implies a good fit. In non-metric MDS, the ideal location for the points in a Shepard diagram is a monotonically increasing line describing the so-called disparities, the optimally scaled proximities (Wickelmaier, 2003).

ii. Remote Sensing Data Analysis

The remote sensing data are initially processed to quantify the land-use of Bangalore city broadly into four classes – built-up, agriculture and vegetation, open land, and water bodies. The multi-spectral data of Landsat TM and Landsat ETM+ with a spatial resolution of 30 m each and IRS LISS-III with a spatial resolution of 23.5 m were analysed using IDRISI Andes (Eastman, 2006). The image analyses included image registration, false colour composite (FCC) generation, enhancement and classification. The image geo-registration was rectified with respect to the ground control points collected from the geo-referenced Survey of India toposheets. The images were rectified using a linear mapping function for the ground control points and the nearest neighbourhood resampling type. After image geo-registration, the false colour composites were generated using the bands: green, red and near-infrared (Figure 4-2). The next step involved classification of the multi-spectral remote sensing data, which was carried through a two-stage classification process: unsupervised and supervised. The ISOCLUST module, which is an iterative self-organising unsupervised classifier based on a concept similar to the well-known ISODATA routine (Ball and Hall, 1965; In: Eastman, 2006) and cluster routines such as the H-means and K-means procedures was used for performing the unsupervised classification. In the unsupervised classification the number of clusters for classification was identified through the number of distinct peaks obtained from the histogram. For the supervised classification the signatures were derived from the training data obtained in the field using global positioning system (GPS) for distinctive land-uses and some of the land-use features obtained from unsupervised classification. The signatures were generated for each of the land-uses and were verified with the composite image. Based on these signatures, corresponding to various land features, supervised image classification was done using Gaussian Maximum Likelihood Classifier (Maps 3, 4 and 5). The Maximum Likelihood classification is based on the probability density function associated with a particular training site signature. Pixels are assigned to the most likely class based on a comparison of the posterior probability that it belongs to each of the signatures being considered. This is also known as a Bayesian classifier since it has the ability to incorporate prior knowledge using Bayes' Theorem. Prior knowledge is expressed as a prior probability that each class exists. It can be specified as a single value applicable to all pixels, or as an image expressing different prior probabilities for each pixel (Eastman, 2006). Post classification from the IRS LISS-III data for 2006 was resampled to 30 m so as to enable comparison with the Landsat data outputs.

The classification accuracy was tested for the classified images using some of the training data collected and generated during the classification process. These were compared with the classified land-uses with the actual land-use. For the recent (2006) IRS LISS-III data, there were ground control points obtained from the field that were used in comparison. However, for the earlier time data (1992 and 2000), some of the control points with known land-use classes were used as reference along with the false colour composite image to ascertain the accuracy of classified land-use classes. The classification accuracies of Landsat TM (1992), Landsat ETM+ and IRS LISS-III were 76.9 %, 84.6 % and 71.8 % respectively.

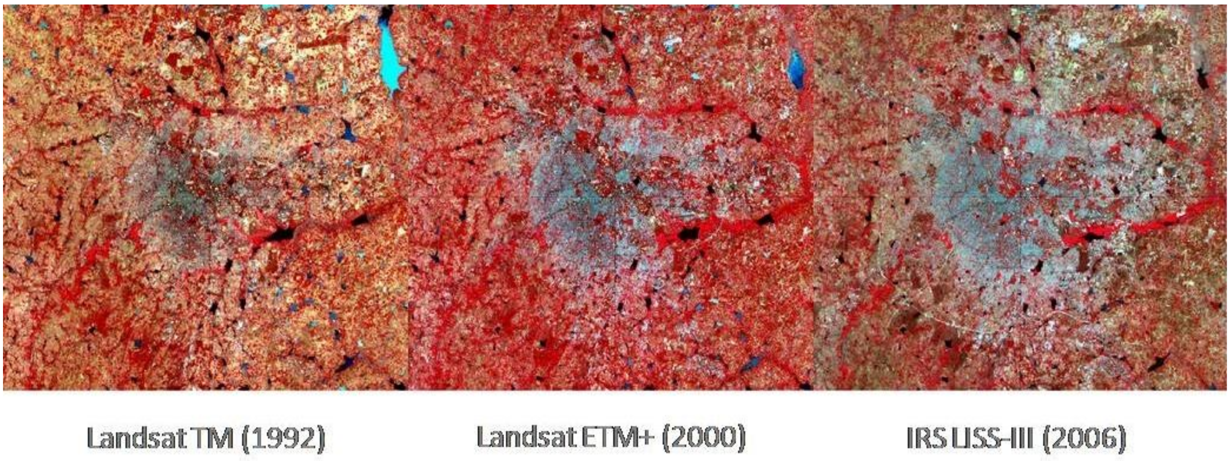


Figure 4-2: False colour composites for 1992, 2000 and 2006

4.4 Results and Discussions

4.4.1 Demography and Economy

i. Nativity

Among the first set of indicators that were enumerated based on the samples was the nativity of respondents (Figure 4-3) in different zones of BBMP. This indicates that Bangalore West and

East zones had more than 80 percent natives while Bangalore South zone had only about 45 percent natives similar to most of the zones in the periphery. It appeared that most migrants were in Raja Rajeshwari Nagara (RR Nagara) zone followed by Bommanahalli, Byatarayanapura, and Dasarahalli zones.

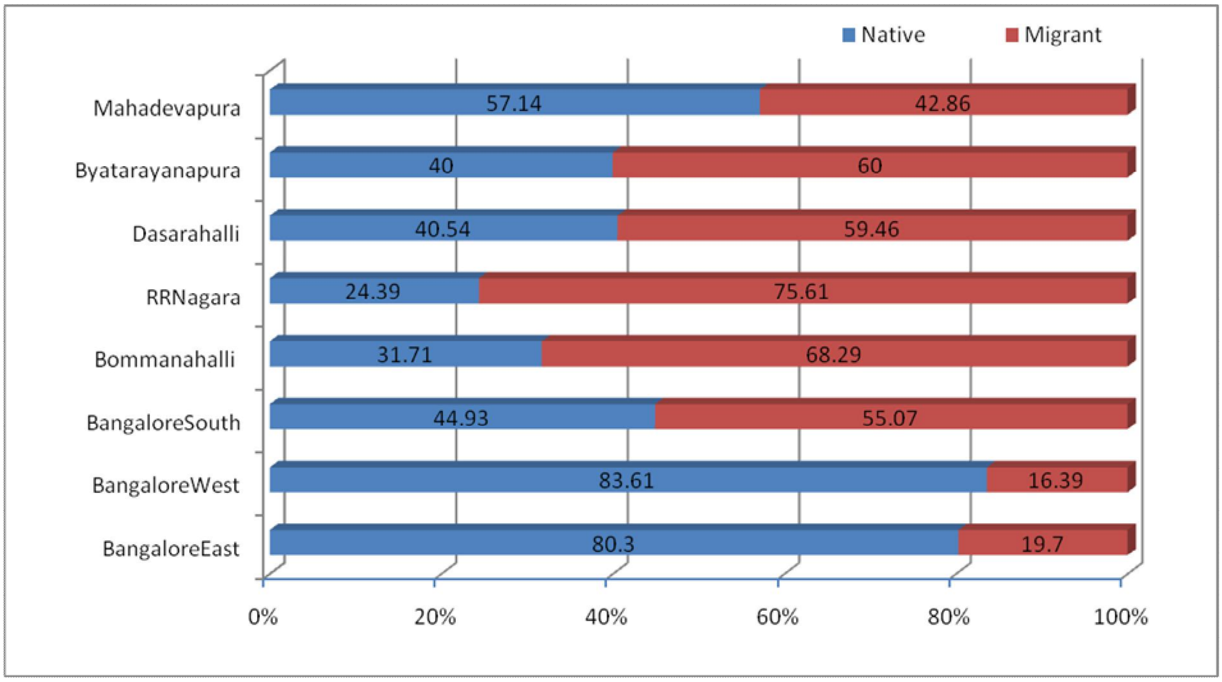


Figure 4-3: Nativity among the residents

ii. House Ownership, Type and Criteria for Housing

The next set of indicators addressed house ownership, housing type and criteria for housing. They appeared to be positively correlated but the correlation was not statistically significant ($r= 0.68$; $p=0.065$) with the houses owned and nativity. The percentage of residents living in rented houses appeared to be higher than those living in their own houses in Mahadevapura, Raja Rajeshwari Nagara, Bommanahalli and Bangalore South zones (Figure 4-4).

Further, majority of the houses were brick-walled with RCC roofing except fewer instances in Raja Rajeshwari Nagara and Bommanahalli, where majority of the houses were brick-walled with asbestos sheet roofing (Figure 4-5). The hut / mud walled type of houses mostly belonging to urban poor settlements was observed from Bangalore West and Byatarayanapura zones.

The criteria for choosing the new residence were ranked on a scale of 1 to 5, where 1 was the most preferred and 5 the less preferred. Among the choices provided were: access to services, access to education, access to workplace, land prices or rent value and proximity to city centre or main roads. Accordingly, the mean rankings for all the criteria are shown in Table 4-3 and Figure 4-6 with respect to each zone. It showed that ‘access to workplace’ emerged as the top criteria with a mean ranking of 1.97 followed by access to services (2.13), land prices or rent value (2.68), access to education (3.00) and proximity to city centre or main roads (3.04). The criteria of proximity to city centre or main road getting the least rank amongst the rest of the ranks suggests that residents may actually prefer to stay away from the city (even in the outskirts) as long as it is closer to their workplace and they have access to services.

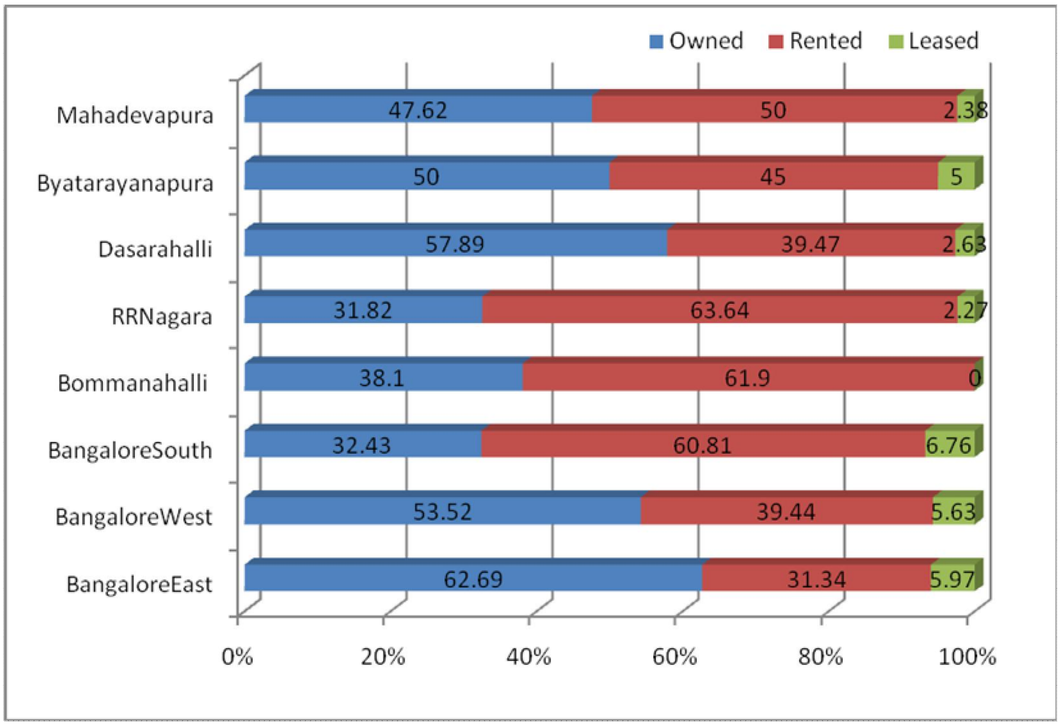


Figure 4-4: House ownership

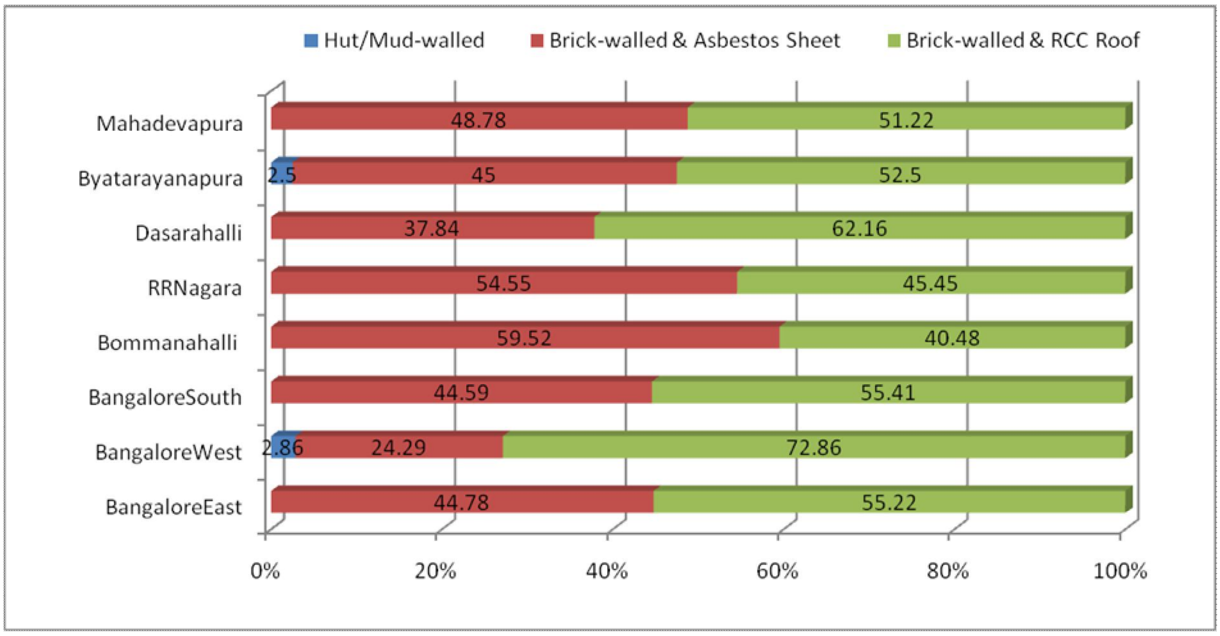


Figure 4-5: House type

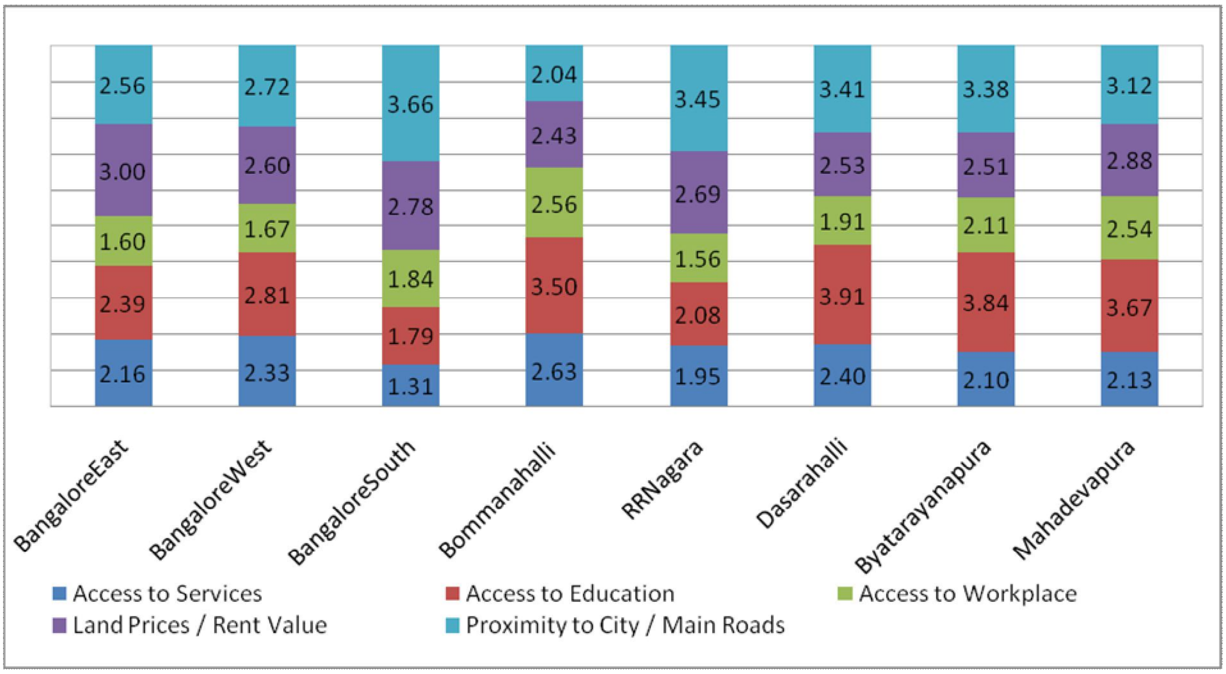


Figure 4-6: Criteria for housing

Table 4-3: Mean ranking for housing criteria

Criteria for Housing	Mean Ranking
Access to Workplace	1.97
Access to Services	2.13
Land Prices / Rent Value	2.68
Access to Education	3.00
Proximity to City / Main Roads	3.04

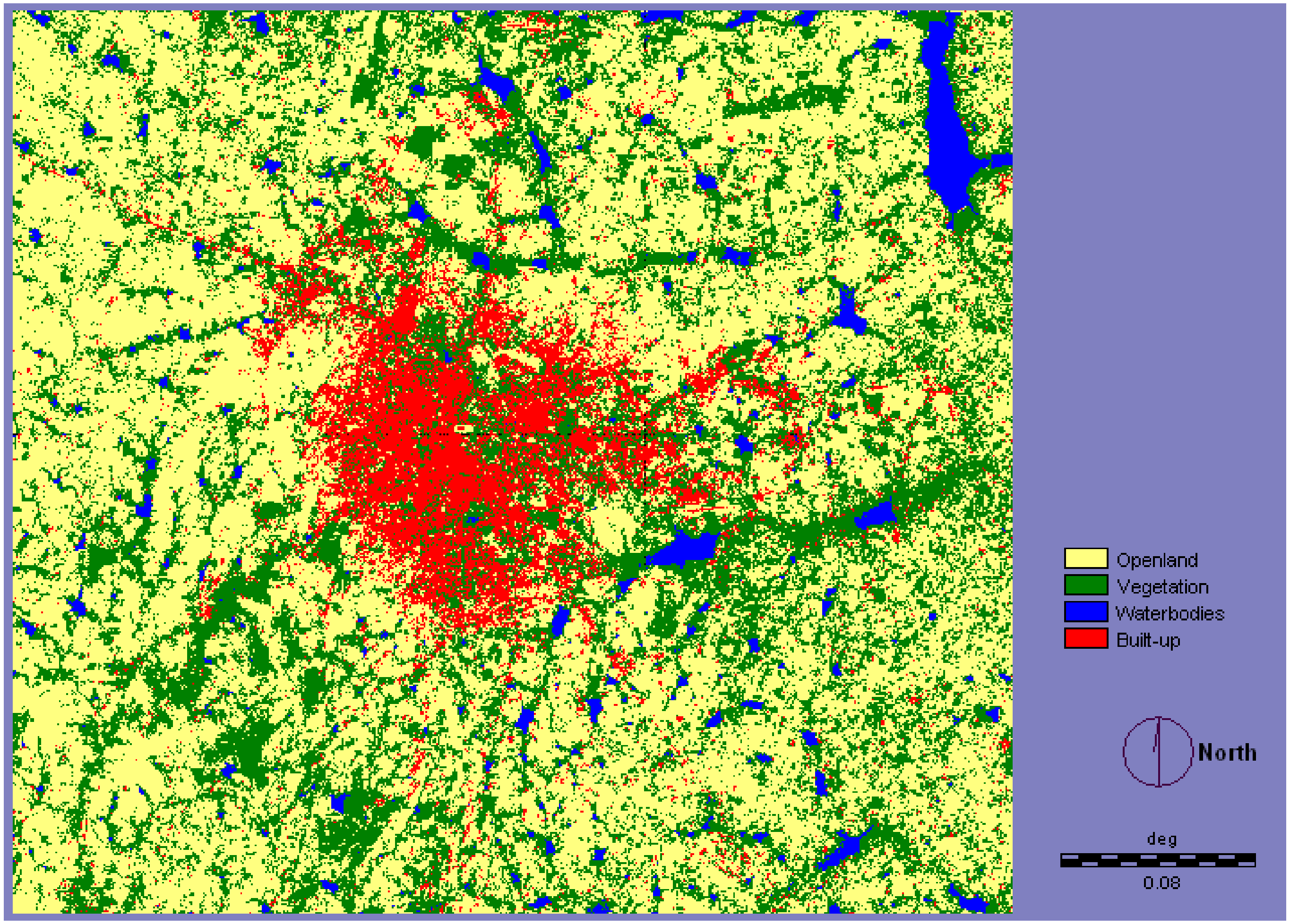
4.4.2 Environment and Resources

i. Land-use

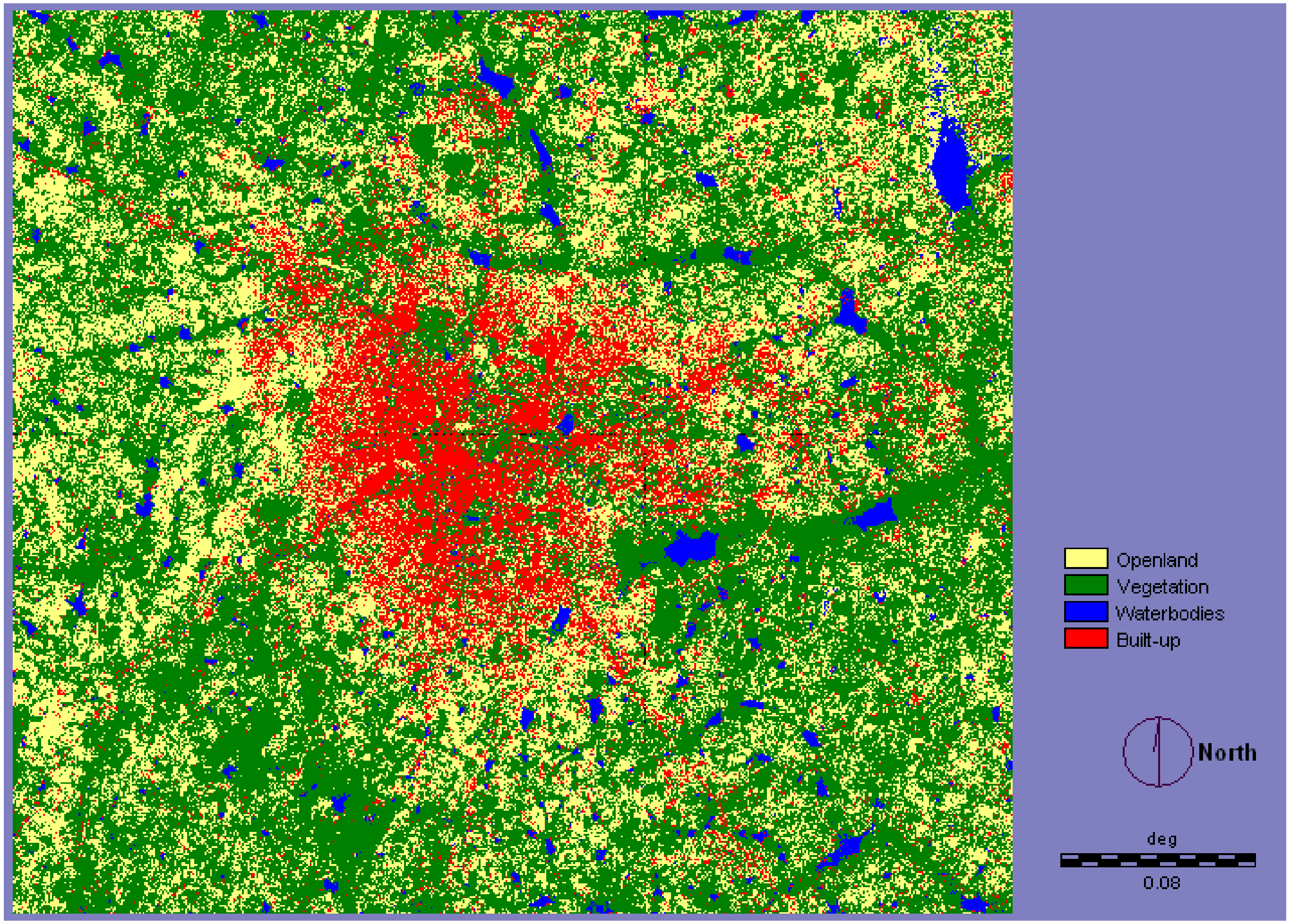
Typically the degree of urban growth or sprawl is attempted by quantifying the amount of paved surface or built-up area in a given region obtained from the classification of remotely sensed data or other geospatial data (Torrens and Alberti, 2000; Barnes *et al*., 2001; Galster *et al*., 2001; Epstein, Payne, and Kramer, 2002). Characterising the pattern of urban sprawl would then rest on noting the extent of built-up areas and its associated measures that depict sprawl based on the notion of built-up or paved area. A key aspect in the expansion of built-up area is its engulfing of surrounding open spaces within the landscape. It is noted that prevalence of open spaces like water bodies, vegetation, open land, etc. are landscape elements. Addressing urban growth resulting in sprawl at a landscape level, this expanse is ascribed as erosion of landscape elements. Hence, an attempt is made to assess the extent and pattern of such expanse while answering whether urban sprawl has resulted in erosion of landscapes leading to loss of open spaces comprising water bodies, vegetation, etc.

a. Land-use Change Detection

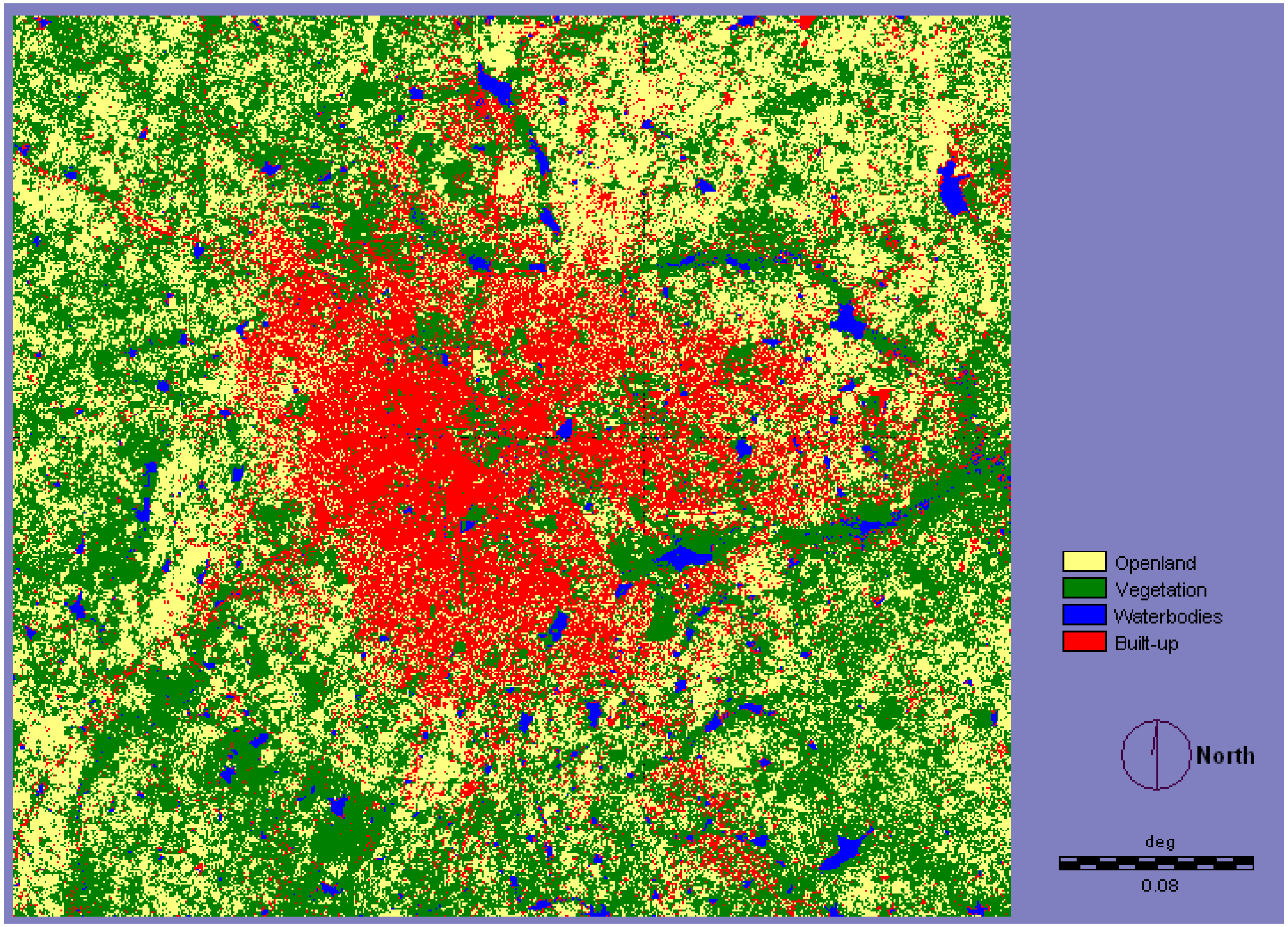
The spatial analysis was performed at the landscape level extending beyond the Greater Bangalore's administrative boundary. The classified images for land-use in 1992, 2000 and 2006 are shown in Maps 3, 4 and 5. The extent of land-use during 1992, 2000 and 2006 comprised built-up with 142.54 sq. km, 186.42 sq. km and 301.27 sq. km respectively. Similarly, the extent of non-built-up area comprising open land, vegetation and water bodies were 1449.35 sq. km, 1405.42 sq. km and 1291.58 sq. km during 1992, 2000 and 2006 respectively. The land-use change analysis was carried out based on the differences in temporal land-uses. During 1992 to 2000, it is observed that the extent of built-up area has increased by 30.8 percent, while the built-up area increased by 61.61 percent during 2000 to 2006 (Table 4-4). The extent of increase in built-up area depicts only the magnitude of change and does not suggest the pattern of this transition. Analysing the probable land-use change from various non-built-up classes to built-up the cross-tabulation for the classified images were performed. It was noted that during 1992 to 2000, the land-use change from open land into vegetation was significant as the data corresponded to different seasons. The major land-use that contributed to the increase of built-up area was by the open land-use class. Similarly, during 2000 to 2006, the vegetation was the major land-use that was lost (by almost 180 sq. km) due to conversions into built-up areas.



Map 3: Land-use classification - Bangalore (Landsat TM 1992)



Map 4: Land-use classification - Bangalore (Landsat ETM+ 2000)



Map 5: Land-use classification - Bangalore (IRS LISS-III 2006)

Table 4-4: Extent of land-use change among built-up and non-built-up

Land-use	1992 (sq. km)	2000 (sq. km)	2006 (sq. km)	Percentage Change (1992-2000)	Percentage Change (2000-2006)
Built-up	142.54	186.42	301.27	+ 30.78	+ 61.61
Non Built-up	1449.35	1405.47	1291.58	- 03.03	- 08.10

b. Landscape Metrics for Characterising Sprawl

Characterising landscape properties at the landscape level involves calculating the fragmentation, patchiness, porosity, patch density, interspersion and juxtaposition, relative richness, diversity, and dominance in terms of structure, function, and change (ICIMOD, 1999; Civco *et al.,* 2002). The landscape metrics, normally used in investigations of landscape ecology are extended here to characterise the pattern of urban sprawl.

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. In order to quantify urban sprawl in terms of spatial patterns, the landscape metrics (patchiness, built-up density) were computed.

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 3x3 window (Maps 6, 7 and 8). The computation of patchiness using 3x3 moving window revealed that single class category was maximum in 1992 (47.5 %) while the 2 heterogeneous class category were maximum in 2000 (51.58 %) and 2006 (52.86 %). The minimum distribution of patches was that of 4 heterogeneous classes with 0.16 % in 1992, 0.72 % in 2000 and 0.48 % in 2006 (Figure 4-7). This also revealed that the change in homogeneous patch came down from 47.5 % in 1992 to 30.12 % in 2000 and subsequently to 26.47 % in 2006. The 3 heterogeneous class category has shown steady increase from 8.81 % in 1992, 17.57 % in 2000 to 20.19 % in 2006.

Map density values are computed by dividing number of built-up pixels to the total number of pixels in a kernel. This converts land cover classes to density classes, which is given in Maps 9, 10 and 11. Depending on the density levels, it could be further grouped as low, medium and high density (Maps 12, 13 and 14). Based on this, relative share of each category was computed (area and percentage). The computation of built-up density gave the distribution of 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 areas, while medium density would refer to relatively lesser compact built-up and low density referred to loosely or sparsely spread built-up areas. The high-density built-up area showed variation from 23.98 % in 1992 to 15.65 % in 2000 and 22.80 % in 2006. However, the low-density built-up area, which increased from 55.71 % in 1992 to 62.41 % in 2000, came down to 53.06 % in 2006 (Figure 4-8). This revealed that the compact or high density built-up proportionally decreased during 1992-2000 but eventually has again increased during 2000-2006. Further, the low density built-up increase during 1992-2000, suggested more dispersed growth. However, the low density built-up has decreased during 2000-2006 paving way for high density built-up in 2006 (22.80 %). It is observed the low and medium density areas were found all along the periphery of the city and high density was dominated in the core city. The distribution of low density was the maximum in the study area and this can be inferred as the higher dispersion of the built-up in the study area.

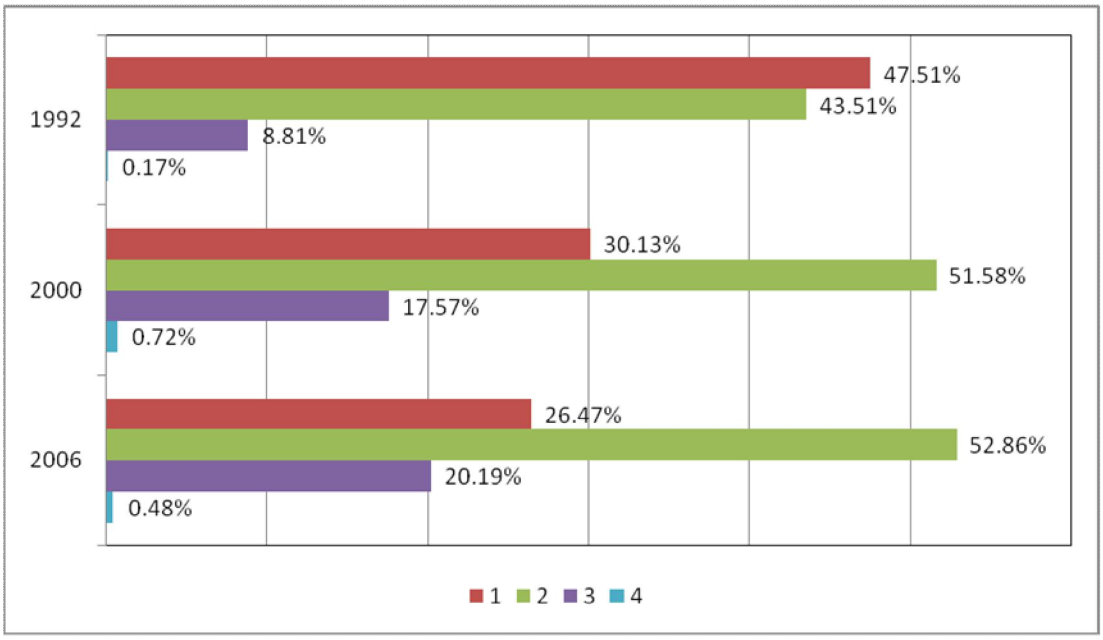


Figure 4-7: Percentage distribution of patchiness or number of different classes

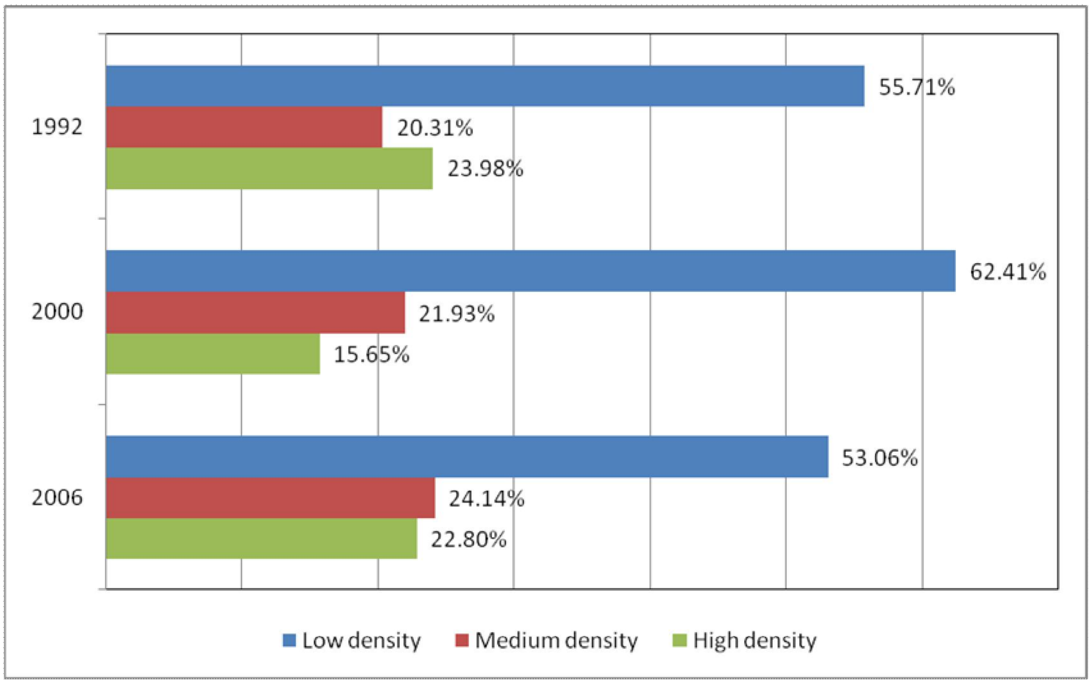
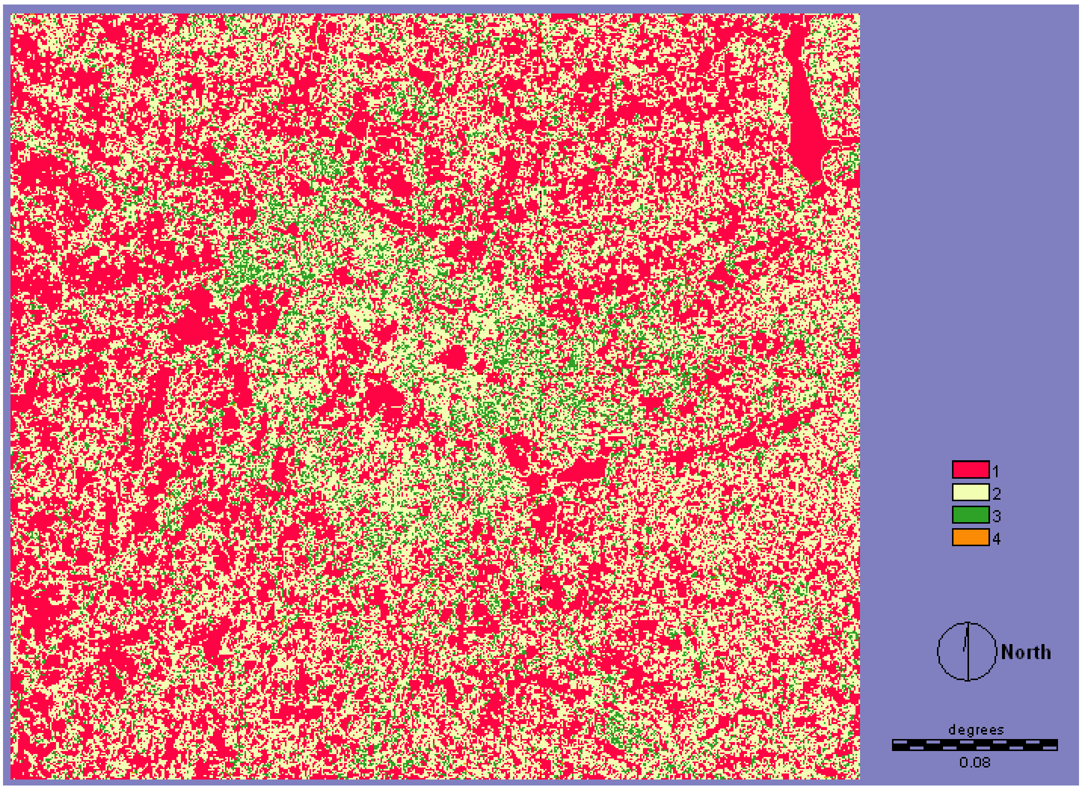
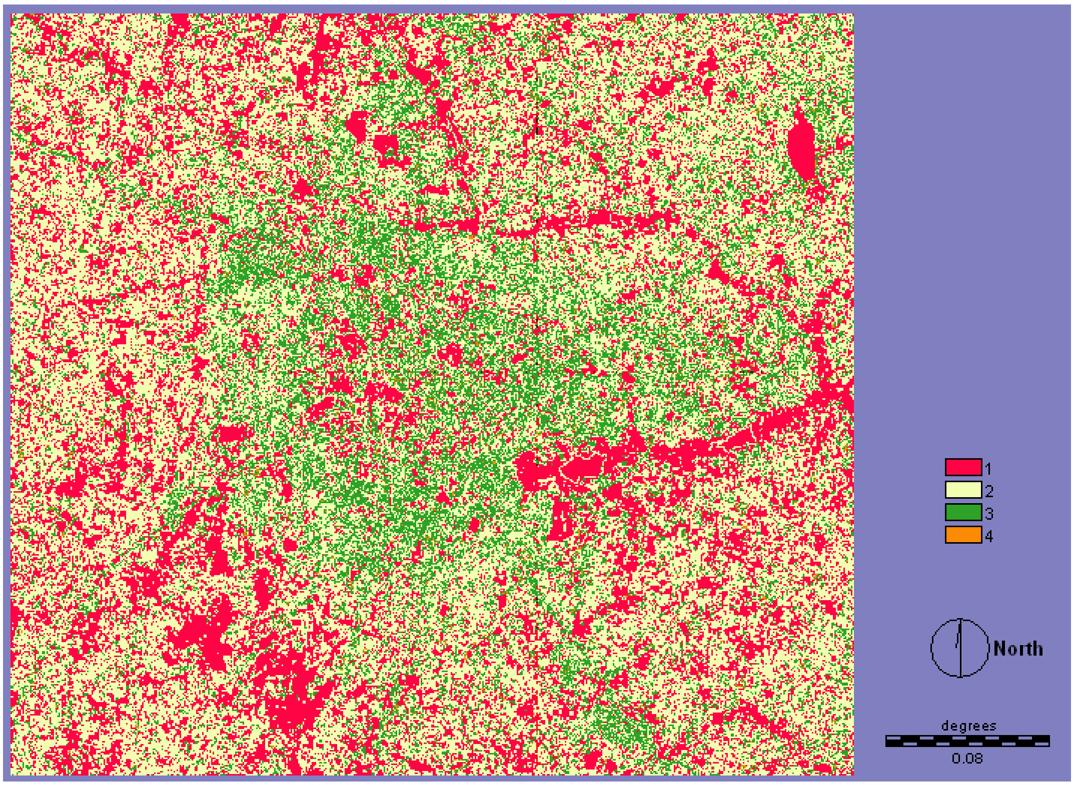


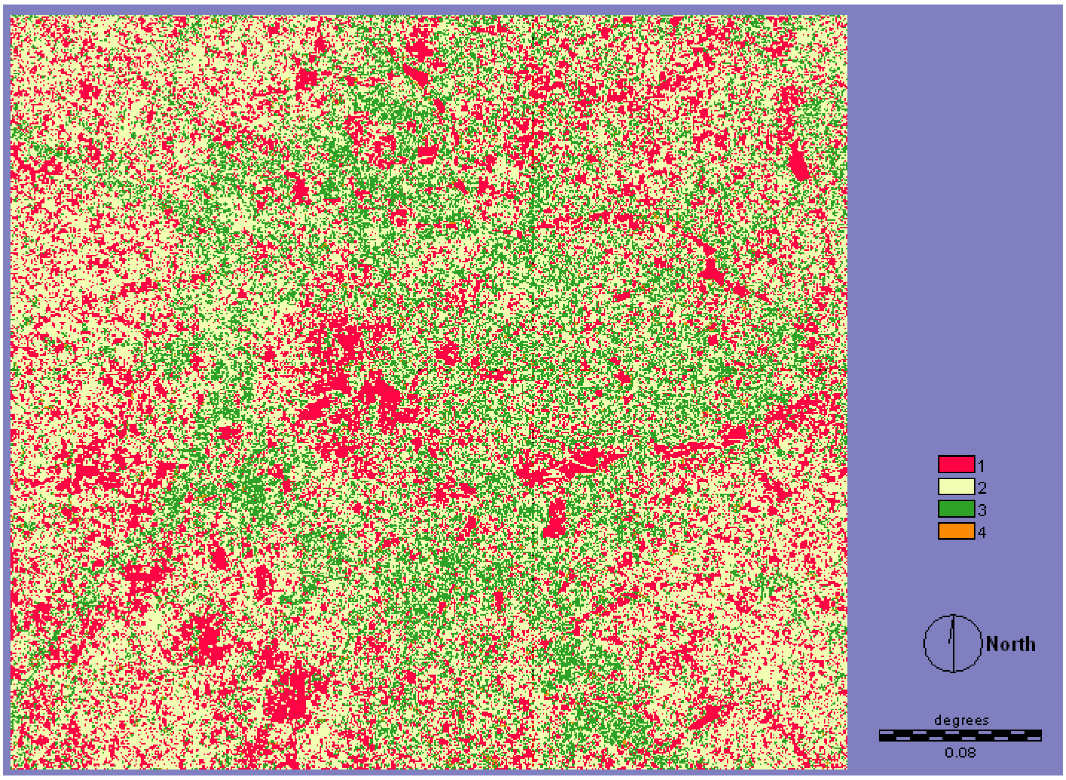
Figure 4-8: Percentage distribution of built-up densities



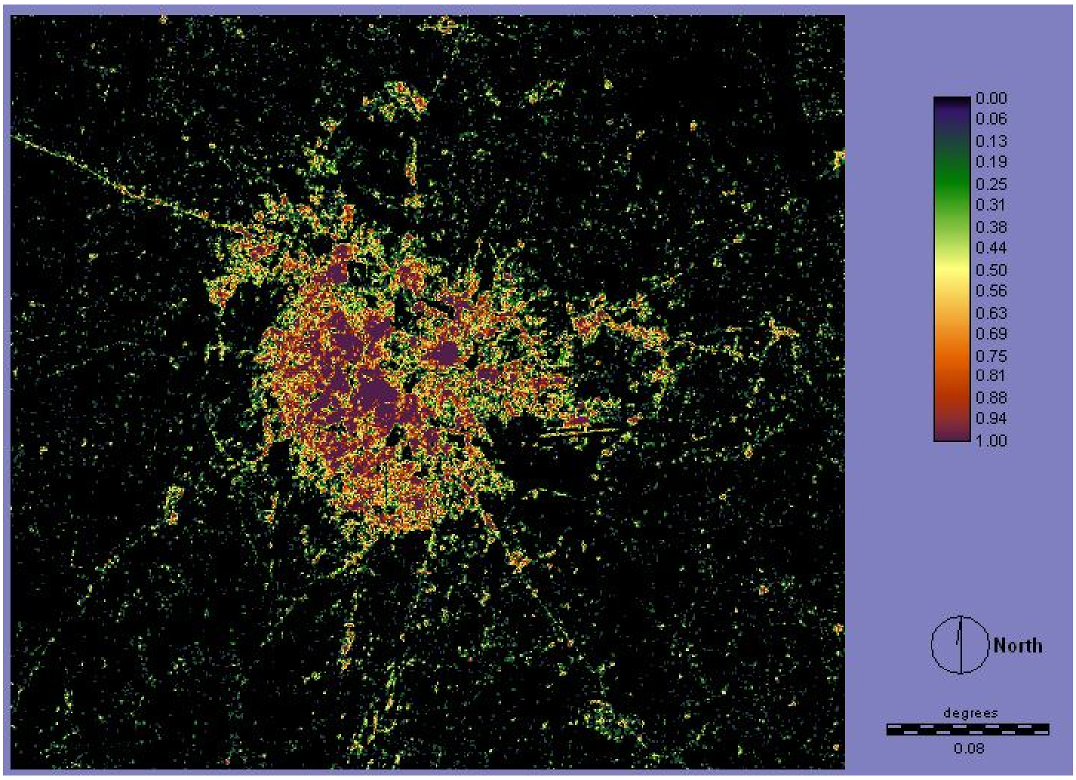
Map 6: Patchiness in 1992



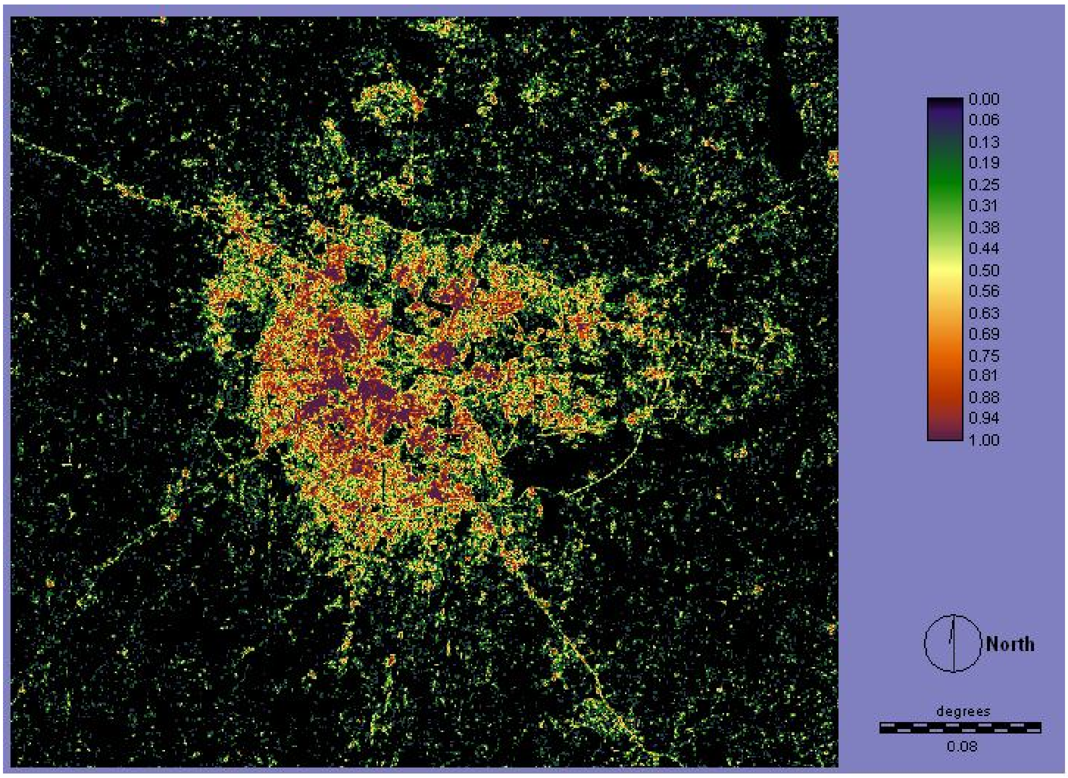
Map 7: Patchiness in 2000



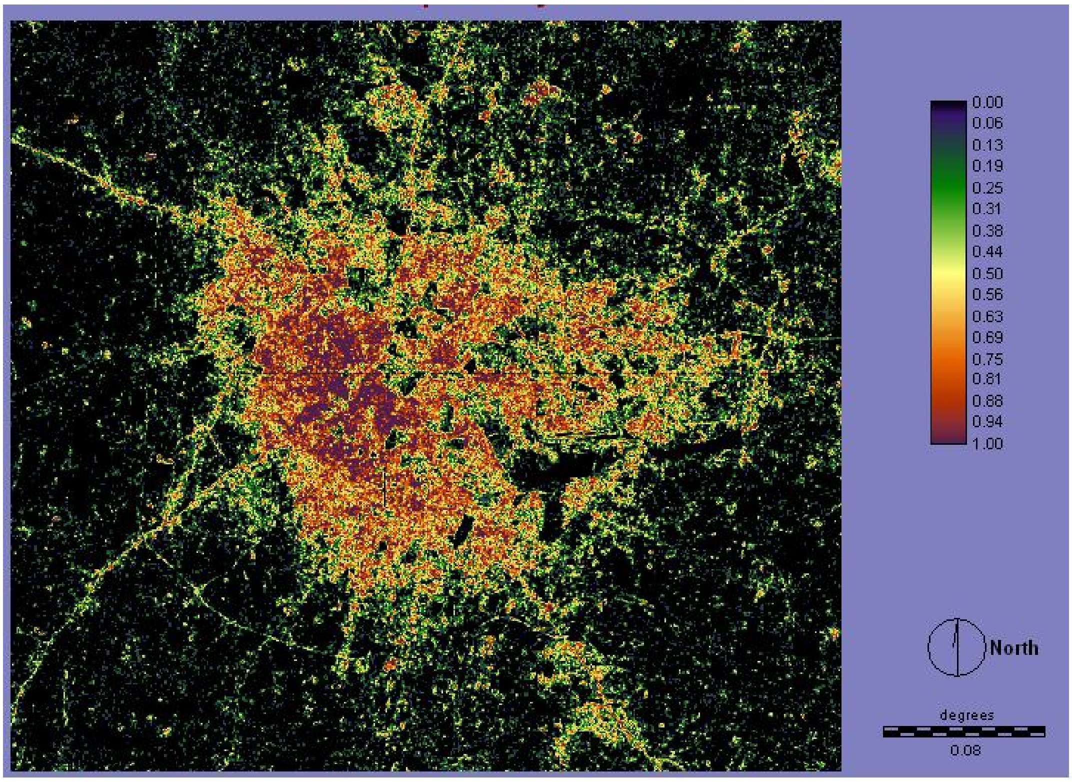
Map 8: Patchiness in 2006



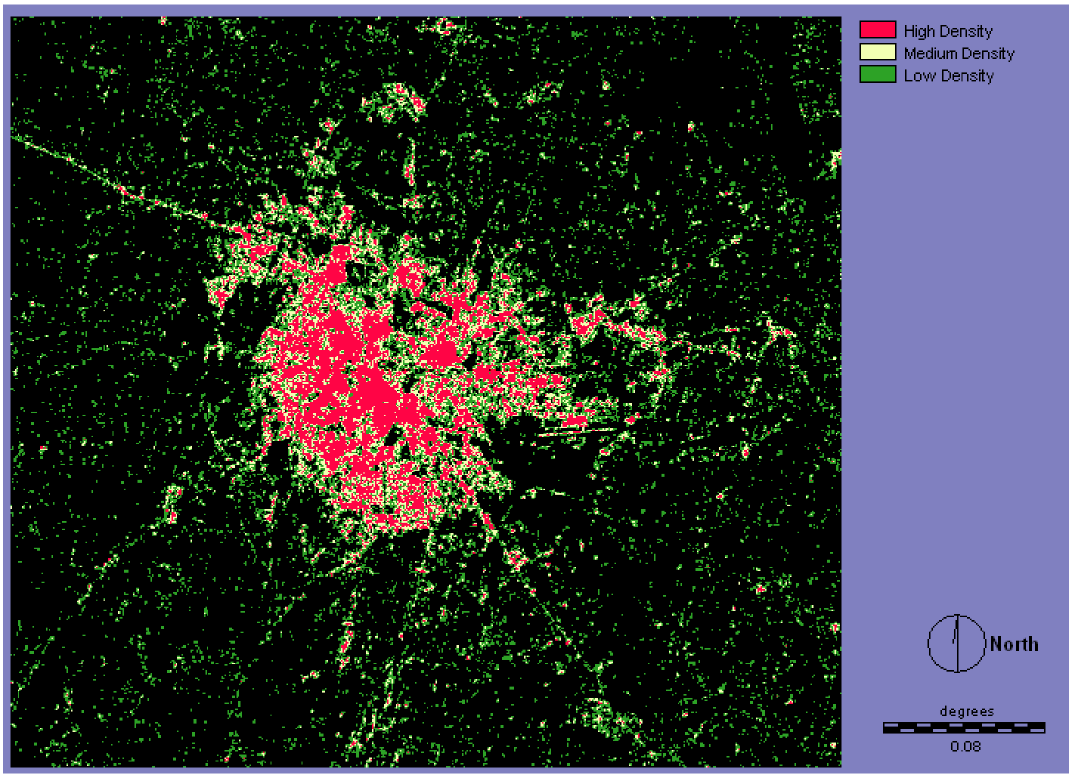
Map 9: Built-up density in 1992



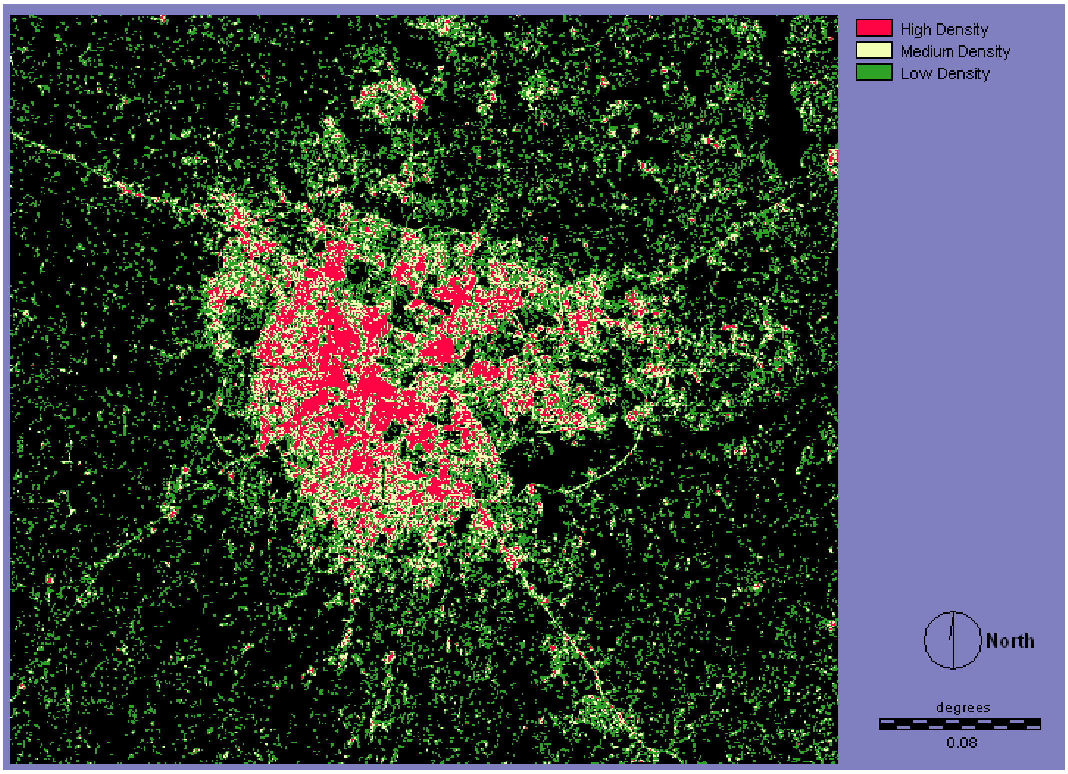
Map 10: Built-up density in 2000



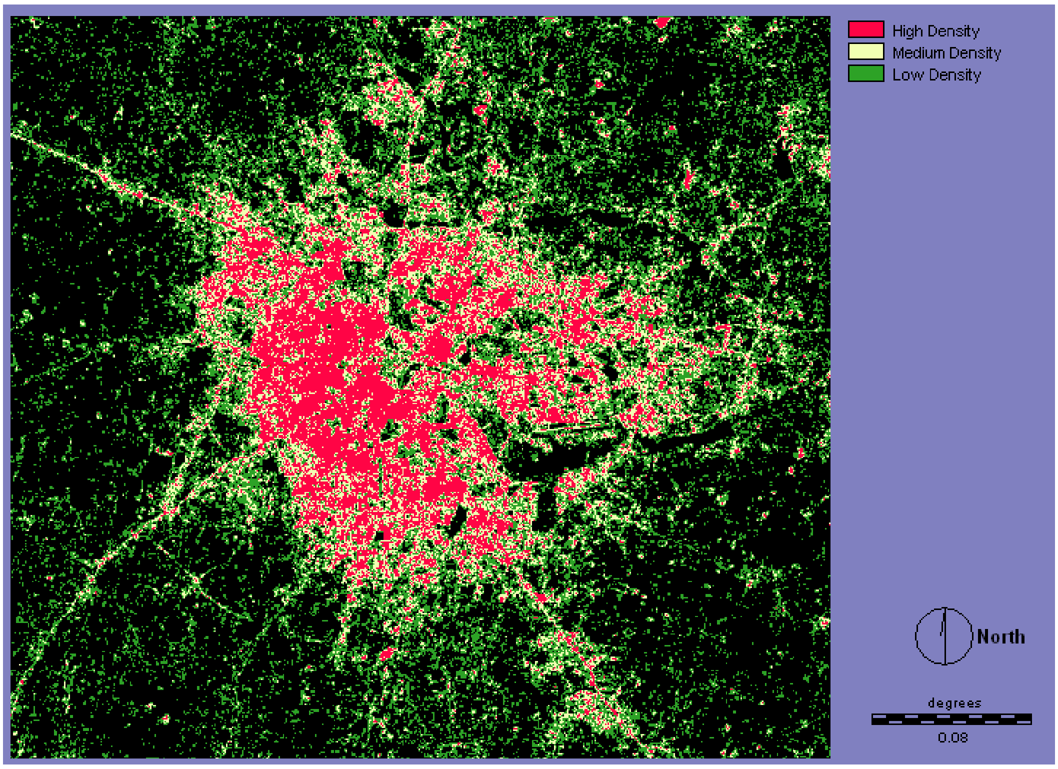
Map 11: Built-up density in 2006



Map 12: Classified built-up densities - 1992



Map 13: Classified built-up densities - 2000



Map 14: Classified built-up densities – 2006

c. *Land-use Changes in Bruhat Bangalore*

The proportion of land-use changes especially the percentage built-up area, which is a key metric to measure sprawl, were estimated across all the zones of Bruhat Bangalore Mahanagara Palike. The corresponding land-use changes within the BBMP region are shown in Table 4-5. It was clearly evident that on an average the increase in built-up area in the central zones was from 47.8 %, to 64.2 %, while in outer zones built-up area shot from a mere 6.8 % in 1992 to 25.6 %. This implies that the change in built-up areas in the central zones being about 35 % while the change in built-up areas in the outer zones was nearly 300 %. Perhaps the relatively higher percentage of built-up areas during 1992 in Dasarahalli zone and Mahadevapura zones with 10.04 % and 8.03 % respectively, may be due to the industrial estates in these locations while by 2006 this has increased to 30.32 % and 26.89 %. Further, while the change in built-up areas in central zones increased modestly, this indicated these zones were getting denser. However, it was noted that there was a slight reduction in the percentage built-up area in Bangalore West zone for 2000. Perhaps this should be viewed in the light of classification accuracies for the respective time data. Among the outer zones, Bommanahalli has witnessed the highest relative change in percentage built-up areas from 5.05 to 27.90 indicating the magnitude of growth in the region. Indeed this change in land-use here may be attributed to the IT based companies located in the region and the proximity to the Electronic city along the Hosur Road.

Table 4-5: Percentage built-up areas across zones

	1992	2000	2006
Bangalore East	35.79	37.30	50.93
Bangalore West	58.09	54.23	69.38
Bangalore South	49.54	54.48	72.47
Bommanahalli	5.05	11.08	27.90
RRNagara	4.70	8.24	18.87
Dasarahalli	10.04	16.56	30.32
Byatarayanapura	6.01	11.15	24.01
Mahadevapura	8.03	13.28	26.89

ii. *Energy Sources*

The assessment of access to energy sources reveal that electricity and LPG were among the most widely accessed source (Figure 4-9). Firewood is still used mostly in the new zones especially Raja Rajeshwari Nagara, Bommanahalli, Dasarahalli and Mahadevapura zones followed by kerosene in Bommanahalli and Bangalore East zones. Perhaps, the availability of firewood being more accessible in the periphery of the city explains the larger number of residents accessing this source. It was further interesting to note that solar energy was being tapped mostly in the newly constructed houses in the new zones. The other energy sources that were accessed though not in large numbers were: charcoal, biogas and dung / waste. Electricity was the most accessed source for lighting and minimally for water heating and cooking, while LPG was the source accessed most for cooking. Firewood was used mostly for water heating followed by cooking.

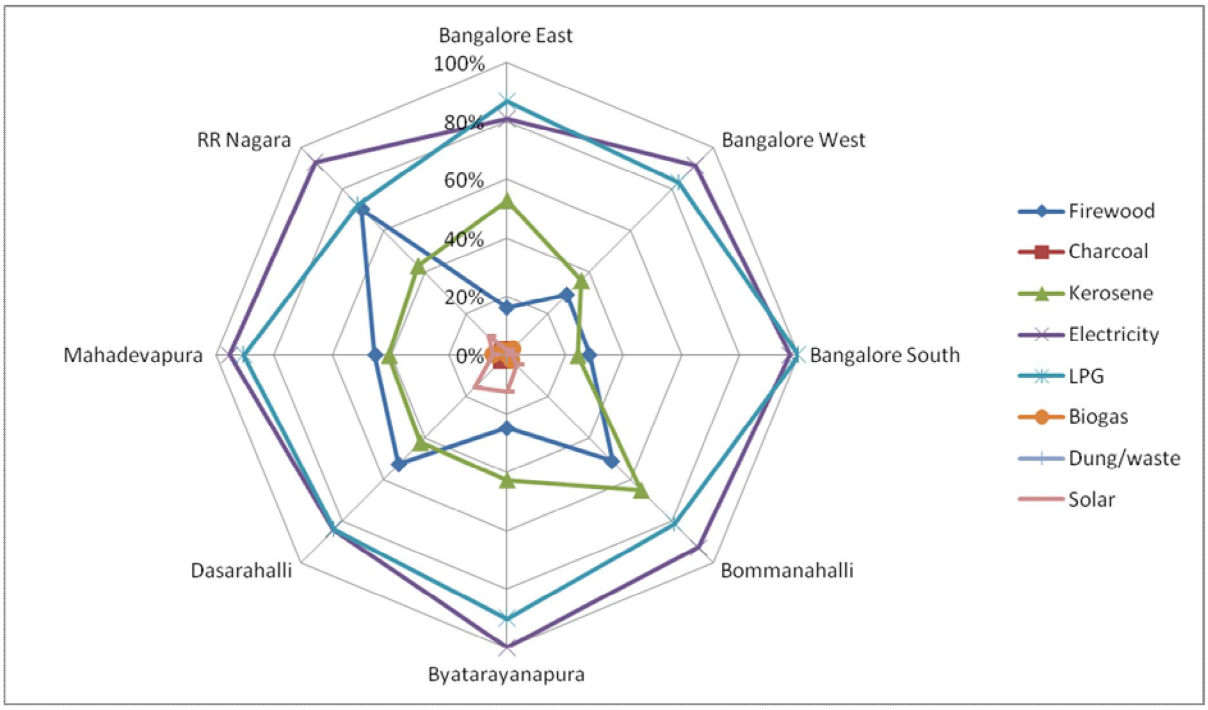


Figure 4-9: Energy resources accessed

iii. Water, Mode of Disposal of Wastewater and Solid Waste

Water is one of the key resources and therefore is accessed from different sources. In the central zones of Bangalore, viz. East, West and South, the source of supply was mainly from Bangalore Water Supply and Sewerage Board (BWSSB) for nearly 90 % of the residents (Figure 4-10). The erstwhile City Municipal Council (CMC) administered water supply with as much as 80 % to the outer zones of Byatarayanapura and Raja Rajeshwari Nagar. However, in the Bommanahalli, Dasarahalli and Mahadevapura zones 60 % of the respondents were serviced by CMC sources. This has resulted in residents sourcing water from private water supply (through tankers), followed by bore-wells, community taps and other sources in Bommanahalli, Dasarahalli and Byatarayanapura zones.

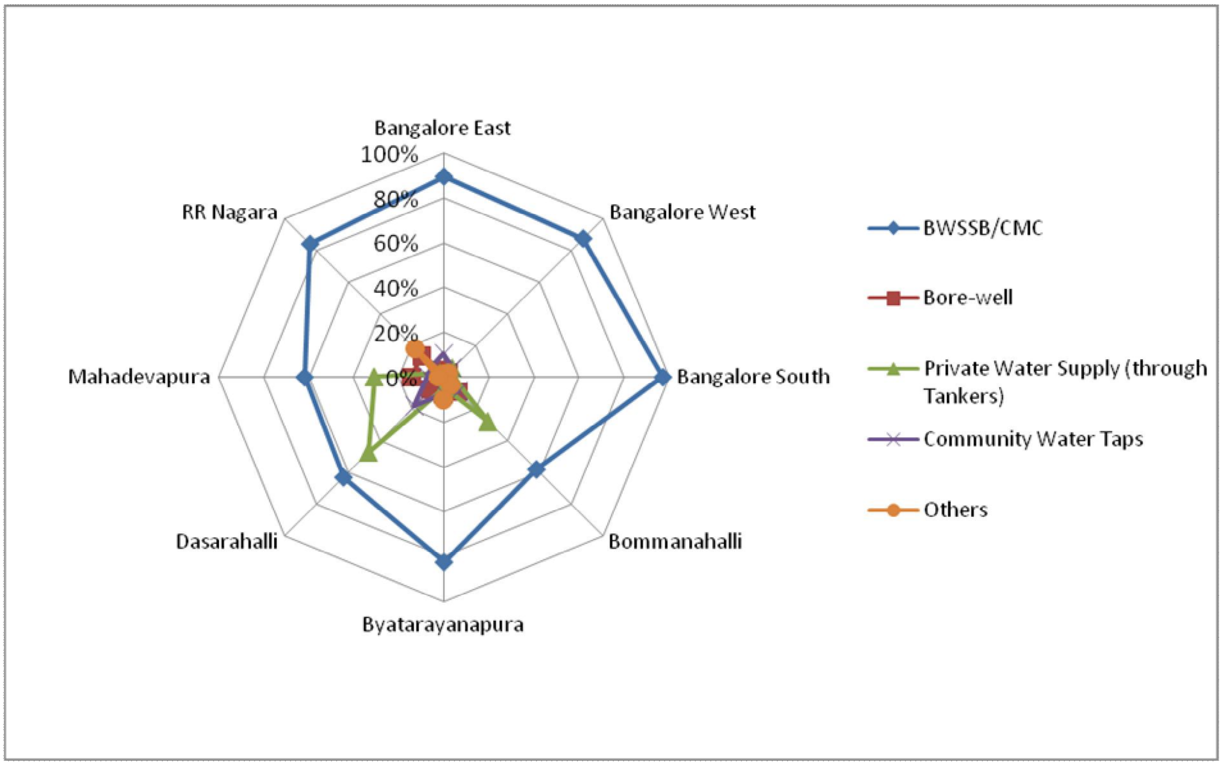


Figure 4-10: Sources of water supply

In spite of shortfalls in supplying water to all zones by the BWSSB and respective municipal councils, the sewage collection in the zones appeared to be well serviced through higher sewer connections (Figure 4-11). It was revealed that the central zones of Bangalore: East, West and South followed by Mahadevapura zone was serviced with sewer connections to almost 100 %. However, the outer zones of Bommanahalli, Byatarayanapura, Dasarahalli and Raja Rajeshawari Nagar zones were serviced between 60 to 80 %. Sewage disposal by way of septic tank was more prevalent in Dasarahalli, Byatarayanapura and Bommanahalli zones.

Similar to the water supply and sewage collection, the solid waste collection too indicated that the central zones of Bangalore: East, West and South were better serviced with more than 85 % of solid waste collected through door-to-door collection (Figure 4-12). Among the outer zones, only Byatarayanpura had a better coverage for the door-to-door collection with about 75 %, while Mahadevapura and Bommanahalli zones had coverage of about 60 %. The Raja Rajeshwari Nagara zone had coverage of about 50 % while Dasarahalli zone was the least covered with less than 20 % for door-to-door collection. In the zones where the door-to-door collection was poor, road-side dumping was more prevalent

(Dasarahalli, Raja Rajeshwari Nagara and Bommanahalli zones) followed by disposal in community bins and a combination of all the above three methods of disposal.

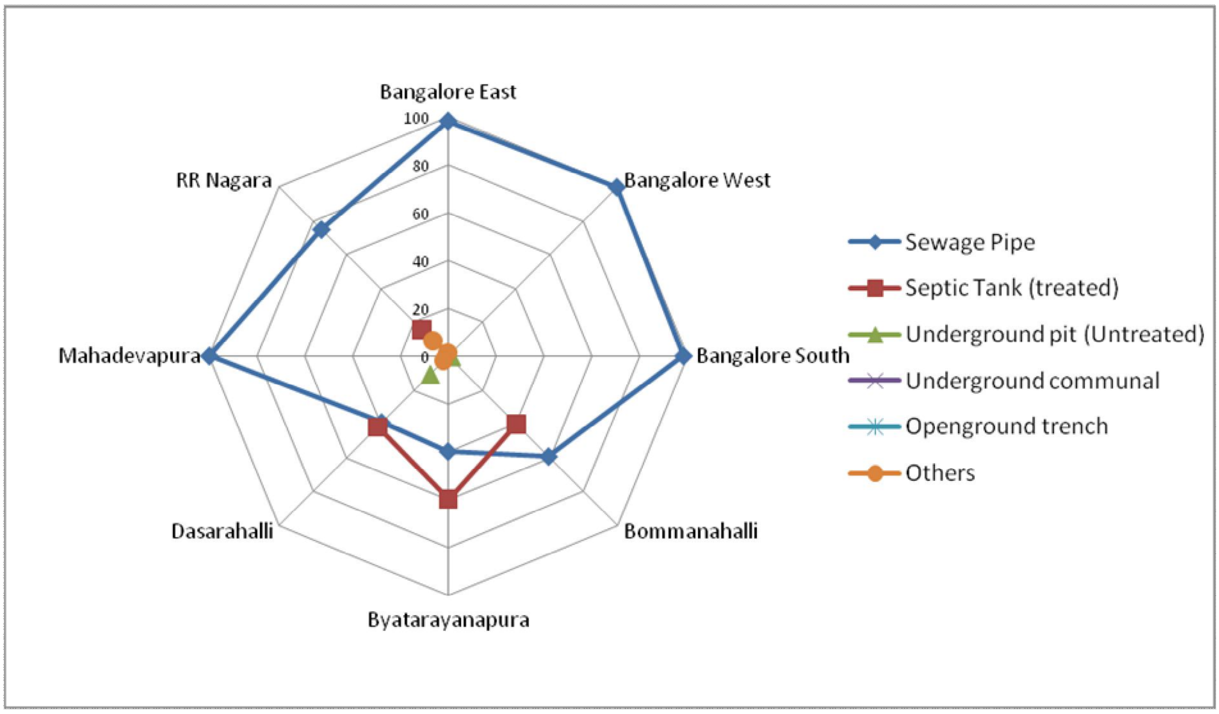


Figure 4-11: Mode of wastewater disposal

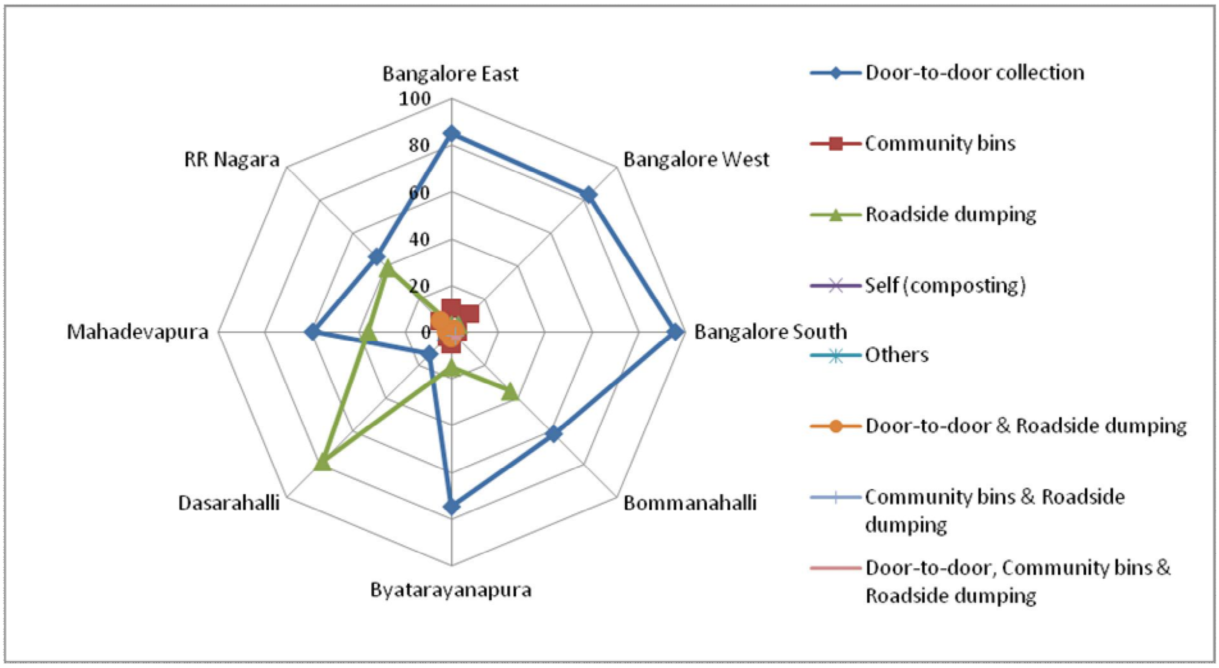


Figure 4-12: Solid-waste disposal

These indicators clearly depict that the central zones were well serviced in comparison to the outer zones in terms of water supply, wastewater collection and solid waste collection. This also brings out how different zones fare in delivery of these services.

4.4.3 Mobility

One of the key city functions, that is regarded as a metric, is mobility, which determines why and how citizens are commuting within the city. This throws some light on the composition of people commuting for different purposes and modes employed for their commuting. This revealed that among the respondents in the central zones (East, West and South), almost 90 % commuted for their work, while few commuted for education and other purposes. However, in the outer zones, 86 % commuted for work, about 3 % for education, 1 % each for entertainment and shopping, followed by 4.4 % for other purposes (Figure 4-13).

Addressing the modes employed for commuting, it was revealed that in all, 37 % used the bus-based public transport service (BMTC), followed by individual motor transport (2-wheelers with 35 %). It was startling to note that 27 % ‘walk’, while 14 % used a combination of different modes. About 5.3 % used bicycles, 4.6 % used auto-rickshaws and only 1.7 % four-wheelers. The rise in number of two-wheeler traffic in the city (around 1.8 million) explains the large percentage of people plying on the roads (35 %). However, the significant percentages who ‘walk’ strongly suggest adequate measures for facilitating safer pedestrian commuting. The percentage of respondents commuting by multiple combinations (14 %) includes different modes of bus, walk, two-wheelers, auto-rickshaws and four-wheelers, while this also masks the percentage of respondents exclusively commuting by four-wheelers (1.7 %).

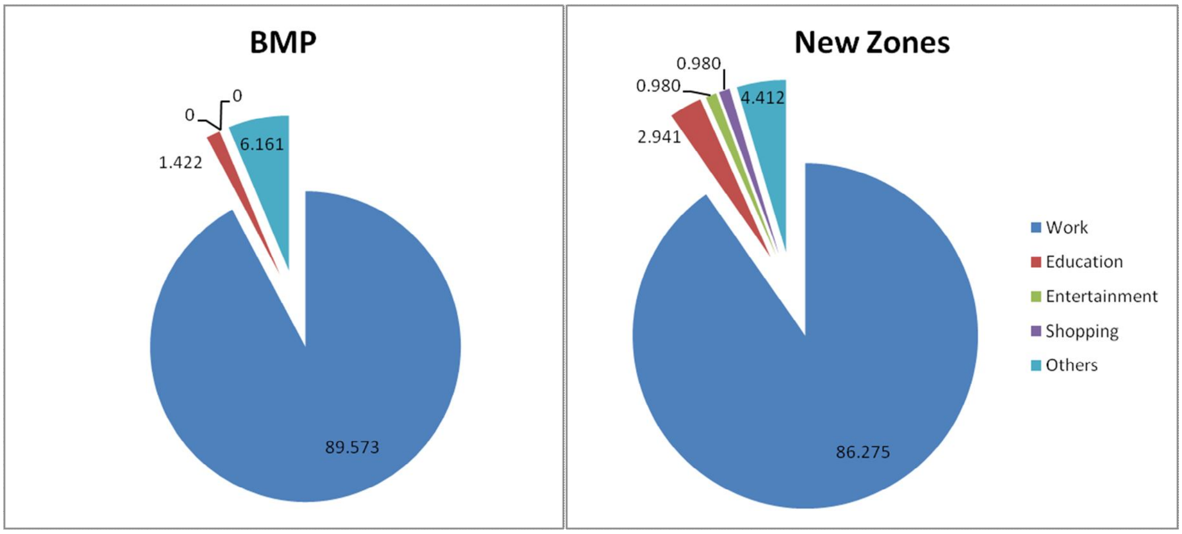


Figure 4-13: Reasons for mobility

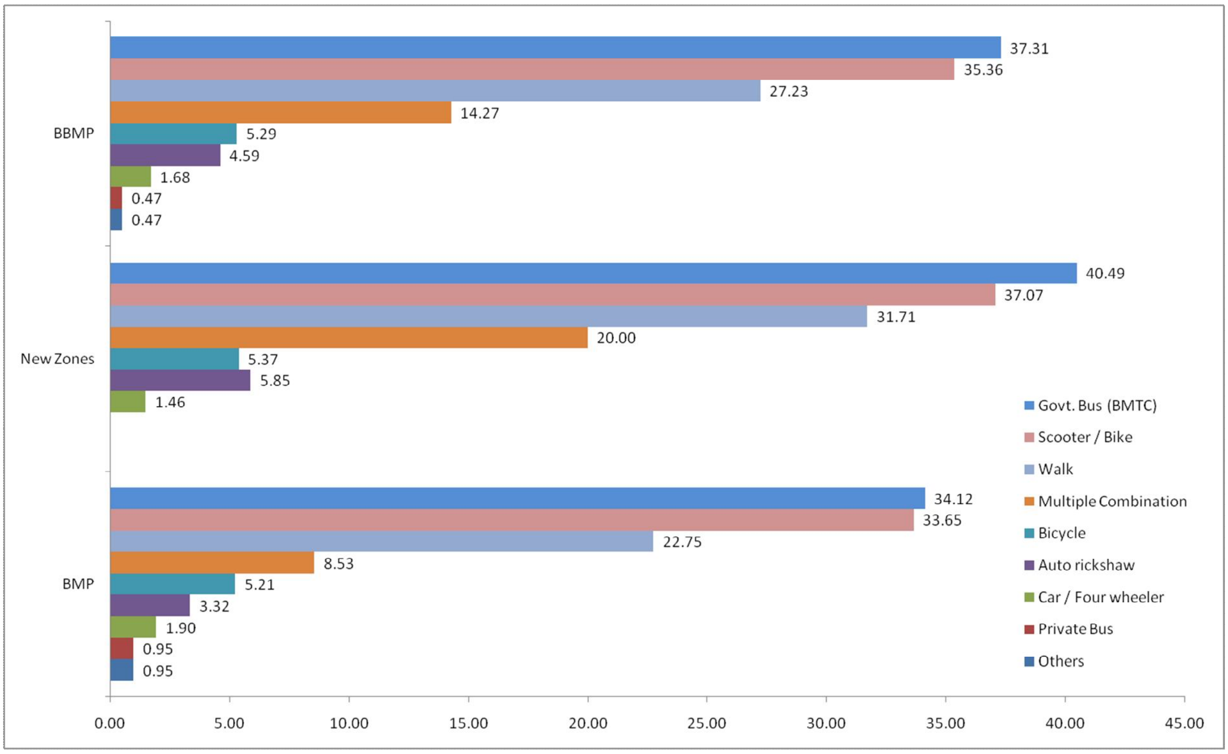


Figure 4-14: Modes of commuting

4.4.4 Planning and Governance

i. Planning

Planning and governance are imperative for ensuring effective service delivery and management of resources. As noted earlier, this set of indicators includes both quantitative and qualitative variables. The presence / absence of elected local body and their participation in planning are also considered. The indicators under planning and governance included: nature of urban local governance that prevailed until the formation of Greater Bangalore (BBMP), preparation and publication of master plans, public participation, and per capita expenditure in the budget of the local body (Table 4-6). The data to these were collected mainly from secondary sources. It can be seen that per capita expenditure is clearly more in case of the central zones (as it was under erstwhile BMP limits) while the neighbouring municipal councils have much lesser expenditure. Planning function is completely taken over by the parastatal agency, Bangalore Development Authority (BDA) and thus the local bodies have to abide by the policies formulated by the parastatal body. However, the effectiveness of solid waste collection in all the zones when compared with the per capita expenditure is positively correlated ($r = 0.79$, $p = 0.018$).

Table 4-6: Indicators of planning and governance

Zones	Population #	Nature of Local Governance (until formation of BBMP)	Public Participation in Preparation of Master Plan	Preparation and Publication Master Plan	Per Capita Expenditure (Rs.) *
Bangalore East	1414831	City Corporation	No	Yes (BDA)	1653
Bangalore West	1292771	City Corporation	No	Yes (BDA)	1653
Bangalore South	1584621	City Corporation	No	Yes (BDA)	1653
Bommanahalli	201652	City Municipal Council	No	Yes (BDA)	546
Raja Rajeshwari Nagara	138840	City &Z Town Municipal Council	No	Yes (BDA)	583.5
Dasarahalli	264940	City Municipal Council	No	Yes (BDA)	187
Byatarayanapura	272571	City and Town Municipal Council	No	Yes (BDA)	602.5
Mahadevapura	322013	City Municipal Council	No	Yes (BDA)	168.65

Based on Census of India (2001)

* Based on recent budget estimates of BMP and other municipal councils

ii. Accessibilities

The level of accessibilities to different amenities, services and healthcare were estimated based on the sample survey in all the zones. The level of access of services is meant as a proxy to assess the effectiveness of governance in different zones. The respondents were asked to rate according to the distances for accessing the different amenities (Table 4-7). The different amenities that were assessed are given in Table 4-8.

The ranking based on distances were useful in enumerating the proximity of the different services as accessed by the respondents. The mean ranking was considered for determining the overall level of access in different zones. In all, it was observed that the level of access scores (ranking) was almost similar in all the zones irrespective of the administrative differences (town and city municipals and city corporation limits) (Figure 4-15). This perhaps suggests that irrespective of the administrative jurisdictions, the level of services ranged almost similarly across the entire urban agglomeration. It was found that irrespective of governance and their level of services (mean rank of 3.57), the accessibilities to basic amenities (mean ranking of 2.34) were better and same in both central and outer zones. Further, the differences in ranking between services and healthcare were not significant (p=0.27) while they were significantly different from amenities (p=0.00093).

Table 4-7: Ranking criteria for level of access

Rank	Distances
1	< 500 m
2	500 m to 1 km
3	1 km to 2 km
4	2 km to 5 km
5	> 5 km

Table 4-8: Amenities, services and healthcare assessed

Amenities	Services	Healthcare
Cooking gas / LPG	Water Supply Source and Sanitation (Waste water)	Primary health care centers
Kerosene	Electricity	Government hospitals
Fuel wood	Road works	Local clinics / small nursing homes
Grocery (including Rice, Sugar, Oil, etc.)	Street Lighting	Private hospitals
Vegetables	Communication (Telephone)	Specialty hospitals
Milk	Park or other Open Space	Maternity homes

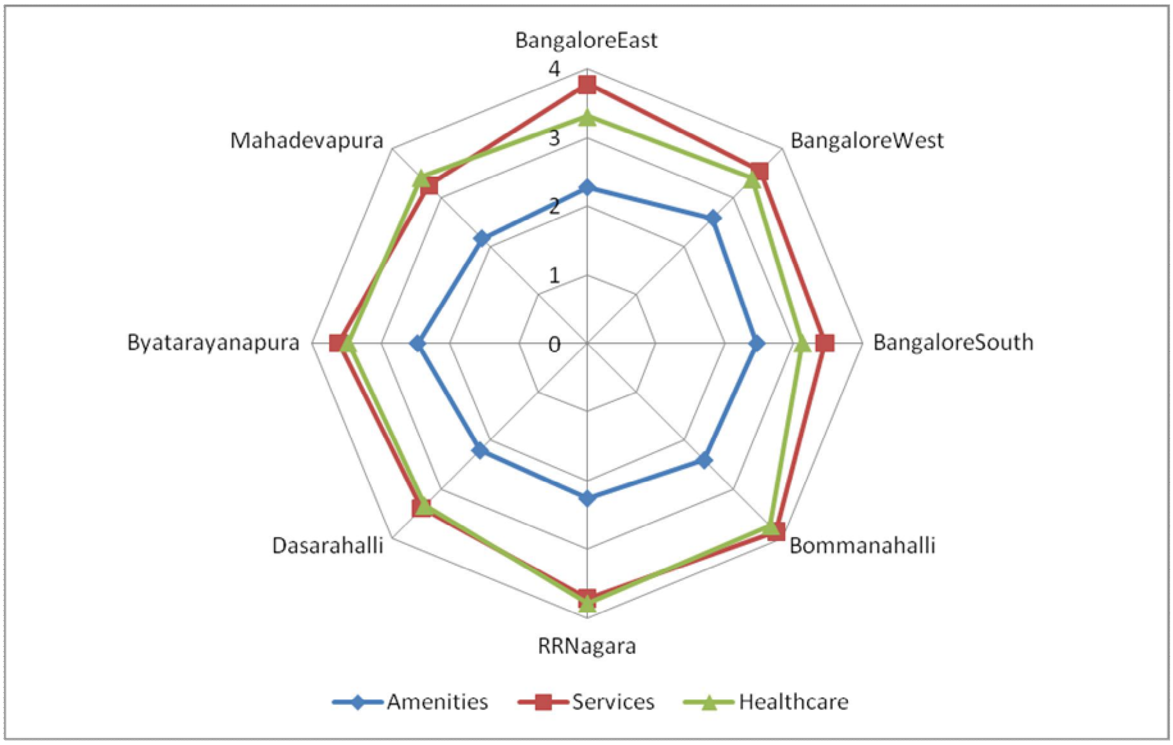


Figure 4-15: Mean ranking of level of access to amenities, services and healthcare

4.5 Implications of Planning and Governance on Sprawl and Level of Services

In order to first explore any underlying structure within the zones of Greater Bangalore using the above set of indicators, non-metric multidimensional scaling (MDS) analysis was carried out. The variables so considered were population, per capita expenditure, amenities score, services score, healthcare score, nativity, house ownership, house-type: brick-walled and asbestos sheet, and brick-walled and RCC roof, access to energy sources: electricity, LPG, kerosene, firewood, solar and biogas, access to water: BWSSB / CMC, borewell, private water supply (tankers), community water taps, wastewater disposal by sewage pipe and solid waste disposal: door-to-door collection, community bins and roadside dumping.

The statistical package PAST was used to perform the MDS. The resultant ordination plot is shown in Figure 4-16. Judging the goodness of the fit is normally through the interpretation of the stress value. In this case, the stress was found to be 0 indicating a perfect fit. An additional technique commonly used in judging the adequacy of an MDS solution is by the Shepard diagram. The corresponding Shepard diagram (Figure 4-17) reveals a monotonically increasing line implying that the MDS solution fits well.

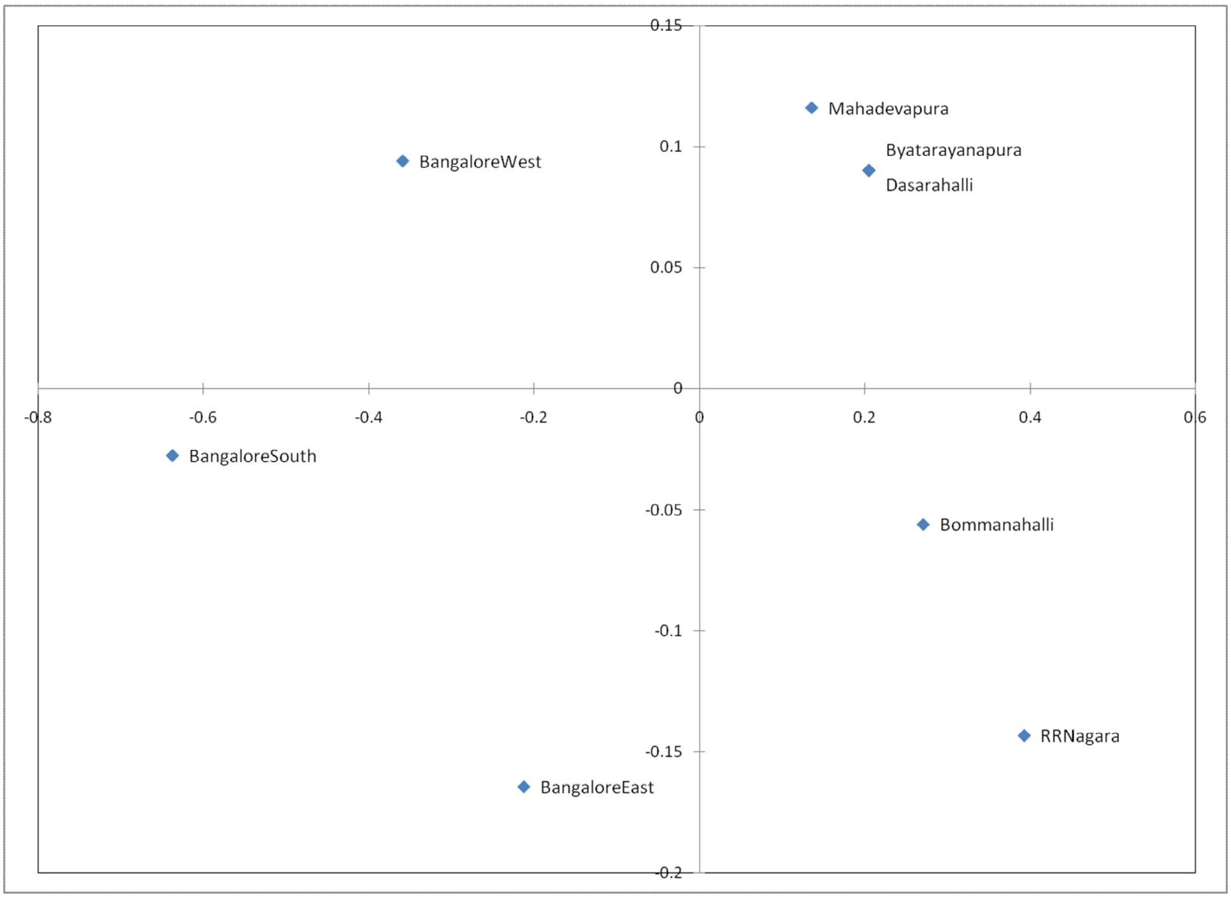


Figure 4-16: Non-metric scaling multidimensional plot

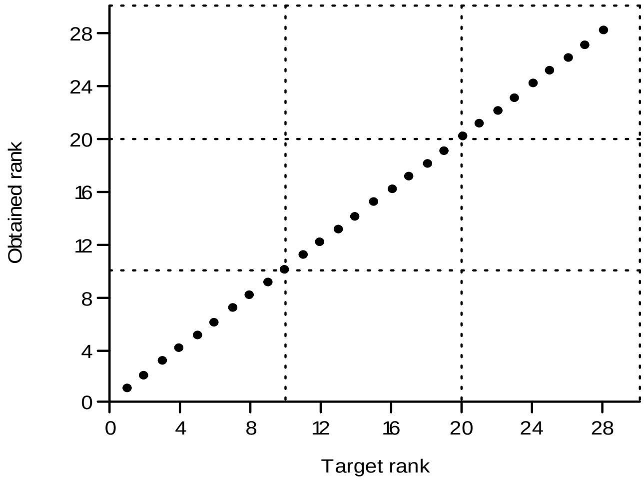


Figure 4-17: Shepard diagram

The plot (Figure 4-16) reveals that the central zones of Bangalore: East, South and West are distinctively away from the outer zones. The outer zones - Mahadevapura, Byatarayanapura and Dasarahalli have positioned very close to each other, while

Bommanahalli and Raja Rajeshwari Nagara zones are slightly away. In any case, the analysis brings out the distinctions with respect to each of the zones especially from those in the central and outer zones. This brings out the clear distinctions depicting the structural similarities (or dissimilarities) with respect to the different indicators considered for characterising sprawl.

From the above analysis (through MDS) and enumeration of various indicators across the different zones of Greater Bangalore, it was evident that central areas and the outer areas were clearly different in several aspects. It is observed that the outer zones are considered the sprawl areas though they have been only recently merged with Greater Bangalore. Although the level of access to different services and amenities were the same across the different zones, the access to resources (water supply, energy, wastewater and solid waste disposal) was different across the central and outer zones. Further, with the effectiveness of planning and governance on the overall level of services (including that of resources), the outer zones had poor delivery of services while the central zones had better delivery of these services. Further, it was also found that the per capita expenditure was positively correlated with the solid waste collection (the solid waste management is the onus of the urban local body and hence this resource was compared with the per capita expenditure of the respective local bodies). This conforms to the theoretical framework proposed in chapter 2.4, on the effect of planning and governance on services and extent of outgrowth (sprawl). Perhaps, with this outcome, this would suggest more effective governance in the outer zones to ensure better delivery of services through greater allocation of funds for the same. This can be further possible when planning and governance is proactive in forecasting the respective amenities, services along with necessary infrastructure in the these zones.

4.6 Summary

The efficiency of urban settlements largely depends on how well they are planned; how well they are developed economically and how efficiently they are managed. With rapid urbanisation in developing countries, urban sprawl seems inevitable. However, much of the understanding of sprawl in developing countries is still vague. A starting point for this is the development of appropriate indicators for measuring / quantifying urban sprawl in developing countries. It is now imperative to have robust information systems depicting the above said indicators for effective communication, planning, review and monitoring of urban sprawl. Furthermore, such an information system when deployed over the Internet can be made accessible to a wider community with round the clock accessibility.

Combining the goals of achieving sustainability and addressing the problem of sprawl has been the underlying principle of the present description of sprawl indicators for developing countries. This would allow the concerned authorities of urban areas to regularly plan, review and monitor the direction in which urban growth heads towards achieving sustainable development. It is in this spirit the chapter first reviewed existing indicator frameworks and arrived at the indicators for urban sprawl. Further, these were operationalised for the city based on both primary and secondary data collection.

It is noted that although the extent of built-up area increase was around 30 percent, it did not reveal any pattern of the built-up spread or suggested the characteristic of sprawl. However by computing the landscape metrics of patchiness and map densities, it revealed the pattern of sprawl over the three periods. The computation of patchiness enabled us to infer that there is a reduction in homogenous patches and a consequent increase in patches with 2 heterogeneous classes. It may be noted that the reliance on the metrics is dependent on the accuracy of classification. Further, the computation of built-up densities based on the notion of map density in landscape metrics revealed the high distribution of low-density built-up areas along the periphery with the high-density built-up areas towards the city centre. The analyses revealed the nature and pattern of sprawl whereby suggesting a radial pattern of urban sprawl. An important aspect of the study was to indicate the erosion of landscape elements with loss of water bodies, vegetation, etc. Though, the study brought out the extent of such loss, the implications of such loss was not attempted.

The different dimensions of sprawl based on Environment and Resources, Demography and Economy, Mobility, and Planning and Governance were ascertained and enumerated. The utility of spatial indicators combined with non-spatial indicators were useful in characterising the patterns of sprawl across the urban agglomeration. The estimation of different indicators and the subsequent analysis clearly brought out the distinction between the sprawl regions (outer zones) and the central city (central zones). Characterising urban growth using multi-temporal remote sensing data has been quite popular for a while although there have been a few studies that addressed the extent of urban growth resulting in sprawl through appropriate metrics. In this chapter we demonstrate the utility of landscape metrics like patchiness and built-up density for characterising urban sprawl. However, a critical challenge is to identify ecologically sensitive habitats (like water bodies) that may be prone to sprawl and address the extent of low-density sprawl that results in inefficient resource usage, which is explored in sixth chapter. Further, the pattern of development, taking place along the periphery of the Bangalore city, should be used as tool for effective monitoring and enhancing management options for land-use. In the next stage, it is imperative to understand the process of sprawl by the change in patterns. This might help one to understand the dynamics that lead to such outgrowths.

V. Processes and Causes

All things appear and disappear because of the concurrence of causes and conditions. Nothing ever exists entirely alone; everything is in relation to everything else.

- Buddha

5.1 Approaches and Issues

Urban sprawl is a dynamic process requiring models to capture the sensitivities of space and time apart from acknowledging the agents and interactions that determine the dynamics. It is imperative for the models, capturing the dynamics of sprawl, to represent them in both space and time. While most of the existing models capture them in either space or time, it implies that many others do not capture both of these dimensions. Also, only some of the questions like "*what*, *when* and *where?*" are answered by these models and not necessarily aid in answering questions like "*why?*" and "*how?*". Among the models that attempt a response to these questions are a variety of geospatial models, which explicitly acknowledge the notions of "what, when and where?". Answering questions of "*why* and *how?*" requires an understanding of the processes and causes of the phenomenon in question. This necessitated modelling approaches to evolve towards acknowledging these critical issues by graduating from empirically fitted or predictive models to process based models.

Several approaches and methods originating from the disciplines of engineering, management, geography and artificial intelligence have been used for capturing (modelling) the dynamics of urban systems. With most of the approaches, it was not possible to represent / capture the behaviour of the system dynamically over a spatial domain, necessitating for modelling the systems in both spatial and temporal domains. The combination of operations research techniques in geospatial modelling using the tools of geographic information system (GIS) has been attempted for some time. The dynamics had been captured effectively using the temporal remote sensing data as the spatial component. Nevertheless, it still required representing some of the causal factors and internal processes effectively. The utility of multi-criteria decision-making using the analytical hierarchy process or the suitability-based multi-criteria evaluation to represent some of the externalities and constraints had been used especially in site selection and allocation of new land for residential development, etc. However, these models are not dynamic in nature and fail to capture many of the interactions and feedbacks.

The interactions among the agents of sprawl like the population or infrastructure can be complementary to each other. Subsequently, the reactions of these agent manifestations can lead to fuel further sprawl. Further, these agent-behaviours are not the same in space and time; in effect these agents have a dynamic impact both in space and time. The traditional GIS have not adequately handled visualising such space-time phenomenon like the urban sprawl. Hence, different approaches like system dynamics, automata-based and agent-based modelling, individually or in combination, could significantly transform the way urban modelling is undertaken in the geospatial domain. Thus, the process based modelling of urban sprawl using a combination of system dynamics and agent-based models over a geospatial domain would also aid in answering "*why* and *how?*" apart from "*what*, *when* and *where?*" of the phenomenon in question.

5.1.1 Approaches

i. System Dynamics

System dynamics (SD) is an approach to modelling the dynamics of population, ecological systems, and economic systems, and the interrelationship between all the three. Modelling under *system dynamics* framework serves as a useful first step in making some reasonable assumptions about the pattern that a particular system might produce. However, by no accurate means and more in depth analysis, modelling is attempted with a few assumptions and outputs as logical conclusions. Systems model were devised out of a long inductive process whereby computer modellers, using formal modelling techniques, noticed systems characteristic patterns in various systems.

Systems thinking use diagrams, graphs and pictures to describe and structure interrelationships and behaviours of situations. Every element in a situation is called a variable, and the influence of one element on another element is called a link; drawing an arrow from the causing element to the affected element can represent this. In SD, links always comprise a 'circle of causality', or a feedback loop, in which every element is both a cause and an effect.

The SD framework captures the system based on complexity involving the dynamism of stocks and flows determined by the various activity volumes in the city, which were synthesised from casual knowledge and observations. The process of modelling in system dynamics begins with a clear statement of the problem, followed by gathering necessary data and identifying the key variables that would be responsible for the processes involved. The variables are mapped on to what is referred to as causal loop diagrams (CLDs). Further, data is gathered for most variables identified by the CLD. Typically, it so happens that many variables cannot be quantified, thus forcing the model to be truncated. Establishing the relations amongst the remaining variables, the stock flow diagrams are created. It is possible to simulate the behaviour of the system through a stock flow diagram and plot the behaviour of key variables, test for different hypothesis and study the implications of specific interventions.

Batty (2007) notes that the systems approach promoted the notion of the city as a machine and planning as its controller but it took the move from thinking of systems as physical entities to biological to generate the kind of insights that complexity theory is now suggesting. While there were various sub-systems that made up the system as a whole, it had a working cliché that 'the whole is greater than sum of its parts'. Processes acting through subsystem interactions kept such systems in equilibrium with the controller; a special subsystem responsible for coordinating all the others (Batty, 2007). The behaviour of such systems was considered to be ordered with the controller acting to restore the balance if the system deviated from the desired goals. This led to the ideas that urban systems could be perhaps controlled or 'planned' to meet certain goals or targets (Batty, 2007).

The systems approach limited the processes to *emerge* beyond the aspects for which they have been developed. Ascribing this notion to Jane Jacobs, Batty (2007) notes that the mechanistic way in which cities were conceived and planned was entirely counter to the diversity that made up vibrant and living cities, with the result that post second world war urban planning (and modern architecture) was killing the heterogeneity and diversity that characterised urban life. This implied that cities should not be treated like machines but like living systems with the implication that life, hence city form, emerges from bottom up following the Darwinian paradigm of natural selection. Indeed, almost as soon as the systems approach was articulated, its limits became evident in that thinking of cities as systems in equilibrium with planning aimed at restoring this equilibrium, clearly conflicted with innovation, competition, conflict, diversity and heterogeneity, all hallmarks of successful city life. Though the SD framework is responsive and accounts for feedback, it is inept to represent models over a spatial domain. This lacuna has been addressed in recent times by the use of automata-based and multi-agent systems in conjunction with geospatial models to capture the dynamics of urban sprawl.

ii. Geospatial Modelling

The geospatial sciences aided by the concepts from complexity sciences have been in the forefront in addressing issues and approaches towards modelling the urban dynamics. Over the last decade, tremendous impetus has been gained by the geospatial sciences driven by emerging technologies and interdisciplinary initiatives. This has virtually transformed the traditional geographic information systems (GIS) into a full-fledged discipline of geographic information science (GISc) or the geospatial science. Some of these advances in GISc have also contributed to geospatial modelling in both spatial and temporal dimensions. Capturing the spatial and temporal dimensions has been an intense subject of discussion and study for philosophy, mathematics, geography and the cognitive science (Claramunt and Jiang, 2001).

Different models for representing the spatial and temporal phenomenon have evolved from the traditional Location-based / Snapshot models to Entity-based models (Object-oriented approach) to Event-based models to Process-based models and so on. In spite of the continuous developments in the representations of the geospatial data along with their temporal attributes, these systems with the goal of gaining insights about cause-effect relationships are not yet ready to answer the questions of patterns of change through time (Peuquet, 1999). Essentially, geospatial models attempt to answer questions of "*How?*" and "*Why?*" apart from answering "*When, Where* and *What?*".

"*What about People in Regional Science?*" was a question Torsten Hägerstrand posed in 1970. After about thirty years, Miller (2003) has revisited this concern in the realm of geospatial modelling, addressing the central issue of ascribing time. Miller argues that most GIS today are place-based rather than people-based as they are incapable of answering questions concerning access, exclusion and evolution and it is not possible for addressing policy and theoretical questions. Reviewing the principles, state of the art and research needs, Miller (2003) has suggested for a people based GIS based on integrating time geography and space-time activity concepts with the theories of and tools of geographic information science and systems.

In geocomputation for modelling geographic phenomenon, especially in dynamic land-use models, Liu and Anderson (2004) have categorised models as process-based and transition-based. Process-based models are known to describe the causality between different components of the system explicitly. Transition-based models use probability or similar terms to summarise the changes that happened over an interval.

iii. Automata-based Approach

Modelling and simulations in the geospatial domain is now extensively done using the techniques of Cellular Automata (CA), to model processes in space and time. CA is a cell-based approach to model processes in a two–dimensional space. Torrens and Benenson (2005) define an automaton as a discrete entity, which has some form of input and internal states. These states can change over time according to a set of rules to determine a new state in a subsequent time step. These rules control the transformation of a cell state to another cell state over the specific period of time depending on the neighbourhood of the cells.

In CA based modelling, the temporal variability of spatio-temporal processes is less emphasised than its spatial counterpart. CA based models are used for studying temporal dynamics (Clarke and Gaydos, 1998; Liu and Anderson, 2004) wherein the temporal dimension is mostly considered to be the time duration in discrete points. Normally in a CA model, the transitions take place from time t to time t+1 and would ideally simulate the physical states between time t=0 and t+1 (Batty and Jiang, 1999). Although time can be discretised at a higher scale (discrete-time stepped), the state changes of the CA for certain transition rules can be assumed to be within a specific time only and not at all the discretised time units. In certain situations there can be more transition rules for various state changes at varied time units underlying the importance of the events that take place based on the transitions and not all transitions that may or may not happen at every time step. In case of CA, the state changes are only within the discrete set of time, thus they are a fit case of both discrete-time model and discrete-event model.

Though CA based models have been used for simulating various dynamics extensively, CA are considered immobile geographical automata (Torrens and Benenson, 2005). They are immobile because individual automata are not free to move in the space in which they reside; all spatial movement takes place through the diffusion of information through neighbourhoods. In addition, Batty and Jiang (1999) argue that the development of spatial interaction in spaces wider than the neighbourhood itself and in enabling the model dynamics to take account of system-wide conservation constraints, are usually destroyed by the CA transitions. Most importantly transition rules account only for the states and neighbourhood and not for externalities driving the processes. To address these shortcomings, multi-agent systems are being used in the realm of modelling urban dynamics.

iv. Multi-Agent Systems / Agent-based Models

The aim of agent design is to create a program, which interacts `intelligently' with its environment. The term 'agent' is usually applied to describe self-contained programs, which can control their own actions based on their perceptions of their operating environment. The key hallmarks of agent-hood are autonomy, social ability, responsiveness, and pro-activeness (Jennings and Wooldridge, 1996). Agents, have their origins in software engineering and artificial intelligence where they are used in networking, communications, etc. An agent is an encapsulated computer system that is situated in some environment and that is capable of flexible, autonomous action in that environment in order to meet its design objectives.

With intense research in the realm of multi-agent systems / agent-based modelling (ABM), under the distributed artificial intelligence domain, scores of tools are developed for building ABMs, particularly by making use of the programming languages C, Objective C and Java. The development of these ABM tools came up with the academic and research institutions for applications in social simulations and studying complex behaviour. Although there is significant number of tools for building agent-based models, these tools are yet to evolve for applications in geosimulation. A main reason for this is that the spatial relationships or the topology and geometry have to be defined in these tools for ensuring that they handle the geospatial databases. Most of the prevalent tools for building ABM are of significance only while dealing without any spatial relationships. In other words, these agents are not bound by the geospatial data models. Consequently, researchers had to attempt formalising the spatial relationships for the agents modelled so that they can be used in the geospatial domain.

The initial application of agent-based models within a GIS was made in studying the dynamics of pedestrian behaviour in streets (Batty, Desyllas, and Duxbury, 2003). Amongst other application domains agent-based models are now also used for studying the urban dynamics (Batty, 2003; Benenson, 1998; Portugali, Benenson, and Omer, 1997; Sanders, Pumain, and Mathian, 1997) over a GIS environment. Agents can be considered a special case of an automaton, having all features of the general automaton, with a distinction that these agents are mobile and they can represent the external drivers or causal factors responsible for the processes. The idea is to treat each of the individual drivers as agent-based automata enabling the spatial and temporal relationships. Thus, agent-based models are treated as mobile geographical automata with transition rules. The new trend of research is driving towards integrating the agent-based models (multi-agent systems) with the CA models, for enabling geosimulation by incorporating different causal agents involved. A key distinction of this model is the ability to represent the emergent behaviour of the system originating out of complexity.

v. Fusion of OO, Automata approach and MAS for Temporal GIS

The combination of CA and agent-based models has enabled to address the interactions in space and time (Batty and Jiang, 1999) by the representation of different behaviours (drivers) as objects. Object-oriented approaches to cells, where cells represent land parcels, administrative areas, or even individual buildings, and almost invariably require non-regular lattices, but may ease the problem of defining transition rules (O'Sullivans and Torrens, 2000). The agent-based models would have all the characteristics of cellular automata, but unlike in cellular automata, agents in an agent-based model would be programmed for spatial mobility within the regions they inhabit.

To depict the fusion of cellular automata and multi-agent systems in a spatial context for simulating discrete, dynamic and action-oriented spatial systems, Torrens and Benenson (2005) propose Geographic Automata Systems (GAS). The GAS framework defines the automata collectively considering type of automata, states, transition rules, location, movement rules, neighbours, and neighbourhood transition rules. Thus, the GAS framework addresses the fusion of CA and ABM in a spatial context, by tight coupling of GAS with GIS. With this, there can be many automata with different scales for space and time, defined based on the process / phenomenon in question. However, when there are two or more automata waiting to be executed at the same space and time, such cases are handled only by synchronous or asynchronous updating.

Furthermore, the management of time in the GAS framework is less advanced to handle multiple simulations simultaneously, for which their framework uses 'synchronous' and 'asynchronous' updating. The GAS framework uses the Object-based Environment for Urban Systems (OBEUS) for validation (Benenson, Aronovich, and Noam, 2005).

Although the geospatial community has until now, attempted to model and simulate these different processes on the desktop aided by the advances in the computational capabilities, a significant thirst unquenched for the geospatial community is the need of reusable and interoperable architecture for modelling and simulation capable of integrating or synchronising the different models of environmental processes at their respective scales. The GAS framework comes 'very close' to realise this. However, if the temporal synchronisation can be effectively addressed by the GAS framework, then there lies an enormous opportunity for research, application and development.

To address the shortcomings of GAS framework in terms of time synchronisation, an integrated framework enabling distributed geospatial simulations in an interoperable framework has been recently proposed by Sudhira *et al.* (2005). For facilitating the efficient integration of geospatial models and the agent-based models at appropriate scales in space and time, the models are considered in 2-dimensional space and as discrete-time stepped models with a single time-advancement mechanisms. The framework consists of GeoSpatial Analyser (GSA) for handling space-variant simulations and incorporates the industry standard, High Level Architecture (HLA) for synchronising time-variant simulations. The key conditions for the integration of these models are that the spatio-temporal extents of the processes in question are to be predefined. By predefining the spatio-temporal characteristics of the models (agents), GSA would schedule them while the HLA addresses the synchronisation of time for these models. With the possibility of defining all these processes as agent-based models, the agent-automata described for the scenario over a specific period of time, can be coupled in overall simulation.

5.1.2 Issues

Yet there are other issues while capturing the dynamics of sprawl. Two such issues are: scale and representation of causal factors. The scale would refer to the spatial and temporal resolution over which the process has to be captured for appropriately emulating the system behaviour. Since there are numerous processes that can take place at various scales, an imminent task for the modeller is to acknowledge this and evaluate the implications of the same over different scales. Further, it should be noted that not all causal factors could be represented as spatial objects since some could be just rates or a derived variable. When some of the causal factors represented as spatial objects, what is the appropriate type of representation; raster (as cells) or vector? These are some of the issues that would arise while attempting to capture the dynamics of sprawl using several approaches. This needs to be addressed while capturing the dynamics of sprawl using system dynamics and agent-based models.

5.2 Modelling the Dynamics: Factoring Processes and Causes

Modelling the sprawl process is attempted in relation to land-use and transport by a combination of system dynamics and agent-based models over a geospatial domain. Initially, the systems approach is employed by building – Causal Loop Diagrams. Subsequently, the processes captured are translated into agent-behaviours. The systems approach for addressing traffic congestion has almost become a classic textbook case while demonstrating / studying the implication of road widening for easing congestion in road network. Such an example can be found in Sterman (2000). The typical approach to cause-effect modelling, the 'disjointed viewpoint' and 'linear, control viewpoint' of one cause leading to one effect, is replaced by a 'causal-loop, nonlinear feedback viewpoint' where multiple effects are the result of multiple factors (Sterman, 2000). The prevalent independent planning perspectives of transportation planning and land-use planning were addressed in relation to the outgrowth (or the sprawl) through systems approach.

5.2.1 Transportation Planning

With a view to understand the implications of transportation planning on land-use and the consequent outgrowth resulting in sprawl, the problem of mobility was considered first. The existing condition of traffic congestion and methods adopted to ease this were addressed. As noted earlier, the modes of commuting and the key reasons for commuting were considered. The significant proportion of two-wheelers and the limited road capacities resulted in congestion of traffic. Though there are efforts underway to augment the mass rapid transit by way of a Metro, the existing bus-based public transport is the only solace. Typical efforts to ease congestion are by way of road widening and junction improvements like construction of fly-over, underpasses, etc.

Accordingly, based on the study and analysis the key variables identified were: travel time, desired travel time, pressure to reduce congestion, interventions by road widening / other construction, road capacity, attractiveness of driving, adequacy of public transport, public transit fare, trips per day, average trip length, traffic volume, public transit ridership, vehicles per person, vehicles in the region, extent of city within desired travel time, population and economic activity. The causal loop diagram for the same is depicted in Figure 5-1. The five feedbacks generated in this system – CLD are:

(i) Reinforcing Feedbacks: outgrowth of city (R1)

(ii) Balancing Feedbacks:

a. Capacity Expansion (B1)
b. Discretionary Trips (B2)
c. Extra Travel (B3)
d. Availing Public Transport (B4)

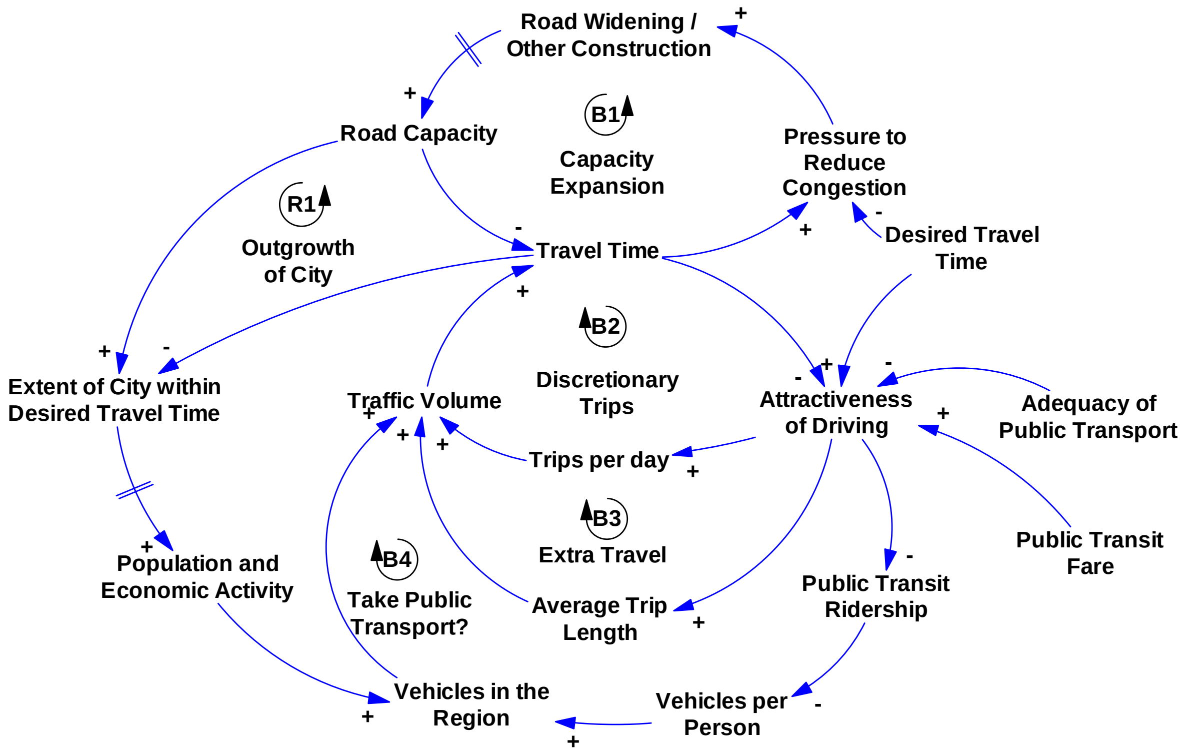


Figure 5-1: Causal loop diagram for mobility

Reinforcing loops, by definition, are incomplete. Somewhere, sometime, it will encounter at least one balancing mechanism that limits the spiralling up or spiralling down effect. The reinforcing feedback, R1, results in outgrowth of city by the creation of an outer / peripheral ring road which is created as part of capacity expansion, caused by another balancing feedback B1. Reinforcing feedbacks often generate exponential growth and then collapse. Figure 5-1 demonstrates the evidence of this reinforcing loop in and around Bangalore, where congestion, leads to outer ring roads, which lead to new suburbs, leading to more congestion. Over the 8-year trends observed through remote sensing satellite images the rapid-growth around Bangalore reveal how quickly urban sprawl takes over the landscape.

Balancing loops are forces of resistance that balance reinforcing loops. They can be found in nature (such as climate) and indeed other systems, and are the processes that fix problems and maintain stability. Systems that are self-regulating or self-correcting comprise balancing loops. Balancing processes are bound to a constraint or target which is often set by the forces of the system, and will continue to add pressure until that target has been met. The balancing feedback, B1, emerges and simply remains to operate as long as there are road widening and other constructions leading capacity expansion. As a counter to this, is the only reinforcing feedback of outgrowth of the city. Further, with increased traffic volume and consequent travel time, there is little attractiveness to driving that can contribute to discretionary trips and extra travel. In the absence of adequate public transport and significant public transit ridership there is little incentive for people to avail public transport. A significant characteristic of every system, and often the most ignored, are delays. Delays in loops occur when a link takes a relatively long time to act out, and can have an enormous influence on a system, often exaggerating the behaviour of parts of the system and hence the general behaviour of the whole system. Delays are subtle and often neglected, yet they are prevalent in systems and must be actively considered. The above analysis offers insights into the existing practices and suggests the need to re-look / reinvent the approaches towards addressing the problem of congestion as existing practices are counter-productive.

Typically, CLD is translated with gathered data and then establishing relations with the variables in stock-and-flow diagrams (SFD). It is possible to simulate the behaviour of the system through stock-and-flow diagram and plot the behaviour of key variables, test for different hypothesis and study the implications of specific interventions. A limitation of the above analysis is that the systems' modelling is concluded only with a CLD. However, a detailed systems modelling can be taken up once all the relevant data are gathered and the possible nature of interventions on the system are explored.

5.2.2 Land-use Planning

The second problem was land-use planning coping the pressure on land due to the extent of city outgrowth or the sprawl. The consequences of the interventions that can be attempted towards addressing this are analysed through systems analysis. In Bangalore, one of the prominent measures to limit growth is by way of enforcing building height restrictions formalised through the floor area ratio (FAR). These restrictions are one of the popular measures of controlling the zoning of central and several parts of the city. Though the planners in Bangalore have already enforced such restrictions, this in turn has also resulted in increasing the extent of the city outgrowth. Based on the analysis, the key variables identified were: population growth, economic activity, pressure for new housing and industrial areas, land-use zoning, available land, built-up area, level of services and building height restrictions. The corresponding causal loop diagram is shown in Figure 5-2.

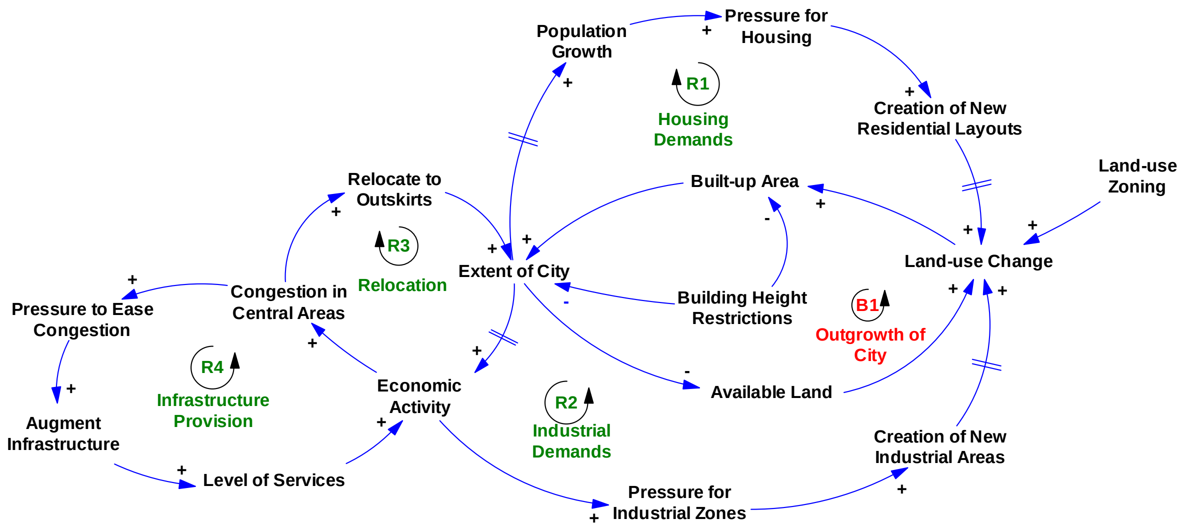


Figure 5-2: Causal loop diagram for urban sprawl

The five feedbacks generated in this system were:

(i) Reinforcing feedbacks:

a. housing demands (R1);

b. industrial demands (R2);

c. relocation (R3) and

d. infrastructure provision (R4);

(ii) Balancing feedback: outgrowth of the city (B1).

The reinforcing feedbacks, R1 and R2, quite natural for most cities, set the demand for development of land into residential layouts / apartments or industrial estates, respectively. As the city grows, there is congestion in central areas forcing residents to relocate in the outskirts. This is captured by the reinforcing feedback, R3. The other reinforcing feedback, R4, for infrastructure provision suggests that augmenting infrastructure in a congested area can be counter-productive. Indeed this insight is well established by the classic Braess paradox (Braess, 1968). This was demonstrated by adding a link within the network to ease congestion, which would be counter-intuitive in a congested road network. Reinforcing feedbacks often generate exponential growth and then collapse. Systems that are self-regulating or self-correcting have balancing loops. The only balancing feedback, B1, results in the outgrowth of the city through the process of land-use change limited by the availability of land for development. The other control variable as envisaged by the land-use planning are land-use zoning and building height restrictions, which suggests that it influences the extent of outgrowth and built-up areas negatively. Bertaud and Brueckner (2005) have shown that in unrestrictive building height conditions, the extent of the city spread is contained with higher densities in central areas.

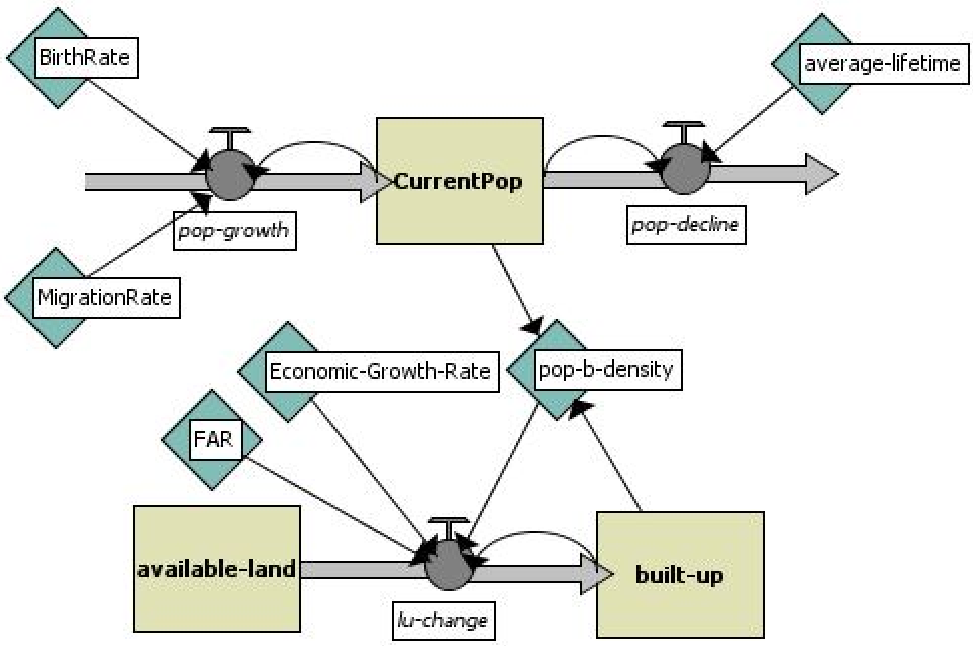


Figure 5-3: Stock and flow diagram capturing population growth and land-use change

Further, the causal loop diagram is translated into a stock-and-flow diagram with appropriate numbers for the variables and assumptions. An important assumption relating to the process of land-use change was that economic activity combined with an increase in the workforce (through migration) would lead to higher demand for land for development and hence drive the land-use change. It is observed that it is the market forces operating in the context of a political economy, which are influencing the process of land-use change. Thus, the analysis of land-use change has to acknowledge the implications of prevailing market conditions and the supply and demand aspects of land. The stock-and-flow diagram capturing the dynamics of population growth and land-use change is depicted in Figure 5-3. Essentially, the stock-and-flow diagram sets the demand for new built-up areas.

The above analyses reveal the stronger linkages between certain policy decisions on sprawl. However, the ability of systems approach is to enhance the understanding of the problem in question while this paradigm does not allow visualising the phenomenon in space. Yet the systems paradigm provides a good starting point to characterise the factors and variables responsible for the emergent dynamics.

5.2.3 Model for Process of Land-use Change

In the next phase, the knowledge of the processes characterised by the systems analysis were translated as rules to certain automata type and agent-behaviours. The classified land-use data were considered and the processes of land-use change were factored by the modules specified below. With the framework for explaining the urban sprawl in relation to planning and governance (chapter 2.4), and noting the various dimensions and causal factors that drive the process of land-use change, a model for the process of land-use change is specified. Thus, land-use change,

$$\boldsymbol{f\,(S_{t+1}) \approx f\,(\mathrm{LUCM, GOV, PGM, DM}) + \varepsilon}$$

where,

- Future Land-use (S_{t+1})
- Land-use Change Module (**LUCM =** $\boldsymbol{f(S_t, N_t, Z_t, S_t^c)}$ **)**
  - Model Current Land-use (S_t)
  - Neighbourhood Land-use (N_t)
  - Suitability Factor (Z_t)
  - Land-use Constraints (Water bodies, Parks, Open spaces, etc.) (S_t^c)
- Governance (GOV)
  - Level of Access to Services and Amenities
- Population Growth Module (PGM)
  - Birth Rate, Migration Rate, Avg. Lifetime
- Planning Module (PM)
  - Land-use Policy (Comprehensive Development Plan)
  - Mobility

        - Transportation Networks
        - Modal Share of Commuting
        - Trip Length and Travel Time
    - Regional Growth Factor (City Development Product, District Domestic Product)
- Error (ε) - Random Development Probability

The land-use change sub-module aids in forecasting the future state of land-use based on the current land-use, its neighbours, constraints and the suitability factor. This emulates the traditional cellular automata based approach for modelling land-use change. Governance is factored by the level of services and access to amenities along with the relative proximity to various utilities that the residents would consider essential. The population growth sub-module is a generic model capturing the birth-death process of the city's population while acknowledging the migrant population. The planning sub-module considers the land-use policy formalised as the comprehensive development plan and the regional growth factor affecting the rate of growth. This module also considers mobility including the transportation networks, modal share of commuting, trip length and travel times. All the sub-modules represent different drivers as the agents whose behaviours are defined again as process-based rules. The description of the above integrated model is the evolution of spatial planning support system, which will be the matter of discussion in the next chapter.

5.3 Summary

Increasingly enough, sciences are acknowledging that all systems: environmental and / or socio-technical systems are 'complex systems'. Although there does not exist any universal definition of a 'complex system', these systems depict sufficient amount of intractability that are complex enough to be captured / modelled. This has led to acknowledge such systems as complex adaptive systems, wherein self-organisation is one of the fundamental processes that lead to emergence in these systems. Urban systems, especially cities are classic examples of complex systems. However, approaches to enhance the understanding of such systems are now evolving and are mainly dominated by the system dynamics and agent-based modelling approaches. Accordingly, the current study has attempted an integrated approach to capture the dynamics of urban sprawl arising out of planning practices on the one hand and on the other hand, the dynamics emanating due to the ongoing activities (economic, etc.). This chapter discussed the approaches and issues concerning modelling of such systems. An attempt was also made to capture the dynamics using systems approach and finally the insights gained were translated into the agent-based modelling after specifying the model for the process of land-use change.

VI. Consequences and Evolution of Spatial Planning Support System

Prediction is very difficult, especially if it's about the future.

- Niels Bohr

6.1 Consequences

With an understanding of the pattern, process and causes, it is important to forecast the consequences of urban sprawl for land-use planning. To identify the consequences, it would require the model to generate possible scenarios of land-use change along with the implications on various indicators. Further the consequences have to be identified based on the choice or decision of certain policy aspects to evaluate for the same. Thus, it is also important for research to identify the appropriate 'policy options' and the instruments that would influence the land-use changes.

This chapter addresses the issue of urban sprawl with a focus on Bangalore city and analyses the status of planning practices in India with a note on utility of spatial planning tools. As a synthesis of the prevailing situation, the ensuing section outlines the critical challenges for addressing sprawl. The subsequent section highlights the need for an integrated spatial planning support system (SPSS), illustrating the evolution of a framework for SPSS, its development and evaluation. The later section presents the policy analysis carried out using the SPSS, which offers insights into areas of concern. The chapter concludes by noting the drawbacks and challenges for future research for managing urban sprawl.

6.2 Critical Challenges for Spatial Planning Support Systems

The management of urban sprawl entails quantifying the pattern of sprawl, and capturing the processes requires analysis of causal driving factors. This requires understanding and visualisation of the consequences of policies applied by local planning and administrations to sprawl, like lack of an effective public transport system with varying work-home distances, giving rise to independent motor vehicles resulting in congestion and spatial expansion. Testing the effects of policy interventions on urban spatial expansion and mobility are some important questions about which a planning support system could offer insights. Operational urban planning seeks answers for many such interventions. This necessitates integrated spatial planning support systems (SPSS) for managing sprawl. The framework of such planning support system is discussed later.

Noting the various studies and prevailing urban fabric conditions in India, it is found that lack of effective governance with operational systems and processes in the local bodies have resulted in unplanned and uncoordinated urban outgrowth. Urban governance requires an information system for keeping track of various services and functions of the urban local body. In the absence of any such systems, at the basic level, there is a strong and pressing need for an information system to cater to all these. In the next level, it becomes essential to build models based on the information systems involving simulation and analysis for specific urban contexts. Thereafter, there is a subsequent level involving the formulation of different strategy and policy options using the models and information systems. Thus, at the outset, there are three levels to address the problem of sprawl and to strengthen planning and decision making – information systems, models and policies. With the interaction of key bureaucrats and concerned officials in Bruhat Bangalore Mahanagara Palike and the Urban Development Department, Government of Karnataka, it is found that, on the one hand, the prevailing policy and practices concerning planning and governance are in line with the State Government’s aspirations, while on the other hand, there does not exist any other mechanisms or modes through which the Government could make this effective and plausible by being citizen centric. The key challenge for research is to encapsulate the spatial information coupled with models to facilitate policy analysis, evaluation and visualisation of these consequences into a spatial planning support system.

6.3 Planning in the Digital Age: Spatial Analysis and Planning Tools

Spatial tools, notably Geographic Information Systems (GIS), for mapping and monitoring urban areas have become extremely popular. Monitoring the spatial patterns of urban sprawl on a temporal scale can be undertaken using temporal remote sensing data acquired from space-borne sensors. These help in inventorying, mapping and monitoring linear and radial growth patterns. In the recent past, the geospatial domain has seen significant developments in modelling urban systems using approaches ranging from operations research to system dynamics and agent-based models. Models of urban systems are essentially built to aid in planning for understanding, evaluating, visualising and deciding various interventions. Thus, geospatial models have become an inseparable aspect of a planning support system. In India, there are some attempts to address urban sprawl using geospatial tools and modelling.

Simulation tools based on the concepts of discrete-event system simulation approaches are being used extensively in recent times to capture and emulate urban systems and their dynamics. With the emergence of multi-agent systems from the domain of artificial intelligence, these are now being used to aid in simulation of urban systems. Another approach to model the urban dynamics is the system dynamics (SD) framework, which captures the system based on complexity involving dynamic relations represented by stocks and flows determined by various activity volumes in the city, which are synthesised from knowledge and observation. Operations research approaches and the SD framework have been applied quite rigorously in urban systems, and in the recent times, geospatial modelling aided by visualisation has been very effective.

Globally, modelling urban sprawl dynamics has closely followed traditional urban growth modelling approaches. Subsequently, with the need to manage urban sprawl, modelling urban sprawl by understanding the nature of growth and its implications has been undertaken since 1960s. The key initial studies in developed countries based on traditional approaches of urban model building include Lowry (1967 in Batty and Torrens, 2001), Walter (1975), Allen and Sanglier (1979), and Pumain *et al.* (1986). The traditional approach of model building involved linking independent to statistically significant dependent variables in a linear or non-linear model. These models although used mostly for policy purposes, could not be used when the processes involved rule-based systems (Batty and Torrens, 2001). Whilst urban development models were developed much earlier, modelling the dynamics of urban sprawl has been undertaken only recently (Batty, Xie, and Sun, 1999; Torrens and Alberti, 2000). Models developed using cellular automata (CA) and agent-based models would prove beneficial to pinpoint where sprawl takes place (including causal factors), which would help in effective visualisation and understanding of the impacts of urban sprawl. Furthermore, to achieve an efficient simulation of urban sprawl, modelling has to be attempted in both spatial and non-spatial domains. Modelling urban sprawl in non-spatial domain is mainly by the application of statistical techniques while CA models and agent-based modelling are known to complement modelling in the spatial domain. The fusion of geospatial and agent-based models has been formalised as geographic automata systems (GAS) by Benenson and Torrens (2004). These approaches and research in geospatial modelling towards a simulation framework can effectively complement spatial planning support system.

6.4 Integrated Spatial Planning Support Systems

For effectively managing the problem of urban sprawl; testing, building and visualising different scenarios, it is imperative to have a robust SPSS. An ideal SPSS would not only aid in managing but also in planning, organising, coordinating, monitoring and evaluating the system in question. SPSS include instruments relating to geoinformation technology that have been primarily developed to support different aspects of the planning process, including problem diagnosis, data collection, mining and extraction, spatial and temporal analysis, data modelling, visualisation and display, scenario-building and projection, plan formulation and evaluation, report preparation, enhanced participation and collaborative decision-making (Geertman and Stillwell, 2004). Integration of different processes associated with the dynamics of sprawl phenomenon is required for addressing the problem of urban sprawl. Accordingly, the previous chapter dealt on capturing the processes of urban sprawl in relation to land-use and transportation planning.

6.4.1 Framework for SPSS

The framework for a planning and decision-making process involving different phases of intelligence, design and decision / choice (Sharifi, 2003) is depicted in Figure 6-1. The intelligence phase is confined to defining, understanding and assessing the existing situation along with evolving appropriate metrics for quantifying urban sprawl. In the design phase, the dynamics of urban sprawl are captured and subsequently modelled. The design phase concludes with the generation of alternatives. In the decision / choice phase, the review and evaluation of the different policy options are undertaken to arrive at policy recommendations for managing and mitigating the urban sprawl.

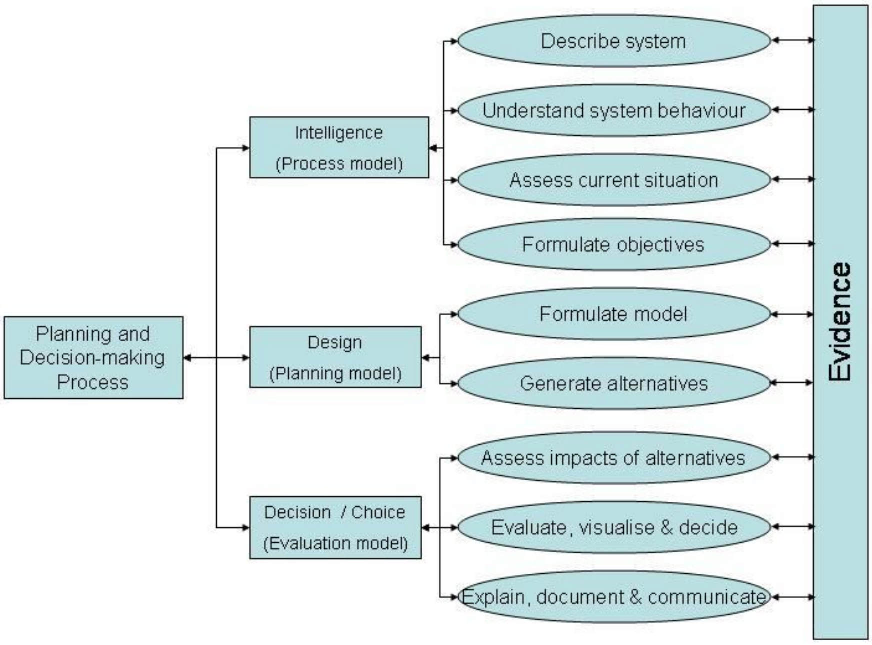


Figure 6-1: Planning and decision-making process (Sharifi, 2003)

6.4.2 Integrated Model for SPSS

Keeping in line with the framework for planning and decision-making suggested by Sharifi (2003), a prototype of the SPSS was developed with the following four components: patterns, processes, causes and consequences. Accordingly, the evolution of the planning support system is depicted in Figure 1-1.

6.4.3 Prototype Design and Implementation

i. Visualisation Environment, Design and Implementation

The prototype of SPSS has been developed as the BangaloreSim model, implemented using NetLogo (Wilensky, 1999), an agent-based modelling environment developed by the Centre for Connected Learning and Computer Based Modelling, Northwestern University, USA which facilitates encapsulation of processes through rule-based procedures and offers adequate monitors and plots to visualise pattern, model the causes and evaluate the consequences through simulation. The pseudo code of the BangaloreSim model is presented in Box 6-1, which outlines the sequence of processes involved in the simulation. The source code of the BangaloreSim NetLogo model Version 17-d is provided in Appendix D.

Box 6-1: BangaloreSim model pseudo code

INITIALIZATION
Set Parameters -> User Defined or Set from earlier start-up
Import land-use data, elevation, transportation networks and CDP (Land-use Policy)
Initialise System Dynamics setup
- Initialise for Population, Economic Growth Rate (City Development Product), Available Land

EACH TIME STEP
Check for Simulation End Time and Available Land [Stop run if exceeds either of them]
Compute Demand for Land (Inputs from System Dynamics Model – Stock & Flow Diagram)
- Population Growth Model Runs -> Current Population
- Current Population -> Population Density -> Land-use Change
- Land-use Change ~ Population Density, Available Land, Economic Growth Rate
- Land-use Change ~ Requirement for New Built-up
Change Land-use
- Obtains Built-up Demand from Land-use Change
- Site-Suitability
  - Suitability for patches based on Distance from City Centre, Transportation Networks, Weightages for Certain Land-use based & LU Policy, and *Proximity to Growth Pole*
- Allocate Land
  - Check for Built-up Demand [Stop run if exceeds current built-up or No Available Land]
  - Check for Maximum Site Suitability in the Neighbourhood (3x3) and allocate Land-use to Built-up
Compute Metrics ~ Check for Impacts on Resources and Access to Services
Update Views and Draw Plots
END

Agents are Growth Pole centres influencing land-use in their neighbourhood

ii. Development of Prototype and Evaluation

Among the key criteria considered during the prototype development was enabling the user-interface for visualisation of land-use along with the other requisite metrics in the common interface. Thus, the entire parameters are presented in a single interface with provisions to change views for different land-uses, sprawl metrics, transportation networks, land-use policy (the comprehensive development plan) and suitability. Subsequently, for an SPSS to be effective, it would require the modeller / expert to control relevant parameters for generating scenarios simultaneously enabling dynamic interaction. Considering these key criteria, the prototype developed is depicted in Figure 6-2. The base year for the model was considered 2000 with the classified land-use map for the same year serving as the input.

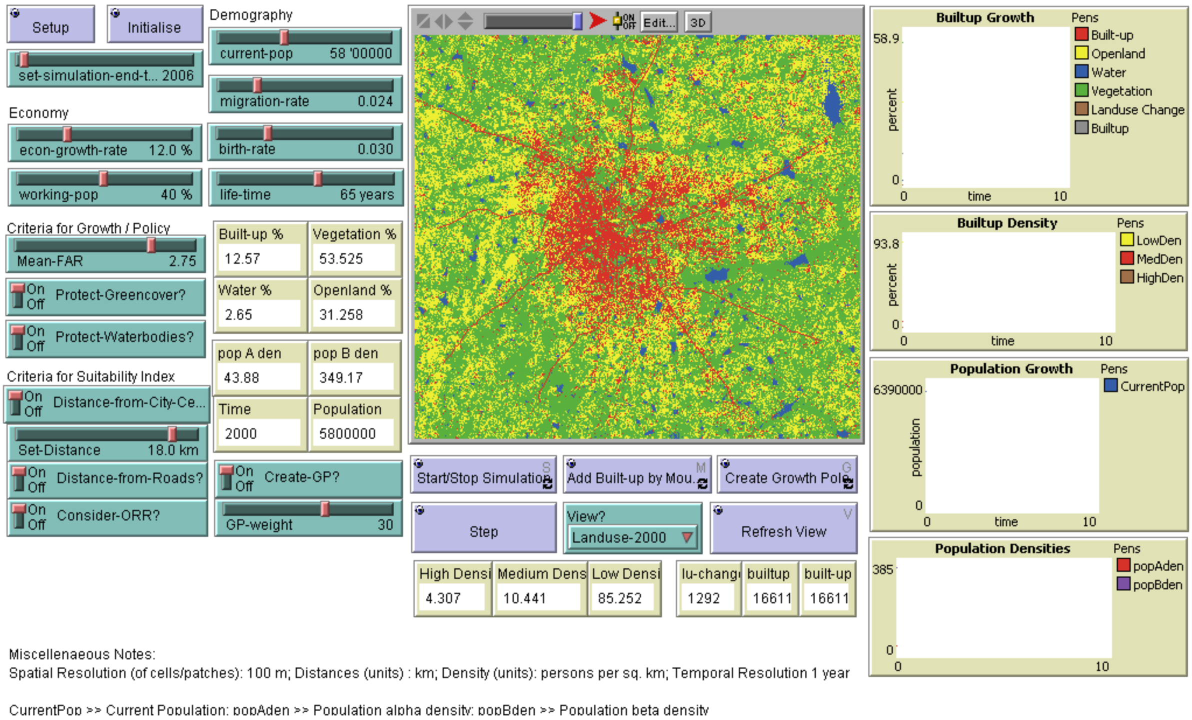


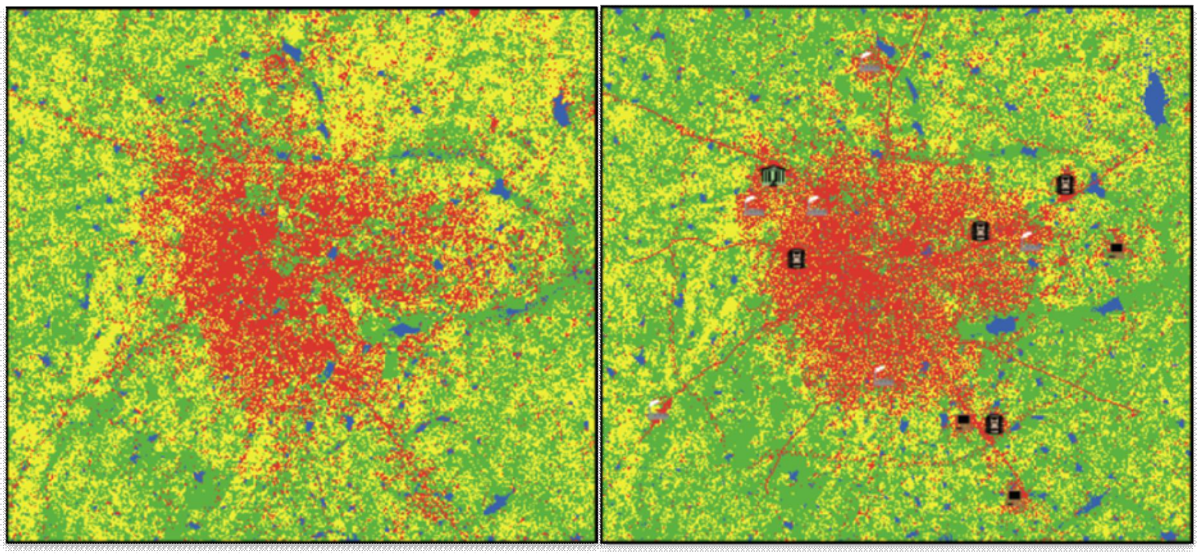
Figure 6-2: Prototype of the SPSS

The evaluation of the SPSS involved calibration of the suitability weights with mean floor-area-ratio and location of industrial estates as growth-poles. The floor-area-ratio was set to 2.75 based on the permissible ratio of the land-use zoning policy. Considering these model set-up parameters, the suitability weights for different factors like land-uses, distance from city centre and distance from transportation network were calibrated. The calibration for the weights was performed comparing the classified land-use and the simulated land-use for 2006.

In the earlier test simulations (before acknowledging growth-poles), the land-use changes could not forecast the land-use for 2006 appropriately. There were other initiatives by the State Government like the creation of outer ring road, which has been captured in the system. The industrial estates were ascribed as a growth pole (GP) agent to capture these changes. The GP agent essentially boosts suitability of any particular land-use in the neighbourhood with the greater probability to change it into built-up (see underlined procedure in the pseudo code in Box 6-1).

The simulation for year 2006 considering the influence of growth-pole agents and the mean floor-area-ratio with the calibrated weights for suitability is presented in Figure 6-3. The comparison of these outputs were also analysed using the Map Comparison Kit 3

(Hagen-Zanker *et al.*, 2006). The simulated land-use (Figure 6-3(a)) was compared with the classified land-use of 2006 (Figure 6-3(b)). The Kappa statistic of built-up areas was 0.413 and Kloc was 0.427 with Moran's I for the simulated and classified image was 0.643. The calibrated model was then used to perform policy analysis.



(a) Classified land-use (2006) (b) Simulated land-use (2006)

Figure 6-3: Classified and simulated land-use of Bangalore for 2006

6.4.4 Policy Analysis

The scope of policy analysis is restricted for evaluating the impact of increasing floor-area-ratio on extent of sprawl up to the year 2015. The effect on sprawl was analysed based on the percentage built-up and built-up densities. The simulations revealed that higher FAR resulted in increase of built-up areas (386.64 sq. km, 93.27%) with high densities and the rate of built-up growth declining. However, in the duration of increase in density of built-up areas, the population-b-density (population over built-up area) depicted "U" type behaviour. Accordingly, the population-b-density decreased initially and increased after certain duration of time. This suggests that initially the expanse of built-up in spite of FAR continued and only after a threshold, the population choose to locate within the city's extent over locating in the outskirts. The increase in built-up areas with high densities suggests more congestion in certain parts of the city. It is in these parts of the city wherein infrastructure and services need to be augmented to accommodate the forecast population-b-densities. The policy analysis revealed the probable effects of change in FAR on extent of built-up areas and their densities. The SPSS was effective in locating areas with higher densities of built-up area and requiring augmentation of infrastructure and services to relieve the impending congestion in these localities. While this exercise was useful in generating a scenario of urban land-use, there can be many more scenarios generated by undertaking the simulations for different policy settings to understand their respective consequences.

6.4.5 Drawbacks and Recommendations

An important distinction in the SPSS was the ability to incorporate the process that lead to land-use changes like creation of growth–poles and studying the effect of outgrowth through floor-area-ratio. SPSS thus facilitates the analysis of choices, visualisation of such decisions and evaluation of certain policy decisions. However, the success of these will rest on the modellers, planners who can identify and capture these processes to realise the best possibilities from an SPSS.

The scale of analysis affects the computational complexity of the system. Higher spatial scales increase the computational resources required to perform the simulations optimally and vice-versa. In the current model, the spatial scale is set for 100 m x 100 m grid, with yearly time scales. Caution should also be exercised on the choice of scale based on the problem and processes that is being modelled.

The research here in this direction is yet to validate the SPSS with the government functionaries. Validation of agent-based land-use models has been a contentious issue in recent times. However, a recent work by Brown *et al.* (2005) has attempted to clarify this debate by acknowledging path dependence and bringing out the distinction of achieving predictive accuracy and process accuracy. Consequently, it is important that any SPSS should have greater process accuracy and be able to generate patterns resulting out of numerous processes. But planners and decision makers would always want some amount of predictive accuracy informing them what type / pattern of growth will emerge at different locations. Thus, SPSS should be ideally achieving reasonable predictive and process accuracies. The process accuracy and predictive accuracy of this model is yet to be ascertained. However, the SPSS in its current state allows the modeller or experimenter to test for various options and evaluate the consequences.

The contention of the process accuracy can be either addressed by following a similar approach of Brown *et al.* (2005) or engaging in a focus group evaluation involving key bureaucrats, planners, policy makers and experts who would verify the processes captured in the SPSS and outcomes of the simulation in the SPSS. With such a focus group evaluation, it will also make it beneficial for SPSS to be adopted in their current planning practices.

6.4.6 Future Trends in PSS

The SPSS is developed on an agent-based modelling environment as a process-based land-use model. The developments in PSS can significantly complement research in temporal geographic information science transforming the temporally static GIS to temporally dynamic systems. The exchange of geospatial data (import and export functions) is now possible for ascii grid formats. In the future, it is imperative that these systems are interoperable and support most of the standard geospatial formats. Provision of PSS over the Internet can also imply that they may be accessible to everyone and can become pervasive. Such a web-based PSS can be a very effective tool for monitoring, planning and decision-making encouraging community participation. At the outset, the future development of the PSS can facilitate exchange of standard geospatial data formats and evolve as a web-based system.

6.5 Conclusions

Proper implementation of master / development plans is a critical aspect in regulating the development of urban areas. Although 1,200 master / development plans for important towns and cities have been prepared in India, their implementation so far has not been satisfactory due to a variety of reasons. City planning mainly addresses the preparation of land-use plans through zoning to cater for projected populations. However, civic authorities also need to plan for meeting the demand for infrastructure facilities and ensuring delivery of basic services. This is dismal in current planning practices since these are normally static master plans or development plans mostly addressing land-use issues. These plans are also less equipped to review and evaluate any policy decisions dynamically by visualising the potential implications of a policy directive and the regions of potential sprawl. It is therefore necessary to support administrators and planners by providing them with better understanding, methods and tools to tackle the problem of urban sprawl. Further, administrators and planners need to be informed of possible areas of sprawl to take corrective actions to mitigate the implications. The problem of urban sprawl is observed to be an outcome of improper planning, inadequate policies and lack of effective governance due to various reasons. The inability of the administration and planning machinery to visualise probable areas of sprawl and its growth is persistent with the lack of appropriate spatial information and indicators.

Thus, in the present context, with the escalating problem of urban sprawl, the evolution of a SPSS in the form of the BangaloreSim model is the first step in this direction. The SPSS aids in undertaking policy analysis for certain policy measures and its consequences on urban land-use. The SPSS was also effective in evaluating the influence of FAR on controlling urban sprawl. However, there are numerous challenges for incorporating the complex urban system in a dynamic modelling framework with which to support participatory decision-making. The SPSS can be used to regularly monitor and check the nature of sprawl for compliance with policy recommendations over time.

VII. Conclusions and Future Challenges

7.1 Overview

The evolution of human-social organisation into towns and cities resulting in large urban agglomerations and metropolitan cities together with an unprecedented urbanisation especially in developing countries like India, has confronted planning and policy making with enormous challenges in addressing them. Coupled with a significant contribution from urban areas to the national economy and the opportunities urban areas offer in terms of livelihood has resulted in urban governance and planning ensuring delivery of requisite infrastructure and facilitating basic services and amenities. The land-use changes that have resulted as a consequence of urban growth and infrastructure initiatives like transportation corridors has resulted in an inevitable urban sprawl. Addressing the issues concerning urban sprawl has been the focus of this research. Alongside the challenges in addressing urban sprawl is the need for comprehensive tools that facilitates policy, planning and decision-making.

An important aspect in enhancing the comprehension of evolution in city systems is an integrated understanding of different sub-systems that manifests the overall outcomes. The integrated understanding should complement spatial planning acknowledging the city functions and its economic activities coupled with the resources availability and environment considerations. All these direct towards leveraging complexity sciences to build such an understanding of urban systems. The learning from complexity sciences on urban systems depicts that the typical characteristics of self-organisation, path dependence and adaptation are all prevalent here. Besides this, it is noted that addressing urban sprawl is closely embedded with how spatial planning confronts the challenges accommodating evolution of cities linked with urban economics and transportation (Batty, 2008). Perhaps the call for 'city planning as a new science' (Batty, 2008) certainly holds merit. The current research addressed urban sprawl while arriving at a spatial planning support system for facilitating policy, planning and decision-making while linking different sub-systems.

7.1.1 *Summary*

Urban sprawl is the uncontrolled and uncoordinated outgrowth of towns and cities. The dispersed development outside of compact urban and rural centres along highways and in rural countryside is referred as sprawl. Sprawl generally refers to some type of development with impacts such as loss of agricultural land, open space, and ecologically sensitive habitats in and around the urban areas. These regions lack basic amenities due to the unplanned growth and lack of prior information and forecasts of such growth during policy, planning and decision-making. Meanwhile, the pressures on the natural resources are increasing day-by-day so as to cater to the rising urban population while towns and cities are expanding hay-way to meet these demands. The phenomenon of urban sprawl is potentially observed as a threat for achieving sustainable urbanisation. It is very essential that effective understanding on the phenomenon of urban sprawl especially with the perspective of a developing country be gained. Thus research should eventually aid in evolving any policy and management options for effectively addressing the problem of urban sprawl.

Noting the various studies, the pattern of urban sprawl is characterised by using spatial metrics based on the extent of paved surface or built-up areas. The process of urban sprawl can be described by changes in pattern over time like proportional increase in built-up surface to population, leading to rapid urban spatial expansion. Analyzing the causes of urban spatial expansion, the externalities are modelled as agents in a geospatial environment like location of jobs, housing, access to services, level of economic activity, etc. With an understanding of the patterns, processes and causes of urban sprawl, the consequences of sprawl can be explored which are reflected by the patterns, thus eventually aiding in the design of spatial planning support system. Following the sequence of patterns, process, causes and consequence, sets the research agenda for this research.

The study on dynamics of urban systems is attempted by acknowledging the effect of scale. In the short time process, the interactions of actors and the activities in urban areas generate dynamics within the city, influencing travel times, market dynamics, etc. At the actor level, the choice and allocation of requisite proportion of resources especially in urban governance evolves as a consequence of these interactions. In the mean time (near to short-term), the consequences of the dynamics are evident by changes in land-uses like reduction in open spaces and green-cover, change in pollution levels, etc. Further, the evolution of towns and cities are studied in the mean time scale over years ranging from decades to a century.

The rise in size of towns and cities in terms of population and its spatial extent are important determinants of urban growth in this scale. The analysis in the long-time process is not attempted due to unavailability of appropriate data ranging over several centuries.

The proposition of organic urbanisation as evolutionary process is put forward, studied and empirically supported by analysis of urban evolution in Karnataka State over the last century. This was supported by the analysis confirming the characteristic scaling behaviour demonstrated by towns and cities in Karnataka. Subsequently, a theoretical framework for explaining sprawl through the process of land-use change in the mean time scale is presented. The theoretical framework sets the context for analysing the interaction of level of services on the one hand and the extent of outgrowth on the other influenced by planning. It is hypothesised that planning and governance affects the evolution of a city.

Bangalore, with all due respect to its status as ‘Silicon Valley’ and ‘Garden City’, faces real challenges in terms of addressing issues like basic infrastructure and services to all its stakeholders. In spite of numerous initiatives and activities envisaged by the urban local bodies, past and present, and by parastatal bodies, the rationalisation of geographical units for these activities could mark the beginning of a coordinated effort in addressing the needs of the city. In the wake of recent notification of Bruhat Bangalore Mahanagara Palike (BBMP; or Greater Bangalore City Corporation) and initiatives under Jawaharlal Nehru National Urban Renewal Mission (*JnNURM)*, Bangalore is currently experiencing a strange transformation. Bangalore also stands out as a beacon of globalising world and to sustain this, the key challenges facing the city in terms of governance and infrastructure are to be addressed.

Subsequently an attempt is made to characterise sprawl for Bangalore based on patterns. Combining the goals of achieving sustainability and addressing the problem of sprawl has been the underlying principle of the present description of sprawl indicators for developing countries. This would allow the concerned authorities of urban areas to regularly plan, review and monitor the direction in which urban growth heads towards achieving sustainable development. It is in this spirit, a few indicator frameworks are reviewed and the indicators for urban sprawl are ascertained. Further, these are operationalised for the city based on both primary and secondary data collection across eight administrative zones of BBMP.

The different dimensions of sprawl based on resources, demography environment, economy, mobility, planning and governance were ascertained and enumerated. The utility of spatial indicators combined with non-spatial indicators were useful in characterising the patterns of sprawl across the urban agglomeration. The estimation of different indicators and the subsequent analysis clearly brought out the similarities (and dissimilarities) between the sprawl regions (outer zones) and the central city (central zones). Multidimensional scaling was employed to ascertain the similarities and dissimilarities across the different zones of BBMP. Characterising urban growth using multi-temporal remote sensing data has been quite popular for a while although there have been a few studies that addressed the extent of urban growth resulting in sprawl through appropriate metrics. The utility of landscape metrics like patchiness and built-up density for characterising urban sprawl is demonstrated. However, a critical challenge is to identify ecologically sensitive habitats (like water bodies) that may be prone to sprawl and address the extent of low-density sprawl that results in inefficient resource usage. Further, the pattern of development, taking place along the periphery of Bangalore city, should be used as a tool for effective monitoring and enhancing management options for land-use. In the next stage, it is imperative to understand the process of sprawl by the change in patterns. This might help one to understand the dynamics that lead to such outgrowths.

Urban sprawl is a dynamic process requiring the models to capture the sensitivities of space and time apart from acknowledging the agents and interactions that determine the dynamics. It is imperative for models capturing the dynamics of sprawl to represent them in both space and time. Most of the existing models capture them either in space or time and not many capture both these dimensions. The approaches and issues concerning modelling of such systems are discussed.

Increasingly enough, sciences are acknowledging that all systems: environmental and / or socio-technical systems are ‘complex systems’. Although there does not exist any universal definition of a ‘complex system’, these systems depict sufficient amount of intractability that are complex enough to be captured / modelled. This has led to acknowledgement of such systems as complex adaptive systems, wherein self-organization is one of the fundamental processes that lead to emergence in these systems. Urban systems, especially cities are classic examples of complex systems. However, approaches to enhance the understanding of such systems are now evolving and are mainly dominated by the system dynamics and agent-based modelling approaches. Accordingly, the current study has attempted an integrated approach to capture the dynamics of urban sprawl arising out of planning practices on the one hand and the dynamics emanating due to the ongoing activities (economic, etc.) on the other. An attempt was also made to capture the dynamics using systems approach and finally the insights gained were translated into the agent-based modelling after specifying the model for the process of land-use change.

With an understanding of the pattern, process and causes, it is important to forecast the consequences of urban sprawl for land-use planning. To identify the consequences, it would require the model to generate possible scenarios of land-use change along with the implications on various indicators. Further the consequences have to be identified based on the choice or decision of certain policy aspects to evaluate for the same. Thus it is also important for research to identify the appropriate ‘policy options’ and the instruments that would influence the land-use changes. Noting the evolution of spatial planning support system (SPSS), the consequences of sprawl are explored. The SPSS is developed on an agent-based modelling environment as a process-based land-use model.

The need for an integrated spatial planning support system (SPSS) is highlighted, illustrating the evolution of a framework for SPSS, its development and evaluation. The policy analysis carried out using the SPSS offers insights into areas of concern. It is concluded by noting the drawbacks and challenges for future research for managing urban sprawl. In the present context, with the escalating problem of urban sprawl, the evolution of a SPSS in the form of the BangaloreSim model is the first step in this direction. The SPSS aids in undertaking policy analysis for certain policy measures and its consequences on urban land-use. The SPSS was also effective in evaluating the influence of floor-area-ratio (FAR; or floor-space-index) on controlling urban sprawl. However, there are numerous challenges for incorporating the complex urban system in a dynamic modelling framework with which to support participatory decision making. The SPSS can be used to regularly monitor and check the nature of sprawl for compliance with policy recommendations over time.

7.1.2 Limitations

The current research has attempted to study urban sprawl for the city of Bangalore, which is a rapidly growing city compared to many other cities in the country. That apart the study focussed on the outgrowth outside the periphery of the city alone (radial sprawl) and not necessarily the uncontrolled development that take place around highways and major road connecting towns and cities (linear sprawl). The scale of analysis has been mostly in the near-to-short term (10-15 years timeline) rather than shorter term scale or very long term time scale with the scale for spatial analysis too was moderate (100 m x 100 m). As noted earlier the scale of analysis has greater implications on the analysis and necessary outcomes of the study. However the immediate consequence of change in scale would affect the processes that are captured therein and their respective behaviours.

A key drawback of this research is the limited study and analysis on the economic and financial implications of sprawl. While the characterisation of sprawl wrested mainly on the four themes, they did not incorporate the costs associated with the same. In the future, it can be beneficial to choose the nature of development if the costs associated with dispersed development (with sprawl) and compact development (without sprawl) is estimated.

The policy analysis carried out using SPSS was with the focus on evaluating existing policy levers like the FAR. As noted earlier, the scale of analysis affects the computational complexity of the system and hence increasing scale of analysis would call for higher computational resources.

7.2 Policy Recommendations

Achieving the multi-faceted goals of sustainable development through more efficient utilization of resources poses formidable challenges while providing great opportunities in India. Major economic reforms gained momentum in India in early nineties, but it failed to deliver effectively on all spheres (education, sanitation, etc.) due to the lack of appropriate implementation measures that were required to ensure sustainability. In a rapidly urbanizing economy with fast technological changes, there is a need for governments to quickly and continuously ‘adapt’ to these changes ensuring that smooth and sustained workflow through interactions with the government and the people. Thus, the governance is the exercise of economic, political and administrative authority to manage a country’s affairs at all levels. It consists of the mechanisms, processes and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations and mediate their differences. Poor governance generates and reinforces poverty and subverts efforts to reduce it. Good governance would ensure that developmental schemes reach all sections of the society and aid in enhancing the quality of life. Strengthening planning and governance is an essential ingredient for promoting sustainable development while minimising resource utilisation and eradicating poverty.

7.2.1 Planning and Governance

i. From Urban Planning towards Regional Planning

In India, as per the 74th Constitutional Amendment Act (1993), there is a mandate with urban local bodies for administering, managing and preparing master / development plans [Govt. of India, IndiaCode: http://indiacode.nic.in/coiweb/amend/amend74.htm]. Mostly these plans are static maps with limited forecasting capabilities and there is a dearth of models for planning process and hence leading to ad hoc decisions. Besides this, these plans mostly restrict to demarcate only land-use zones with little or no effective regulation for the same. Further, with planning authorities restricting to mostly land-uses, there is hardly any coordinated effort to involve or integrate transport, water and sanitation, etc. in the planning process. This results in organisations involved or catering to different services (transport, health, water, energy, etc.) work in isolation to address basic amenities. Lack of coordination among many agencies has lead to unsustainable use of land and other resources and also uncoordinated urban growth. Much of this growth is normally attributed to migration of people from other places. Migration takes place mainly due to uncertain employment in rural areas where the majority relies on agriculture, which is dependent on unpredictable monsoons. In the absence of effective rural-employment guarantee schemes and prevalent macro-economic initiatives catering to urban areas further fuel rural-urban migration with some formal or informal employment in the offing. Thus, for certain critical issues administration and planning cannot confine itself even to limited boundaries of the urban area, but acknowledge conditions and factors to address and plan effectively at a regional level. In this perspective, planning and administration have to be responsive to local and regional issues while ensuring requisite infrastructure and delivery of basic services.

ii. Empowering Urban Local Bodies

Democracy empowers citizens through decentralization of power, effective people's participation through state and non-state mechanisms, greater synergy and consolidation among various agencies and programmes of government, civil service reforms, transparency, rationalization of governmental schemes and mode of financial assistance to states, improved access to formal justice system to enforce rights, reforms and strengthening of land administration and harnessing the power of technology for governance. In contrary, policy-making takes place at the centre (macro-level), and the actual implementations at the end-user (micro-level), by the bureaucrats / administrators are mostly different than what was originally conceptualized or intended for, as implementation practices are embedded with colonial structures, bureaucratic autonomy and opaque systems leading to economic inefficiency, ineffectiveness and inappropriateness of some of these set-ups. With the onset of economic reforms, emergence of technology-driven society (socio-technical systems) and markets, it is imperative for the governments to reinvent, realign and adapt to remain or sustain the external pressures from different stakeholders, especially with pressures of globalization and calls for decentralization for overall development of India's rising 300 million plus strong urban population. The necessity to achieve 'sustainability' by the administration with local governance or in public sector organisations or any reforms has become a cornerstone. A key issue on achieving sustainability and sustainable development is through administrative reforms.

The key organisational structure responsible and representing the citizens in urban areas are the elected local bodies. In the case of Bangalore, the Bangalore urban agglomeration until recently composed of nine urban local bodies comprising Bangalore City Corporation, neighbouring seven City Municipal Councils and one Town Municipal Council. During January 2007, the State government has issued notification of Bruhat Bangalore Mahanagara Palike (BBMP; or Greater Bangalore City Corporation) through merger of nine local bodies and 110 neighbouring villages. Planning for this region in the form of land-use zoning and their regulation are vested with Bangalore Development Authority (BDA), a parastatal agency. Significant administration and decision-making in these areas with regard to delivery of various services rests with other parastatal organisations. Apart from the City Corporation represented by the local elected representatives, all other organisations responsible for essential services are parastatal bodies controlled by the State government. Thus, the urban local bodies have minimal powers to react and address many of the interconnected issues. It is in this context that the urban local bodies have to be empowered as mandated by the constitution and pursued by the mandatory reforms of *JnNURM*.

From the analysis on the nature of urban local governance, certain policy measures and operation plans drawn are ineffective in addressing smooth coordination with other agencies concerned with delivery of services. Essentially much of the chaos is contributed due to the disengagement with the planning organisation and the organisation involved with daily operations. A stark contrasting fact with the planning organisation is its lack of acknowledgement of key city functions: mobility, jobs, economy, energy, etc. The planning organisation on the one hand is focussed on land-use plans and its regulation alone with any acknowledgment of integrating land-use with transportation for enhancing mobility. On the other hand, the local administration has to be awake overnight to act for daily operations management with little realisation on the implications of the planning organisation ignoring the city functions. With numerous organisations responsible for addressing various city functions, it is imperative that these organisations acknowledge their interdependencies formally through appropriate mechanisms. Thus the possible way to break the gridlock is by facilitating systems and practices that ensure feedback and coordination effectively. Essentially the interplay of these organisations involved with different city functions has to be acknowledged and bridged from short-to-medium (5 to 10 years) time frame planning undertaken by BDA to near-to-short term operations undertaken by City Corporation. Thus, it is essential to link the daily-operations with the planning of 10 years time period so that future chaos is arrested.

With the creation of BBMP, the State government also set up an expert committee to study and suggest alternate planning and governance structures under the Chairmanship of K. Kasturirangan, a member of upper house of National Parliament, Rajya Sabha. The committee has only recently (March 2008) submitted the final report along with the recommendations for the same. One of the key contentions in the report is the breach of constitutional obligation for creating the Metropolitan Planning Committee (MPC) for Bangalore metropolitan region. Therefore, it strongly recommends setting up of MPC with the Chief Minister of the State to head this committee along with about 66 % of elected representatives from the region and the remaining (including experts) members appointed by the Government to undertake holistic planning for the entire metropolitan region. The report notes several far reaching and legal changes for facilitating an empowered, responsive and accountable urban local body.

iii. Evolving Best Practices

A significant realization and common ground in all the ‘best practices’ presented in Singh (2003) is that different stakeholders are able to acknowledge the feedback of other entities and respond, realign and refocus to benefit for the greater common good. Another key aspect noted here though not explicitly identified is that most of these socio-technical systems exhibit self-organization and have emerged out of the need to enhance performance which are initiated by the administrator at the local level or by the civic participation or through a public–private partnership or even by the judiciary. It is these local interactions that have resulted in global changes that result in self-organization, micro-innovations leading to macro-changes.

The creation of Directorate of Urban Land Transport (DULT) for the major city corporations in Karnataka and Bangalore Metropolitan Land Transport Authority (BMLTA) recently by the Government of Karnataka to address the integration of land-use planning with transportation planning is noteworthy. However, much of the success of these organisations wrests in addressing key processes that emanate through the interplay of land-use and mobility and bringing in systemic changes to address the same. Perhaps the outcomes and any success of these organisations could emerge as one of the 'best practices' in urban planning and governance. However, for effective realisation of the objectives of BMLTA, the organisations should be empowered through adequate statutory support. Note that successful functioning of BMLTA with added regulation through legislation and functioning under MPC as envisaged could evolve as a *Best Practice* in urban governance and planning.

iv. A Common Jurisdictional Unit: Key for Coordination

A key reason for the persistence of lack of effective coordination is the absence of "common jurisdictional unit". Much of the mess, the planning or the administration currently facing are the implications of having different jurisdictions for different parastatal agencies. With multiple organisations addressing urban governance, it is rather incomprehensive that none of these organisations have a common jurisdictional unit. Due to this, it is not possible to collate and assimilate data for different city functions, which has lead to isolated interventions evident from the current practices. The landscape of Bangalore has been formally extended with the amalgamation of neighbouring municipal councils and villages forming Greater Bangalore. However, with the demarcation of regions, zones and wards based on possibly Census and settlement patterns, it is imperative a common jurisdictional unit is mooted with the involvement of all the stakeholders in this region. By ensuring that all other stakeholder organisations comply with the same jurisdictional unit, planning for operations would become effective. The advantage of having common jurisdictional unit would also ensure easy collection, collation and dissemination of the data at a common place. Thus the integration and coordination has to begin for having a common jurisdictional unit.

7.3 Future Challenges: Tackling Sprawl by Regulating Development

Tackling sprawl to contain the outgrowth on the one hand and ensuring adequate level of services facilitated by planning and governance on the other remain as persistent challenges. It is noted that there does not exist one single solution but a combination of multiple solutions and approaches in addressing sprawl. In view of the understanding gained and the challenges in addressing urban sprawl there are certain critical areas which require immediate attention.

- **Distributed PSS:** Most PSS allow analysis, evaluation and visualisation only on standalone systems, wherein each stakeholder has to choose / decide the options on same system / platform. This would suggest that all stakeholders have to meet physically to evaluate and decide. Moreover, such initiatives are not normal and very difficult to moderate. In this context, it becomes necessary for a parallel and distributed simulation framework to support PSS so that all stakeholders and managers / administrators are able to interact, organise, plan, evaluate and decide through a network. Then the challenges are twofold: initially to integrate different models that are required to carry out the simulations, and then to synchronise the model inputs, feedbacks and outputs over space and time. Design of PSS with participatory simulation framework will largely contribute to its ready usage in urban planning and decision-making process.
- **FAR and Impact Fee:** Among the key policy levers to restrict the outgrowth is by way of enforcing Floor-Area-Ratio (FAR). In Bangalore, the prevalence of building height restrictions has indeed led to the outgrowth of the city, but has also avoided over-crowding inducing high density central areas. However, in view of the limited supply of land and ensuring efficient utilisation of land, it is suggested to moderately relax building height restrictions to accommodate the demand for more space. Meanwhile, it is imperative that consequent infrastructure and services in such localities be augmented for which an 'Impact Fee' can be levied. The locations for such relaxations, pricing for the same and permissible limits for relaxation has to be arrived through a participatory mechanism involving all the key stakeholders. Already there have been divergent views on continuing with the existing building height restrictions and allowing the city to

expand, and *vice versa*. It is in this context that there has to be adequate public debate and public awareness has to be raised. Any debate can take place when concerned and affected stakeholders concur on such measures through sufficient understanding of the consequences of adopting any of the divergent paths. Perhaps arriving at this middle course would be the toughest task in the times to come. Caution should be exercised that such ‘Impact Fee’ would not affect the urban poor residents. Instead the services for urban poor should be addressed in parallel and systematically through integrated housing.

- **Development Charges:** From the forecast of future land-use based on the SPSS forecasts it was evident that there would be more high-density areas in the central zones of the city while a few more such areas would emerge along the outer zones as well. In line with the prevailing land-use zoning, it is imperative that such localities are augmented with better infrastructure and adequate level of services. In these circumstances, financing such additional development has to be borne by the respective urban local body. Accordingly, the urban local body can levy ‘Development Charges’ based on the proposed land-use changes in the neighbourhood from the respective land-holders. The necessary mechanisms, pricing based on amount of land-holding, should be again evolved by the urban local body though public participation and necessary stakeholder consultations. Though such measures are unpopular, they are inevitable.
- **No Development along Ring Roads / Expressways:** Among the key driver for the city outgrowth is the development of outer ring roads around which development of land takes place rapidly resulting in significant land-use changes. Such land-use changes would also operate under speculative land markets and result in unplanned development. These were evident in the case of Bangalore from the land-use change analyses. Hence it is imperative to contain any development along the expressways and ring roads. To this effect, the Punjab Regulation of Development Act of 1960s can be worth pursing and passed by the State Legislature.
- **Confronting Linear (Ribbon) Sprawl:** The linear (ribbon) pattern of sprawl that takes place along the transportation corridors connecting two cities in Karnataka are studied and documented for Bangalore-Mysore and Mangalore-Udupi segments (Sudhira *et al.*, 2003; 2004a). In the case of Bangalore too, the outgrowth was prevalent along all the major transportation networks (National Highways and State Highways) that emanated from the city in radial directions (like those on Mysore road, Tumkur road, Bellary road, Hosur road, etc.). Provision of adequate level of services and amenities in these regions

would rest on the neighbouring local bodies with little clarity and anticipation of such development. As evinced for the studies, the local bodies are inept in addressing these challenges and require external support to confront them. Therefore, it is important for planning machinery to acknowledge the organic development that takes along the major transportation networks that connect the city. Noting the importance of such organic development in terms of providing informal employment in different services, curtailing the same may not be wise. Instead, this can be encouraged with adequate planning and requisite regulation. However, in the course of such development any threats on ecologically sensitive habitats and natural ecosystems should be curtailed. In this context the delivery of services and provision of amenities in these areas shall be planned by the local planning authorities or entrust a new special purpose vehicle / agency as the Corridor Development Authority supported by necessary statutory powers to address the same. It is important to note the distinction between the linear development taking place in radial directions along the transportation networks and the development taking place around the concentric ring roads / expressways around a city.

- **Regulation on Change in Land-use:** Typically the comprehensive development plans / master plans prepared by the local planning authority stipulate the permissible land-use. In spite of such ascription there exists deviation by way of subjecting the land to different uses beyond the permitted usage, encroachment of public lands and violation of building byelaws. The checks and enforcements for the same have been dismal owing to political pressures and various forces operating in a political economy. Yet it is every essential to devise mechanisms to restrain such unsustainable change in land-use beyond the prescribed land-use. Effective information disclosure on permitted land-use in the neighbourhood aided by an enhanced public awareness and enforcement can lead to successful regulation of illegal change in land-use.

Nevertheless, the challenges for managing urban sprawl remains as the human population evolves and settle in large agglomerations resulting in the expansion of cities. However the policies to tackle them also have to be reviewed from time-to-time, discarding the ineffective ones and adopting newer and effective ones.

A concluding caveat is that the contribution of research by way of spatial planning support system is only a short-to-medium term solution to this problem. The significant driver of sprawl in developing countries is the migration of people from rural areas to urban areas aspiring for livelihood, which is compounding the problem of sprawl. Therefore, a long term solution can only be achieved through an overall economic development of the region by way of better employment and livelihood generation activities beyond urban areas that can lessen the migration of people from other regions to urban areas and mitigate urban sprawl. The research on urban sprawl presented in this thesis, is perhaps, only a beginning in understanding and addressing urban sprawl in the Indian context.

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Appendix A: Indicators for Carrying Capacity based Regional Planning by NIUA

Module	Sector	Indicator	Description	Units
A	Air Environment	1	Natural Assimilation: Ventilation of pollutants in m^2/s in the local air shed during lowest wind flow seasons and times of the day	m^2/s
A	Air Environment	2	Emission Control: Air pollutant emissions in kg/hr from point, line and area sources in the urban area	kg.hr
A	Air Environment	3	Cross media transfer from air to land / water, especially of dust particles and acid rain. (Monthly rainfall in mm)	Monthly rainfall in mm
A	Water Environment	4	Natural Assimilation: Maximum pollutant load of the critical water quality parameters (viz. BOD, DO, toxic chemicals, etc.) that can be discharged into the local water shed without impairing water quality for designated urban uses.	
A	Water Environment	5	Emission Control: Installed capacities in MLD of wastewater treatment facilities as proportion of wastewater generation in the urban area in terms of:	MLD
A	Water Environment	5.1	Municipal Sewage Treatment plants	
A	Water Environment	5.2	Industrial Wastewater Treatment / Recycling plants	
A	Land / Soil Environment	6	Natural Assimilation: Bio-degradation rate of solid wastes in local soil	
A	Land / Soil Environment	7	Solid Waste Management: Installed capacities of:	
A	Land / Soil Environment	7.1	Municipal solid waste collection in grams per unit population	grams per unit population
A	Land / Soil Environment	7.2	Municipal solid waste collection as percentage of generation in MTD	MTD
A	Land / Soil Environment	7.3	Garbage disposal in Ha/10,000 persons	Ha/10,000 persons
A	Land / Soil Environment	7.4	Municipal / industrial solid waste treatment / recycling plant in MTD per 10,000 population	MTD / 10,000 persons
A	Biological Environment	8	Diversity and stability of the ecosystem in the urban region (Types and densities of flora and fauna)	

A	Biological Environment	9	Air pollution sink potential of land vegetation in the urban region (Types and densities of vegetation)	
A	Biological Environment	10	Bio-degradation and nutrient uptake rates in the aquatic ecosystem in the urban region (marshlands, lakes, ponds, rivers, and marine ecosystems)	
A	Acoustic Environment	11	Sound attenuation in DBA though open air media across the urban area (% open space and vegetation density)	%
A	Acoustic Environment	12	Sound attenuation in DBA at critical point and line sources of noise across the urban area (presence / absence of control installation and legislations)	
B	Urban Land Resources	13	Population holding capacity of developed land within urban area in terms of acceptable gross density / land-man ratio (land-man ratio / gross density)	
B	Urban Land Resources	14	Suitable land for physical expansion of the urban area in hectares/sq. km	Ha/sq. km
B	Housing	15	Census housing index: Ratio of existing housing stock per thousand households	
B	Housing	16	Rate of housing supply: No of housing units constructed and transferred to users per year	units/year
B	Housing	17	Occupancy Rate: Average floor area per person (or person per room) in housing units	
B	Housing	18	Permanent structures: Percentage of housing units with structural stability of 20 years under normal maintenance (% Census pucca houses)	
B	Housing	19	Household amenities: Percentage of housing units with:	
B	Housing	19.1	Municipal Water Supply	
B	Housing	19.2	Electricity	
B	Housing	19.3	Sanitary Latrine having Municipal Sewerage / Community Septic Tank Connections	
B	Housing	20	Outdoor Living Space: Percentage of households in residential areas of having net densities less than acceptable maximum standard	
B	Housing	21	(Stress Indicator) Extent of slums: Percentage of urba+D17n population living in recognised slums	
B	Social Amenities	22	No of medical beds per 1000 persons (in hospitals, clinics, dispensaries, etc.)	
B	Social Amenities	23	No of doctors per 1000 persons	
B	Social Amenities	24	School capacity: Class room capacity (in number of students) per 1000 persons in:	

B	Social Amenities	24.1	Primary Schools	
B	Social Amenities	24.2	Secondary Schools	
B	Social Amenities	24.3	High Schools	(No. of schools per 1000 or lakh population)
B	Social Amenities	25	Outdoor recreational space: Area under parks and playgrounds (in m^2 or hectare) per 1000 persons	Ha/1,000 persons
B	Social Amenities	26	Indoor recreational space: No of seats memberships in cinema / theatre / auditorium / clubs per 1000 persons	no / 1,000 persons
B	Social Amenities	27	Public security: Size of police force per 10,000 persons (No of recorded thefts / robbery and other crimes per 10,000 persons)	no / 10,000 persons
C	Regional Accessibility	28	No of highways and railway lines linking the urban area	
C	Regional Accessibility	29	Highway link capacity: cumulative right of ways or the no of lanes of all highway links to the urban area.	(Peak hour traffic volumes)
C	Regional Accessibility	30	Railway line capacity: no of chartered Up and Down trains in the railway sections linking the urban area	
C	Regional Accessibility	31	Regional bus service:	
C	Regional Accessibility	31.1	Daily regional bus trips to and fro the urban area	
C	Regional Accessibility	31.2	No of major urban centres as destination points of bus service from the urban area	
C	Intra-urban Accessibility	32	Extent of road network: Total road area as percentage of total land area of urban area in sq km / Ha	sq. km / Ha
C	Intra-urban Accessibility	33	Surface road length in km in the urban area:	
C	Intra-urban Accessibility	33.1	Per sq km / Ha of urban land area	sq. km / Ha
C	Intra-urban Accessibility	33.2	Per 1000 urban population	
C	Intra-urban Accessibility	34	Planned road capacity in terms of cumulative R.O.W. in meters/No. of lanes in urban roads of different hierarchies, viz.	(Peak hour traffic volumes)
C	Intra-urban Accessibility	34.1	Arterial Roads	(Peak hour traffic volumes)
C	Intra-urban Accessibility	34.2	Sub-arterial Roads	(Peak hour traffic volumes)

C	Intra-urban Accessibility	34.3	Collector Roads	(Peak hour traffic volumes)
C	Intra-urban Accessibility	34.4	Local Access Roads	(Peak hour traffic volumes)
C	Intra-urban Accessibility	35	Public bus service capacity: Total no of bus routes x frequencies of service	
C	Intra-urban Accessibility	36	MRTS capacity: No of seats / passenger capacity x frequency of service	
C	Intra-urban Accessibility	37	(Stress Indicator) Average peak hour journey speed 11 kmph between city centre and periphery along different directions	(Peak hour traffic volumes along major arteries)
C	Intra-urban Accessibility	37.1	By car	(Peak hour traffic volumes along major arteries)
C	Intra-urban Accessibility	37.2	By bus	(Peak hour traffic volumes along major arteries)
C	Intra-urban Accessibility	38	(Stress Indicator) No of traffic accidents per year	
C	Intra-urban Accessibility	38.1	Per 1000 vehicles	
C	Intra-urban Accessibility	38.2	Per unit road length	
C	Intra-urban Accessibility	39	(Stress Indicator) Vehicle density: No of registered vehicles per unit road area (sq. km)/road lengths (km)	
C	Communication Facility	40	Density of communication services: No of urban population served per unit of	
C	Communication Facility	40.1	Post and Telegraph office	
C	Communication Facility	40.2	Telephone Line	
D	Water Supply	41	Distance in km of urban area from water source: main water line length from city centre to main pumping station / water works	
D	Water Supply	42	Utilizable water in MCM/Y for the urban area in:	
D	Water Supply	42.1	Rivers / Lakes / Reservoirs	
D	Water Supply	42.2	Ground Water Aquifers	

D	Water Supply	43	Water quality parameters in relation to prescribed norms of designated water use for the urban area in	
D	Water Supply	43.1	Rivers / Lakes / Reservoirs	
D	Water Supply	43.2	Ground Water Aquifers	
D	Water Supply	44	Installed capacity of public water works, including treatment plant capacity (if any), in LPCD	
D	Water Supply	45	Coverage of public water supply network as percentage of:	
D	Water Supply	45.1	Urban Population	
D	Water Supply	45.2	Urban Land Area	
D	Sanitation	46	Percentage of urban population served by sanitary latrines connected to:	
D	Sanitation	46.1	Municipal Sewerage System	
D	Sanitation	46.2	Public Septic Tanks	
D	Sanitation	46.3	Private Septic Tanks	
D	Sanitation		Indicator (5): (Sewage / wastewater treatment plant capacity)	
D	Sanitation		Indicator (7): (Solid waste management capacity)	
D	Energy	47	Installed capacities of power plants in kWh per 1000 urban population supplying electricity to the urban area	
D	Energy	48	Power supply as percentage of peak hour requirement or demand in MU	
D	Energy		Indicator (19): Percentage of housing units/population with electricity)	
D	Non-Conventional Energy Development	49	Installed capacity of non-conventional energy sources in urban area in	
D	Non-Conventional Energy Development	49.1	Biogas plants in BTU/kWh per 1000 persons	kWh / 1,000 persons
D	Non-Conventional Energy Development	49.2	Solar Panels in m^2 per 10,000 persons	m^2 / 10,000 persons
E	Manpower Resource	50	Labour Force: Total and as percentage of urban population for	
E	Manpower Resource	50.1	Male	%
E	Manpower Resource	50.2	Female	%
E	Manpower Resource	51	Participation rate: Workers population ratio (%):	%

E	Manpower Resource	51.1	Main workers	%
E	Manpower Resource	51.2	Marginal workers	%
E	Manpower Resource	52	Adult literacy rate: adult literates as a percentage of population for:	%
E	Manpower Resource	52.1	Male	%
E	Manpower Resource	52.2	Female	%
E	Economic Base	53	Annual value added per capita urban population in industrial economy for:	
E	Economic Base	53.1	Large and medium sector units	
E	Economic Base	53.2	Small scale industries units	
E	Economic Base	53.3	Unorganised sector units	
E	Economic Base	53.4	Commercial establishments	
E	Economic Base	54	Ratio of employed (in Different Urban Sectors) and Total Urban Population	
E	Local Institutional Resource	55	Annual revenue income of local bodies per capita urban population	
E	Local Institutional Resource	56	Annual expenditure, excluding debt service and salary expenditure of local bodies per capita urban population	
E	Local Institutional Resource	57	No of employees in local bodies per 1000 urban population	
E	Local Institutional Resource	58	Political and legal autonomy of urban local bodies under state legislation for:	
E	Local Institutional Resource	58.1	Setting revenue rates	
E	Local Institutional Resource	58.2	Development control	

Appendix B: Urban Indicators for Managing Cities - ADB

Theme	Indicator
1. Population	
	1.1 Urbanisation
	1.2 City Population
	1.2.1 Resident population of municipal area
	1.2.2 Population during daytime working hours
	1.2.3 Annual rate of population increase
	1.3 Annual net migration
	1.3.1 Other parts of the city
	1.3.2 Other parts of the country
	1.3.3 International migration
	1.3.4 Total net migration
	1.4 Population net density
	1.5 Age Pyramid
	1.5.1 Persons 0 -14
	1.5.2 Persons 15-59
	1.5.3 Persons over 60
	1.6 Average household size
	1.7 Household formation rate
	1.8 Women-headed households
	1.9 Minority groups
	1.10 Household types
	1.10.1 Single person
	1.10.2 Adults only
	1.10.3 Single parent family
	1.10.4 Adults and children
	1.11 Informal Settlements
	1.11.1 Population
	1.11.2 Households
	1.11.3 Land occupied
2. Equity	
	2.1 Income distribution
	2.1.1 Q5 Top 20%
	2.1.2 Q4 Next 20%
	2.1.3 Q3 Middle 20%
	2.1.4 Q2 Next bottom 20%
	2.1.5 Q1 Bottom 20%
	2.2 Households below poverty line
	2.3 Women-headed households in poverty
	2.4 Child-labour
	2.5 Informal employment
	2.6 Unemployment
	2.7 Expenditure on poverty reduction
3. Health and Education	
	3.1 Persons per hospital bed
	3.2 Child mortality
	3.3 Life expectancy at birth
	3.4 Infectious diseases mortality
	3.5 Family planning
	3.6 Adult literacy rate

	3.7 School enrolment rates 3.7.1 Primary schools 3.7.2 Secondary schools 3.8 Tertiary graduates 3.9 Median years of education (years) 3.10 School children per classroom 3.10.1 Primary 3.10.2 Secondary
4. Urban Productivity	4.1 City product per capita 4.2 Employment by industry 4.2.1 Secondary and infrastructure (ISIC 3, 4, 5, 7) 4.2.2 Consumer services (ISIC 6, 7, part of 9) 4.2.3 Product services (ISIC 8) 4.2.4 Social services (ISIC 9) 4.2.5 Others (ISIC 1, 2, 9) 4.3 Household expenditure 4.3.1 Food 4.3.2 Shelter 4.3.3 Travel 4.3.4 Others 4.4 Investment by sector 4.4.1 Physical infrastructure 4.4.2 Housing 4.4.3 Services 4.4.4 Others 4.5 Touris m 4.5.1 Persons 4.5.2 Expenditure 4.6 Major products 4.7 Cost of stay 4.8 Corporate headquarters
5. New Technology	5.1 R & D expenditure 5.2 Telephone traffic 5.2.1 Local 5.2.2 International 5.2.3 Mobile or cell phone 5.3 Internet hosts per 1000 population
6. Urban Land	6.1 Urban Land 6.1.1 Residential 6.1.2 Business 6.1.3 Services 6.1.4 Transport 6.1.5 Mixed use 6.1.6 Others 6.1.7 Total area 6.2 Land developer multiplier 6.3 Developer contributions 6.4 Median time for planning permission 6.5 Vacant land with planning permission 6.6 Public open space

- 6.7 Vacant government land
    - 6.7.1 Amount of land owned by government, parastatals or enterprises
    - 6.7.2 Proportion of this land which is vacant
- 6.8 Prime commercial land price
- 6.9 Prime rental and occupancy costs
    - 6.9.1 Prime rental per month
    - 6.9.2 Operating costs per month
    - 6.9.3 Statutory charges per month
- 6.10 Expenditure on development

7. Housing

- 7.1 Dwelling type
    - 7.1.1 Houses (single family)
    - 7.1.2 Medium density
    - 7.1.3 Apartments
    - 7.1.4 Temporary dwellings
    - 7.1.5 Other (institutions, hostels, etc.)
- 7.2 Tenure type
    - 7.2.1 Owned or purchased
    - 7.2.2 Private rental
    - 7.2.3 Social housing
    - 7.2.4 Subtenant
    - 7.2.5 Rent free
    - 7.2.6 Squatter - no rent
    - 7.2.7 Squatter - paying rent
    - 7.2.8 Others
- 7.3 House price to income ratio
- 7.4 House rent to income ratio
- 7.5 Floor area per person
- 7.6 Housing in compliance
- 7.7 Mortgage to credit ratio
- 7.8 Houses with mortgages
- 7.9 Mortgage loans for women
- 7.10 Housing production
    - 7.10.1 On new (vacant) land
    - 7.10.2 Conversions or infill from other uses
- 7.11 Squatter resettlement or normalisation
- 7.12 Net housing outlays by government (per person)
- 7.13 Homeless people

8. Municipal Services

- 8.1 Water
    - 8.1.1 Household connections
    - 8.1.2 Investment per capita
    - 8.1.3 Operations and maintenance expenditures
    - 8.1.4 Cost recovery
    - 8.1.5 Output per staff: Water supplied per employee
    - 8.1.6 List of providers
    - 8.1.7 Nonrevenue water
        - a. Percentage unaccounted for water
        - b. Interruptions of water service
    - 8.1.8 Consumption of water per capita
    - 8.1.9 Median price of water, scarce season
- 8.2 Electricity
    - 8.2.1 Household connections

8.2.2 Investment per capita
8.2.3 Operations and maintenance expenditures
8.2.4 Cost recovery
8.2.5 Output per staff: Megawatt hours of electricity supplied per employee
8.2.6 List of providers
8.2.7 Nonrevenue electricity
a. Line loss for electricity
b. Interruptions in power supply

8.3 Sewerage/wastewater
8.3.1 Household connections
8.3.2 Investment per capita
8.3.3 Operations and maintenance expenditures
8.3.4 Cost recovery
8.3.5 Output per staff: Wastewater discharged or treated per employee
8.3.6 List of providers

8.4 Telephone
8.4.1 Household connections
8.4.2 Investment per capita
8.4.3 Operations and maintenance expenditures
8.4.4 Cost recovery
8.4.5 Output per staff: Thousands of calls per employee
8.4.6 List of providers

8.5 Solid waste collection
8.5.1 Households with regular service
8.5.2 Investment per capita
8.5.3 Operations and maintenance expenditures
8.5.4 Cost recovery
8.5.5 Output per staff: Collected per employee
8.5.6 List of providers

9. Urban Environment

9.1 Solid waste generated
9.2 Household sewage disposal
9.2.1 Sewerage pipe
9.2.2 Septic tank (treated)
9.2.3 Underground pit (untreated)
9.2.4 Underground communal
9.2.5 Pan collection
9.2.6 Open ground trench
9.2.7 Others
9.3 Wastewater treated
9.4 Percent BOD removed from wastewater
9.5 Air pollution concentrations
9.5.1 SO x
9.5.2 NO x
9.5.3 CO
9.5.4 O3
9.5.5 Suspended particulates
9.5.6 Lead
9.6 Energy usage per person
9.7 Noise complaints
9.8 Disasters in last ten years
9.9 Methods of solid waste disposal

	9.9.1	Percent disposed to sanitary landfill
	9.9.2	Percent incinerated (formally)
	9.9.3	Percent dumped or buried in the open
	9.9.4	Recycled
	9.9.5	Others
10. Urban Transport		
10.1	Mode of travel	
	10.1.1	Private automobile
	10.1.2	Train, tram, or light rail
	10.1.3	Bus or mini bus
	10.1.4	Motorcycle (2-or-3 wheel motorised vehicle)
	10.1.5	Bicycle, including pedicab (pedal-powered-vehicle)
	10.1.6	Walking
	10.1.7	Others
10.2	Median travel time	
10.3	Expenditure on road infrastructure	
10.4	Road congestion	
10.5	Automobile ownership	
10.6	Cost recovery from fares	
10.7	Port/air activity	
	10.7.1	Commercial ships leaving port (freight and passenger)
	10.7.2	Commercial flights leaving per month
10.8	Goods carried	
	10.8.1	Road
	10.8.2	Rail
	10.8.3	Air
	10.8.4	Sea
10.9	Transport Services	
	10.9.1	Transport-related deaths
	10.9.2	Pedestrian deaths
11. Cultural		
11.1	Attendance at public events	
11.2	Attendance at galleries and museums	
11.3	Participation in sports	
12. Local Government Finance		
12.1	Sources of revenue	
	12.1.1	Taxes
	12.1.2	User charges
	12.1.3	Other own source income
	12.1.4	Transfers
	12.1.5	Loans
	12.1.6	Other income
12.2	Capital and recurrent expenditure per person	
	12.2.1	Capital expenditure
	12.2.2	Recurrent expenditure
12.3	Collection efficiency, property taxes	
	12.3.1	Percent of liabilities actually collected
	12.3.2	Costs of collecting property tax as percentage of receipts passing to the local government
12.4	Debt service charge	
12.5	Employees	
12.6	Wages in budget	

12.7	Contracted recurrent expenditure ratio
12.8	Business permits
12.9	Enterprise revenues
12.10	Computerisation of functions
	12.10.1 Land registration
	12.10.2 Rates collection
	12.10.3 Salaries
	12.10.4 General finances
	12.10.5 Business permits
13. Urban Governance	
13.1	Functions of local government
	13.1.1 Water
	13.1.2 Sewerage
	13.1.3 Refuse collection
	13.1.4 Electricity
	13.1.5 Telephone
	13.1.6 Public or mass transport
	13.1.7 Emergency (fire ambulance)
	13.1.8 Road maintenance
	13.1.9 Education
	13.1.10 Health care
	13.1.11 Public housing
	13.1.12 Recreation/sports facilities
	13.1.13 Police
	13.1.14 Drainage / flood control
	13.1.15 Livelihood assistance
	13.1.16 Others
13.2	Delivery of annual plan
13.3	Voter participation rates, by sex
	13.3.1 Proportion of adult males
	13.3.2 Proportion of adult females
13.4	Independence from higher government
	13.4.1 Closing down the council or removing the councillors from office
	13.4.2 Setting local taxes levies
	13.4.3 Setting user charges for services
	13.4.4 Borrowing funds
	13.4.5 Choosing contractors for projects
13.5	Elected and nominated councillors
	13.5.1 Female
	13.5.2 Male
13.6	Representation of minorities
13.7	Planning applications refused
13.8	Business satisfaction
13.9	Consumer satisfaction
13.10	Perception as place to live
13.11	Reported crimes
	13.11.1 Murders
	13.11.2 Drug-related crimes
	13.11.3 Thefts
13.12	Access to information
	13.12.1 Annual report / budget
	13.12.2 City strategy / vision
	13.12.3 Economic strategy

	13.12.4	Social strategy
13.13	Contact with public	
	13.13.1	Annual number of public local government meetings
	13.13.2	Breakdown of meetings held by mayor or CEO with business, public, officials, average week
	a.	public
	b.	business
	c.	officials and councillors
	d.	others
13.14	Decentralised district units	
	13.14.1	Number of local government units within the metropolis area
	13.14.2	Number of decentralised units in the local government

Appendix C: Questionnaire for the Sprawl Quest

¸ÁªÉð ¥Àæ±ÁßªÀ½ : SPRAWL QUEST		¥Àæ±ÁßªÀ½: QUESTIONNAIRE
¸ÁåA¥À¯ï ¸ÀASÉå : SAMPLE No:		
¸ÀAzÀ±ÀðPÀ¤AzÀ ªÀiÁ»w ¥ÀqÉzÀªÀgÀ °É¸ÀgÀÄ: Name of respondent:		
«¼Á¸À: Address:		
zÀÆgÀªÁt ¸ÀASÉå: Phone Number:	¸ÀAzÀ±ÀðPÀzÀ ¢£ÁAPÀ: Date of interview:	
DgÀA¨sÀzÀ ¸ÀªÀÄAiÀÄ: Interview start time:	ªÀÄÄPÁÛAiÀÄ ¸ÀªÀÄAiÀÄ: Interview end time:	¸ÀAzÀ±ÀðPÀzÀ MlÄÖ CªÀ¢: Interview duration (In minutes):
UÀAqÀÄ: MALE ……………………………………………………..1	°ÉtÄÚ: FEMALE ……………………………………………………..2	

CLUSTER NAME	CLUSTER NO (Circle below)	(TO BE ENTERED IN FIELD)	
		WARD NAME	WARD NO
¨ÉAUÀ¼ÀÆgÀÄ ¥ÀÇªÀð Bangalore East	1		
¨ÉAUÀ¼ÀÆgÀÄ zÀQët Bangalore South	2		
¨ÉAUÀ¼ÀÆgÀÄ ¥À²ÑªÀÄ Bangalore West	3		
gÁdgÁeÉÃ±Àé j ªÀ®AiÀÄ Raja Rajeshwari Zone	4		
zÁ¸ÀgÀºÀ½î ªÀ®AiÀÄ Dasarahalli Zone	5		
¨ÉÆªÀÄä£ÀºÀ½î ªÀ®AiÀÄ Bommanahalli Zone	6		
ªÀÄºÁzÉÃªÀ¥ÀÄgÀ ªÀ®AiÀÄ Mahadevapura Zone	7		
¨Áål gÁAiÀÄ£À¥ÀÄgÀ ªÀ®AiÀÄ Byatarayanapura Zone	8		

ªÀÄ£ÉAiÀÄ°ègÀªÀ 18 ವರ್ಷ ವಯಸ್ಸು zÁnzÀªÀjAzÀ GvÀÛgÀ ¥ÀqÉAiÀÄ¨ÉÃPÀÄ

£ÀªÀÄ¸ÁìgÀ, £Á£ÀÄ ------------ ¨ÉAUÀ¼ÀÆj£À ¨ÁgÀwÃAiÀÄ «eÁÕ£À ¸ÀA¸ÉÜ¬ÄAzÀ §A¢zÉÝÃ£É. £ÁªÀÅ ¸ÀzÀåPÉÌ ¨ÉAUÀ¼ÀÆgÀÄ £ÀUÀgÀzÀ ¨É¼ÀªÀtÂUÉ ªÀÄvÀÄÛ §zÀ¯ÁªÀuÉAiÀÄ, CAzÀgÉ, d£À fÃªÀ£À, ¸ÁjUÉ, EvÀgÉ CA±ÀUÀ¼À §UÉÎ C¨sÁå¸À ªÀiÁqÀÄwÛzÉÝÃªÉ. DzÀÝjAzÀ zÀAiÀÄªÀiÁr vÁªÀÅUÀ¼ÀÄ £ÀªÀÄUÉ vÀªÀÄä CªÀÄÆ®åªÁzÀ ¸ÀªÀÄAiÀÄªÀ£ÀÄß PÉÆlÄÖ ¸ÀºÀPÀj¸À¨ÉÃPÀÄ. ªÀAzÀ£ÉUÀ¼ÀÄ.

SPEAK TO AN ADULT PERSON IN THE HOUSEHOLD

Good Day Sir / Madam! I am ___________ from Indian Institute of Science, Bangalore. We are currently doing a study on Bangalore city. We are trying to understand the processes, causes and consequences of the growth, Bangalore is experiencing. Hence, we would greatly appreciate it if you could spare a few minutes to answer a few questions. Thank you!

Miscellaneous Notes / Observations:

«¨sÁUÀ-1 SECTION 1 – SCREENING

A1. PÀ¼ÉzÀ DgÀÄ wAUÀ¼ÀÄUÀ¼À°è AiÀiÁgÁzÀgÀÆ EzÉÃ jÃwAiÀÄ°è ¤ªÀÄä£ÀÄß ¸ÀAzÀ²ð¹zÁÝgÉÃ?

Have you or anybody in your household been interviewed for a survey like this in the last 6 months?

°ËzÀÄ :……………….1	**TERMINATE**	E®è:...................................... 2	**CONTINUE**

A2. **¤ªÀÄä ªÀÄ£ÉAiÀÄ°è 18 ವರ್ಷದಿಂದ 55 ವರ್ಷದ ವಯಸ್ಸಿನವರೆಗೆ ಎಷ್ಟು ಸದಸ್ಯರಿದ್ದಾರೆ? (ಗಂಡು ಮತ್ತು ಹೆಣ್ಣು ಎಲ್ಲರೂ ಸೇರಿ)**

Can you tell me how many members are there in the household, in the age group of 18-55 years? Please include all men and women in the age group 18-55 years who currently reside in this household?

____

A3. PÀÄ I ÄA§zÀ J¯Áè ¸ÀzÀ¸ÀågÀ ºÉ¸ÀgÀÄUÀ¼ÀÄ£ÀÄß ªÀAiÀÄ¹ì£À PÀæªÀÄzÀ°è §gÉ¬Äj

Could you please tell me the names of members of your family who are aged between ***18 to 55 years***? I would like to know their ages and gender also. (**INV: WRITE DOWN ALL THE NAMES, AGE IN THE GRID BELOW CODE THE GENDER**)
Let us start from the youngest person who is above 18 years. **RECORD IN ASCENDING ORDER**

GRID FOR RECORDING THE RESPONDENT SELECTED FOR THE INTERVIEW				
Number	Name of HH member (18 to 55 years) **Record from youngest to oldest always**	Age	Gender	SELECTED RESPONDENT
1			M F	1
2			M F	2
3			M F	3
4			M F	4
5			M F	5
6			M F	6
7			M F	7
8			M F	8

«¨ÁUÀ 2 - ªÉêªÁ»PÀ CA±ÀUÀ¼ÀÄ, ªÀÄÆ®ªÁ¸À, ºÁUÀÆ ªÀÄ£É ¸ÀA§A¢ «ZÁgÀUÀ¼ÀÄ SECTION B - MARITAL STATUS, NATIVITY & HOUSING

B1.. ¤ÃªÀÅ «ªÁ»vÀgÉÃ?

Can you please look at this card **(SHOW CARD B1)** tell me your marital status? **(ONLY SINGLE CODE POSSIBLE)**

B1.	
«ªÁ»vÀgÀÄ - Married	1
C«ªÁ»vÀgÀÄ - Unmarried	2
EvÀgÉ(«zsÀªÉ/«ZÉÒÃ¢vÀgÀÄ) - Others (widowed / divorced)	3

B2. ¤ÃªÀÅ ªÀÄÆ® ¨ÉAUÀ¼ÀÆj£ÀªÀgÉÃ? d£À¸À¼ÀÄ ¨ÉAUÀ¼ÀÆgÀÄ CxÀªÁ ¨ÉAUÀ¼ÀÆjUÉ ªÀ®¸É §AzÀªÀgÉÃ? ºËzÀÄ / E®è

Can you tell me whether you are a native of Bangalore, i.e. born and brought up in Bangalore? **YES / NO**

B2a. E®è¢zÀÝgÉ ¤ªÀÄä ¸ÀÜAvÀ ¸ÀÜ¼À AiÀiÁªÀÅzÀÄ?

IF NO: Can you tell me which your native place is?

B2b. ಇಲ್ಲದಿದ್ದಲ್ಲಿ ಎಷ್ಟು ಕಾಲದಿಂದ ಬೆಂಗಳೂರಿನಲ್ಲಿ ವಾಸಿಸುತ್ತಿದೀರಿ?

IF NO: Can you also tell me how long you have been staying in Bangalore?

ºËzÀÄ/ YES ... 1	E®è/ NO ... 2
¸ÀéAvÀ ¸ÀܼÀ/ NATIVE PLACE	
ಎಷ್ಟು ಕಾಲದಿಂದ ಬೆಂಗಳೂರಿನಲ್ಲಿ ವಾಸಿಸುತ್ತಿದೀರಿ?/ HOW LONG IN BANGALORE	______ ವರ್ಷಗಳು/ YRS

B2c. E®è¢zÀÝgÉ ¨ÉAUÀ¼ÀÆjUÉ ¤ÃªÀÅ ªÀ®¸É §gÀ®Ä ¥ÀæªÀÄÄR PÁgÀt ªÉÃ£ÀÄ?

IF NO: Can you also tell me **(SHOW CARD B2c)**, what is the primary reason for migrating to Bangalore?

©2¹. 2	
Work/Employment	1
Education	2
Marriage	3
Business	4
Moved with household	5
Moved after birth	6
Others	7

B3. ªÀÄ£ÉAiÀÄ ªÀÄÁzÀj.

Select the type of house? **(ONLY SINGLE CODE POSSIBLE)**

B3
Hut/mud walled 1
Brick walled & asbestos sheet 2
Brick walled & RCC roof..3

B4. F ªÀÄ£ÉAiÀÄÄ ¨ÁrUÉAiÀÄzÉÃ, ¸ÀéAvÀzÉÃ, ¨ÉÆÃUÀåzÉÃ, PÁé l ð¸ïð CxÀªÁ EvÀgÉ, **(ONLY SINGLE CODE POSSIBLE)**

Can you please look at this card **(SHOW CARD B4)** tell me on ownership of house? **(ONLY SINGLE CODE POSSIBLE)**

B4
Owned 1
Rented 2
Leased 3
Quarters……………………………………………………4

B5. F ¥ÀlzÉÃ±ÀzÀ°è ¤ÃªÀÄ ªÁ¸ÀªÁVgÀ®Ä / ºÉÆA¢PÉÆ¼Àî®Ä F PÉ¼ÀV£À AiÀÁªÀ PÁgÀ tUÀ½UÉ ¥ÁæªÀÄÄRåvÉ ¤ÃqÀÄwÛÃj?.

Can you please look at this card **(SHOW CARD B5)** and tell me what would be your criteria for choosing any location for residing?

B5	**CRITERIA**	**RANKING**
A	Access to Services	
B	Access to Education	
C	Access to Work place	
D	Land prices / Rent value	
E	Proximity to City / Main roads	
F	Others	

EvÀgÉ, If others

______________________________ (RECORD VERBATIM)

B6. ¤ªÀÄä ªÁ¸À¸ÀÜ¼ÀzÀ ¥Àj¸ÀgÀzÀ°è F PÉ¼ÀPÀAqÀ ¸Ë®¨sÀåªÀÄÄ ¨É¼ÀªÀ tUÉAiÀÄ CA±ÀUÀ¼ÀÄ EªÉAiÉÃ?

Can you please look at this card **(SHOW CARD B6)** and tell me whether there is any factor that is attracting growth / housing demand in the neighborhood?

B6	**Factor**	**RANKING**
A	Proximity to Services	
B	Proximity to Education (Schools, colleges, etc.)	
C	Proximity to Work place	
D	Land prices / Rent value	
E	Proximity to City / Main roads	
F	Proximity to Industrial Estate	
G	Proximity to Commercial centers	
H	Proximity to Entertainment centers	
I	Others	

EvÀgÉ, If others

______________________________ (RECORD VERBATIM)

«¨ÁUÀ-3-±ÀQÛ ¸ÀA¥À£ÀÆä®UÀ¼ÀÄ SECTION 3 – ENERGY

C1. zÀAiÀÄ«lÄÖ ¤ÃªÀÄ F PÉ¼ÀPÀAqÀ ±ÀQÛ ¸ÀA¥À£ÀÆä®UÀ¼À£ÀÄß AiÀÄÁªÀ jÃwAiÀÄ §¼ÀPÉUÁV §¼À¸ÀÄwÛÃj? Could you please look at this card **(SHOW CARD C1)** and tell me the type of energy source used and its end use? **(MULTIPLE CODING POSSIBLE)**

C1		END USE				
	SOURCE	Cooking & Water Heating	Cooking only	Water Heating only	Supplementary (Pumping, etc.)	Lighting only
A	Firewood	1	2	3	4	5
B	Charcoal	1	2	3	4	5
C	Kerosene	1	2	3	4	5
D	Electricity	1	2	3	4	5
E	LPG	1	2	3	4	5
F	Biogas	1	2	3	4	5
G	Dung / waste	1	2	3	4	5
H	Solar	1	2	3	4	5
I	Others	1	2	3	4	5

«¨ÁUÀ-4- ¤ÃgÀÄ ªÀÄvÀÄÛ vÁådåUÀ¼À §UÉÎ, SECTION 4 – WATER & WASTE

D1. F PÉ¼ÀPÀAqÀ ¤Ãj£À ªÀÄÆ®UÀ¼À£ÀÄß AiÀÄÁªÀ ¥ÀæªÀÄÁtR §¼ÀPÉUÁV G¥ÀAiÉÆÃV¸ÀÄwÛÃj? Could you please look at this card **(SHOW CARD D1)** and tell me the type of water source used and its end use? **(MULTIPLE CODING POSSIBLE)**

D1		END USE				
	SOURCE	Cooking & Drinking	Bathing & Toilet	Cleaning & Mopping	Gardening	Car / Bike washing
A	BWSSB	1	2	3	4	5
B	Bore-well	1	2	3	4	5
C	Private Water Supply (through Tankers)	1	2	3	4	5
D	Community Water Taps	1	2	3	4	5
E	Rain water Harvesting	1	2	3	4	5
F	Others	1	2	3	4	5

D2. M¼ÀZÀgÀAr ªÀåªÀ¸ÉÜAiÀÄ §UÉÎ w½¹. Could you please tell me how is the sewage disposed **(SHOW CARD E2)**?

D2	Sewage disposal
Sewage pipe	1
Septic tank (treated)	2
Underground pit (untreated)	3
Underground communal	4
Open ground trench	5
Others	6

D3. WÀ£À vÁådåUÀ¼À «¯ÉÃªÁjAiÀÄ ªÀåªÀ¸ÉÜAiÀÄ §UÉÎ w½¹. Could you please tell me how is the solid waste disposed **(SHOW CARD E3)**?

D3	Waste disposal
Door-to-door Collection	1
Community Bins	2
Road side dumping	3
Self (Composting)	4
Others	5

EvÀgÉ, If others ______________________________ (RECORD VERBATIM)

«¨ÁUÀ-5 - MqÁI(ZÀ®£ÉAiÀÄ §UÉÎ) SECTION 5 – MOBILITY

E1. ¥Àæw¤vÀå ¤ÃªÀÅ AiÀiÁªÀ ¥ÀæªÀÄÄR PÁgÀt PÁÌV NqÁqÀÄwÛÃj?

Can you please tell me **(SHOWCARD E 1)**, what is the primary reason for you to commute daily? **(MULTIPLE CODING POSSIBLE)**

E 1	Reason for Commuting	
A	Work	1
B	Education	2
C	Entertainment	3
D	Shopping	4
E	Others________________	5

E2. ¤ªÀÄä ¥Àæw¤vÀåzÀ MqÁIPÁÌV ¤ÃªÀÅ AiÀiÁªÀ jÃwAiÀÄ ªÁºÀ£ÀªÀ£ÀÄß CªÀ®A©¹¢ÝÃj?

Can you please tell me **(SHOWCARD E 2)**, which mode of transport do you use to commute on a daily basis? **(MULTIPLE CODING POSSIBLE)**

E 2	Mode of Transport	
A	Government Bus (BMTC)	1
B	Private Bus	2
C	Auto	3
D	Scooter / Bike	4
E	Car	5
F	Bicycle	6
G	Walk	7
H	Others________________	8

E2a. ¤ÃªÀÅ ¥Àæw¤vÀå NqÁIzÀ°è ºÉÆÃV-ಬರಲು ಎಷ್ಟು ದೂರ ಪ್ರಯಾಣಿಸುತ್ತೀರಿ?

Could you please tell me, on an average, how many kilometers do you travel in a day? ___________km (RECORD VERBATIM)

E2b. ¤ÃªÀÅ ¥Àæw¤vÀå NqÁIzÀ°è ºÉÆÃV-ಬರಲು ಎಷ್ಟು ಸಮಯವಾಗುತ್ತದೆ?

Could you please tell me, on an average, how much time do you travel in a day? ___________hrs (RECORD VERBATIM)

E7. ¤ªÀÄä ¥Àಪ್ರದೇಶದಲ್ಲಿ ಈ ಕೆಳಕಂಡ ಆರೋಗ್ಯಕ್ಕೆ ಸಂಬಂಧಿಸಿದ ಕೇಂದ್ರಗಳು ನಿಮ್ಮ ಮನೆಯಿಂದ ಎಷ್ಟು ದೂರದಲ್ಲಿವೆ? **(MULTIPLE CODING POSSIBLE)**

Could you please look at this card **(SHOW CARD E7)** and tell me which of these healthcare services is accessible? Kindly give Distance in km to the attribute. **(MULTIPLE CODING POSSIBLE)**

E7	DISTANCE	< 500 m	500 m to 1 km	1 km to 2 km	2 km to 5 km	> 5 km
A	Primary health care centers	1	2	3	4	5
B	Government hospitals	1	2	3	4	5
C	Local clinics / small nursing homes	1	2	3	4	5
D	Private hospitals	1	2	3	4	5
E	Specialty hospitals	1	2	3	4	5
F	Maternity homes	1	2	3	4	5

E8. ನಿಮ್ಮ ಕುಟುಂಬದ ಈ ಕೆಳಕಂಡ ಅಗತ್ಯಗಳಿಗೆ ನಿಮ್ಮ ಮನೆಯಿಂದ ಎಷ್ಟು ದೂರವಾಗುತ್ತದೆ?

Could you please look at this card and tell me **(SHOWCARD E 8)**, what is the average distance you may have to travel in accessing these basic amenities to household? Kindly give Distance in km to the attribute.

E 8	**BASIC AMENITIES TO HOUSEHOLD**					
	Distance in km	< 500 m	500 m to 1 km	1 km to 2 km	2 km to 5 km	> 5 km
A	Cooking gas / LPG	1	2	3	4	5
B	Kerosene	1	2	3	4	5
C	Fuel wood	1	2	3	4	5
D	Grocery (I mean Rice, Sugar, Oil, etc)	1	2	3	4	5
E	Vegetables	1	2	3	4	5
F	Milk	1	2	3	4	5

E 9. F PÉ¼ÀPÀAqÀ ¸Ë®¨ÀåUÀ¼À C®¨ÀåvÉAiÉÄÃ£ÁzÀgÀÆ ¸ÀA¨À«¹zÀ°è ¤ÃªÀÄ zÀÆgÀÄ ¸À°è¸À®Ä EgÀÄªÀ ¸ÉÃªÁ PÉÃAzÀæUÀ¼ÀÄ ¤ªÀÄä ªÉÄ£É¬ÄAzÀ ಎಷ್ಟು ದೂರದಲ್ಲಿವೆ? Could you please look at this card and tell me **(SHOWCARD E 9),** what is the average distance you may have to travel in accessing (or complaining about) these basic services / infrastructure to household? Kindly give Distance in km to the attribute.

E 9	**BASIC SERVICES / INFRASTRUCTURE TO HOUSEHOLD**					
	Distance in km	< 500 m	500 m to 1 km	1 km to 2 km	2 km to 5 km	> 5 km
A	Water Supply Source and Sanitation (Waste water)	1	2	3	4	5
B	Electricity	1	2	3	4	5
C	Cooking gas / LPG	1	2	3	4	5
D	Road works	1	2	3	4	5
E	Street Lighting	1	2	3	4	5
F	Communication (Telephone)	1	2	3	4	5
G	Park or other Open Space	1	2	3	4	5

zÀ£ÀåªÁzÀUÀ¼ÉÆA¢UÉ ¸ÀAzÀ±Àð£ÀªÀ£ÀÄß ªÀÄÄV¸ÀÄªÀÅzÀÄ

THANK AND CLOSE THE INTERVIEW

Appendix D: Source Code of the SPSS Model: BangaloreSim Version 17-d

```
breed [ industry ]
breed [ growth-pole ]

industry-own [ ind-x ind-y industry-type]
growth-pole-own [ gp-x gp-y ]

globals [
  time ;; how many clock ticks have passed in the model
  builtup vegetation water openland excluded unknown carrying-capacity
  avg-state total i econ-output new-growth-rate temp econ-activity
  popAden popBden pdf effect-of-density
  hden lden mden pcbuilt built-demand
  mouse-clicked       ;; keeps track of click-and-hold
  mouse-double-click  ;; set to true if two mouse clicks are registerd in a quarter second
  ]

patches-own [
  elevation cdp landuse landuse2006 transport road rail builtden patchiness
  change constraint ;; to capture the constraints of water and vegetation
  dist-weight road-weight s-index w1 w2 w3 w4 gp-index lu-weight orr gp-ind gp-type gp-index?
]

to setup
  ca
  output-show "Setting Initial Variables"
  set excluded 0 set builtup 0 set vegetation 0
  set water 0 set openland 0 set unknown 0
  set total 0 set i 0 set time 2000  set effect-of-density 1
  output-show "Reading Elevation Data..."
  ;; import-elevation
     file-open "elev_blore_lowres.txt"
     let patch-elevations file-read
     file-close
  output-show "Read Elevation Data"
  output-show "Reading CDP..."
  import-pcolors "cdp-lowres.jpg"
    ask patches [ set cdp pcolor ]
  output-show "Reading Landuse Data..."
  ;;import-landuse
    file-open "lu2000-lowres.txt"
    let patch-landuses file-read
    file-close
    file-open "lu2006-lowres.txt"
    let patch-landuse2006s file-read
    file-close
  output-show "Read Landuse Data"
  ;;import-transport
    file-open "transport.txt"
    let patch-trans file-read
    file-close
  ;; transfer the date from the file into the sorted patches
     ( foreach sort patches patch-elevations
       [ set elevation-of ?1 ?2 ] )
    ( foreach sort patches patch-landuses
      [ set landuse-of ?1 ?2 ] )
    ( foreach sort patches patch-landuse2006s
      [ set landuse2006-of ?1 ?2 ] )
    ( foreach sort patches patch-trans
      [ set transport-of ?1 ?2 ] )
  output-show "Initialising...."
  initialise
```

```
  output-show "Set Up Complete"
end

to initialise
  update
  set total builtup + water + vegetation + openland
  set available-land openland + vegetation ; This is where suitability can be brought in!
  ask patches [ set change (landuse2006 - landuse) ]
  output-show "Refreshing View..."
  refresh-view
  output-show "Setting up SD Model..."
  system-dynamics-setup
  output-show "Computing Metrics..."
  compute-metrics
  output-show "Computing Stats..."
  compute-stats
  output-show "Setting up Plots..."
  do-plots
end

to update
  ask patches with [ transport > 1 and transport < 3 ]
    [ set orr 1 ]
  ask patches with [ transport >= 15 and transport <= 21 ]
     [ set rail 1 ]
  ask patches with [ transport > 1 and rail != 1 ]
     [ set road 1 ]
  ask patches with [ road = 1 and orr != 1 ] [ set landuse 4 ]
  set water count patches with [ landuse = 3 ]
  set vegetation count patches with [ landuse = 2 ]
  set openland count patches with [ landuse = 1 ]
  set builtup count patches with [ landuse = 4]

end

to refresh-view
  if View? = "Built-up" [ view-built-up ]
  if View? = "Landuse-2000" [ view-landuse ]
  if View? = "Landuse-2006" [ view-landuse-2006 ]
  if View? = "Elevation" [ view-elevation ]
  if View? = "Trasnport" [ view-trans ]
  if View? = "Roads" [ view-roads ]
  if View? = "Railways" [ view-rail ]
  if View? = "Water Bodies" [ view-waterbodies ]
  if View? = "Open Land" [ view-openland ]
  if View? = "Vegetation" [ view-vegetation ]
  if View? = "Built-up Density" [ view-built-den ]
  if View? = "Patchiness" [ view-patchiness ]
  if View? = "Suitability" [ view-suitabilty ]
  if View? = "CDP" [ view-cdp ]
  display
end

to view-cdp
  ask patches [ set pcolor cdp ]
end

to view-trans
  view-roads
  view-rail
end

to view-elevation
  ask patches with [ elevation >= 872 ]
    [ set pcolor scale-color brown elevation 500 1100 ]
  ask patches with [ elevation < 872 ]
    [ set pcolor scale-color brown elevation 500 1100 ] ; 788 956
```

```
end

to view-landuse
  ask patches with [ landuse = 4 ] [ set pcolor red ]     ;;Built-up = 4
  ask patches with [ landuse = 1 ] [ set pcolor yellow ]  ;;Open Land and Barren Land = 1
  ask patches with [ landuse = 3 ] [ set pcolor blue ]    ;;Waterbodies = 3
  ask patches with [ landuse = 2 ] [ set pcolor green ]   ;;Vegetation and Agriculture = 2
end

to view-landuse-2006
  ask patches with [ landuse2006 = 4 ] [ set pcolor red ]     ;;Built-up = 4
  ask patches with [ landuse2006 = 1 ] [ set pcolor yellow ]  ;;Open Land and Barren Land = 1
  ask patches with [ landuse2006 = 3 ] [ set pcolor blue ]    ;;Waterbodies = 3
  ask patches with [ landuse2006 = 2 ] [ set pcolor green ]   ;;Vegetation and Agriculture = 2
end

to view-suitabilty
  ask patches with [ s-index > 0 ] [ set pcolor scale-color white s-index 0 10 ]
end

to view-built-up
  ask patches with [ landuse = 4 ]
    [ set pcolor red ]
  ask patches with [ landuse = 1 ]
    [ set pcolor black ]
  ask patches with [ landuse = 3 ]
    [ set pcolor black ]
  ask patches with [ landuse = 2 ]
    [ set pcolor black ]
end

to view-openland
  ask patches with [ landuse = 4 ]
    [ set pcolor black ]
  ask patches with [ landuse = 1 ]
    [ set pcolor yellow ]
  ask patches with [ landuse = 3 ]
    [ set pcolor black ]
  ask patches with [ landuse = 2 ]
    [ set pcolor black ]
end

to view-vegetation
  ask patches with [ landuse = 4 ]
    [ set pcolor black ]
  ask patches with [ landuse = 1 ]
    [ set pcolor black ]
  ask patches with [ landuse = 3 ]
    [ set pcolor black ]
  ask patches with [ landuse = 2 ]
    [ set pcolor green ]
end

to view-waterbodies
  ask patches with [ landuse = 4 ]
    [ set pcolor black ]
  ask patches with [ landuse = 1 ]
    [ set pcolor black ]
  ask patches with [ landuse = 3 ]
    [ set pcolor blue ]
  ask patches with [ landuse = 2 ]
    [ set pcolor black ]
end

to view-roads
  ask patches with [ transport > 1 and rail != 1 ] [set pcolor brown ]
end
```

```
to view-rail
  ask patches with [ rail = 1 ] [set pcolor brown + 2 ]
end

to view-orr
  ask patches with [ orr = 1 ] [ set pcolor red - 2 ]
end

to view-change
  ask patches with [ change > 0 ] [ set pcolor scale-color red change 1 10 ]
  ask patches with [ change < 0 ] [ set pcolor scale-color blue change 1 10 ]
  ask patches with [ change = 0 ] [ set pcolor green ]
end

;;;Simulation Procedures;;;

to go
  no-display
  if not any? patches with [landuse < 4] [ stop ]
  set time (time + 1)
  set i (i + 1)
  if time > set-simulation-end-time
    [ stop ]

 ;; ask patches [ create-growth-poles ]

  system-dynamics-go
  compute-demand
  output-show "Built-up Demand Computed"
  output-show "Computing Suitability..."
  ask patches [ site-suitability ]
  output-show "Changing Landuse..."
  ask n-of built-demand patches with-max [ s-index ]
    [ change-landuse ]
  calculate
  display
end

to create-growth-poles
  let GP-Whitefield-x 133 let GP-Whitefield-y 17
  let GP-Peenya-x -85 let GP-Peenya-y 55
  let GP-ElectronicCity-x 78 let GP-ElectronicCity-y -148
end

to calculate
  output-show "Computing Metrics..."
  compute-metrics
  output-show "Computing Stats..."
  compute-stats
  output-show "Refreshing View..."
  refresh-view
  output-show "Updating..."
  update
  output-show "Plotting..."
  do-plots
end

to compute-demand
  set built-demand lu-change + builtup
end

to change-landuse
  output-show "Adding Builtup to patches based on highest suitability..."
  let priority-list sort-by [s-index-of ?1 > s-index-of ?2] patches ; (self of patches)
  while [ builtup <= built-up ] [
    let p first priority-list
```

```
    ask p [
      output-show builtup
      output-show s-index
      set builtup builtup + 1
      add-builtup ]
    set priority-list but-first priority-list
    ]
  output-show builtup output-show built-up
end

to site-suitability
  ifelse (landuse = 4)
    [ let neighbor one-of neighbors
      set lu-weight-of neighbor 30
      set lu-weight 0 ]
    [ ifelse landuse = 1
      [ set lu-weight 20 ]
      [ ifelse landuse = 3
        [ set lu-weight 0 ]
        [ set lu-weight 10 ] ] ]
  if Distance-From-City-Centre?
    [ if (distancexy 0 0) < (set-Distance * 10)
      [ set dist-weight scale-color white (distancexy 0 0) (set-distance * 10) 0 ] ]
  if Distance-From-Roads?
     [ ask neighbors with [ road = 1 and orr != 1 ]
     [ set road-weight 25 ] ]
  if Consider-ORR? and time >= 2006
    [ ask neighbors with [ road = 1 ] [ set road-weight 25 ] ]

  set w1 1 set w2 1 set w3 1 set w4 1 ; To give user the choice for weightages
  set s-index  ( w1 * dist-weight + w2 * road-weight + w3 * lu-weight + w4 * gp-ind ) / ( w1 + w2 + w3 + w4 )
end

to build  ;; patch procedure
  locals [neighbor]
  ifelse landuse = 4 and (count patches with [ landuse = 4 ] <= built-up)
    [  ]
    [ set neighbor one-of neighbors
      set landuse-of neighbor 4
      ifelse landuse = 1 and (count patches with [ landuse = 4 ] <= built-up)
        [ set landuse landuse + 3  ]
        [ ifelse landuse = 2 and not Protect-Greencover? ;;and not any? patches with [landuse = 2]
          [ set landuse landuse - 1 ]
          [ if landuse = 3 and not Protect-Waterbodies? ;;and not any? patches with [landuse = 3]
            [ set landuse landuse - 2 ]
          ]
        ]
     ]
  output-show patches with [ landuse = 1 ]
  output-show "Refresh, Update and Recolor..."
  refresh-view update
  recolor
end

to add-builtup  ;; patch procedure
  locals [neighbor]
  set neighbor one-of neighbors
  set landuse-of neighbor 4
  update
end

;;; Mouse handling

to add-builtup-with-mouse
  if not any? patches with [ landuse < 4 ]
    [ stop ]
  if mouse-down?
```

```
  [ ask patch-at mouse-xcor mouse-ycor
    [ add-builtup ] ]
end

;;; Creating Growth Pole

to create-growth-pole
 if not any? patches with [ landuse > 1 ]
  [ stop ]
 if mouse-down? and create-gp?
 [  ask patch-at mouse-xcor mouse-ycor
    [ set gp-ind gp-weight
      set pcolor yellow
      set gp-index? true
      let col user-one-of "What is the type of Growth Pole?"
       ["MANUFACTURING" "TEXTILE"  "ENGINEERING" "IT/ITES"]
      set gp-type col
      sprout 1
        [ ifelse gp-type = "TEXTILE"
          [ set shape "building institution"  set size 15 set color green + 2 ]
          [ ifelse gp-type = "ENGINEERING"
            [ set shape "factory" set size 15 set color grey ]
            [ ifelse gp-type = "MANUFACTURING"
              [ set shape "bulldozer top" set size 15 set color brown + 2 set heading 0 ]
              [ set shape "computer workstation" set size 15 set color brown]
               ] ] ]
  ask patches in-radius 15
  [ set gp-ind gp-weight / 2 ] ]
  diffuse gp-ind 1 ]


end

to growthpole ;; patch procedure
locals [neighbor]
 ask patches in-radius 10
  [  ;set neighbor one-of neighbors
     ;set landuse-of neighbor 4
     set gp-index 25  ]
end

;;; Compute Spatial Metrics
to compute-metrics
 built-density
 est-patchiness
end

to built-density
 locals [neighbor]
 ask patches [
   set neighbor count neighbors with [ landuse = 4 ]
   set builtden ( neighbor / 9 )
   ]
 ;view-built-den
end

to  view-built-den
 locals [temp1]
 ask patches [
   set temp1 builtden * 100
   set pcolor scale-color red temp1 100 1 ]
end

to est-patchiness
 locals [ temp1 temp2 temp3 temp4 ndc ]
 ask patches with [ landuse = 1 ]
   [ set temp1 count neighbors with [ landuse != 1 ] ]
```

```
  ask patches with [ landuse = 2 ]
    [ set temp1 count neighbors with [ landuse != 2 ] ]
  ask patches with [ landuse = 3 ]
    [ set temp1 count neighbors with [ landuse != 3 ] ]
  ask patches with [ landuse = 4 ]
    [ set temp1 count neighbors with [ landuse != 4 ]
      set patchiness temp1  ]
;  view-patchiness
end

to view-patchiness
  locals [temp1]
  ask patches [
    set temp1 patchiness * 10
    set pcolor scale-color green temp1 90 0 ]
end

to compute-stats
  set pcbuilt (builtup / count patches) * 100 ;non-builtup
  set lden ( count patches with [ builtden <= 0.33 ] / count patches ) * 100
  set mden ( count patches with [ builtden > 0.33 and builtden <= 0.66 ] / count patches ) * 100
  set hden ( count patches with [ builtden > 0.66 ] / count patches ) * 100
end

;;; coloring procedures

to recolor  ;; patch procedure
  if landuse = 3
    [ set pcolor blue ]
  if landuse = 1
    [ set pcolor yellow ]
  if landuse = 2
    [ set pcolor green ]
  if landuse = 4
    [ set pcolor red ]
end

;;; plotting procedures

to do-plots
  set-current-plot "Builtup Growth"
  set-current-plot-pen "Builtup"
  plot (builtup / total) * 100

  set-current-plot-pen "Openland"
  plot (openland / total) * 100

  set-current-plot-pen "Water"
  plot (water / total) * 100

  set-current-plot-pen "Vegetation"
  plot (vegetation / total) * 100

  set-current-plot-pen "Landuse Change"
  plot ( lu-change / total ) * 100

  set total builtup + water + vegetation + openland
  set popAden CurrentPop / total
  set popBden CurrentPop / builtup

  set-current-plot "Builtup Density"
  set-current-plot-pen "LowDen"
  plot lden

  set-current-plot-pen "MedDen"
  plot mden
```

```
  set-current-plot-pen "HighDen"
  plot hden

  set-current-plot "Population Densities"
  set-current-plot-pen "popAden"
  plotxy system-dynamics-t popAden
  set-current-plot-pen "popBden"
  plotxy system-dynamics-t popBden

  set-current-plot "Population Growth"
  set-current-plot-pen "CurrentPop"
  plotxy system-dynamics-t CurrentPop
end
```

Credits

If not for Prof. Uri Wilensky and his "NetLogo", this would not have emerged. A BIG THANKS! For more information on NetLogo see http://ccl.northwestern.edu/netlogo/

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To refer to this model in academic publications, please use:

Sudhira, H. S. (2008). *BangaloreSim Model. Ver. 17-d*. Bangalore, India: Centre for Sustainable Technologies and Department of Management Studies, Indian Institute of Science.