SPATIO-TEMPORAL URBAN GROWTH PATTERNS IN THE COLOMBO URBAN FRINGE, SRI LANKA

by

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Thesis submitted in fulfillment of the requirements
for the degree of
Doctor of Philosophy

August 2017

ACKNOWLEDGEMENT

There are few undertakings that are as challenging and at the same time as rewarding as conducting research for a PhD study. Writing, preparing the diagrams and tables and revising the manuscript are all part of process and now I am gratified that I have practically completed my thesis. The journey I had to take in the quest for my PhD degree has proved to be such an amazing learning and working experience. But it was no solo journey as this thesis would not have seen the light of day without the sincere help and support of many people.

I was very fortunate to have as my Supervisor, Prof. Lee Lik Meng and I am genuinely thankful for his great guidance, which he provided through valuable discussions and constructive suggestions for improving the thesis to meet the required high standard. I appreciate the fact that he allowed me plenty of freedom and encouragement to develop fresh ideas when I was conducting the scientific research. He taught me very many valuable lessons despite my having given him the impression at times that I did not listen to him. His wisdom has carefully guided my work throughout the process of formulating and developing this research. His profound knowledge of urban planning and his systematic organisation of research ideas have greatly contributed to improving the scientific thinking underpinning this research.

I am thankful to all of the academic and administrative staff and my colleagues at the School of Housing, Building and Planning and the Institute of Postgraduate Studies, Universiti Sains Malaysia for providing a better learning environment to enable me to complete my PhD journey. I would like to profusely

thank the National Centre for Advanced Studies (NCAS) in Sri Lanka for granting me the scholarship to continue my studies in Malaysia. The field work for this research was conducted over a period of nearly 8 months in Sri Lanka. I would like to acknowledge the support and assistance provided by planner Mrs. Pushpa Gamage, the Director of the GIS division of the Urban Development Authority of Sri Lanka. I wish to extend my special thanks to the urban planners whose rich knowledge of the local urban scene was of great help in understanding practical planning issues.

I am also thankful to my colleagues in the Department of Estate Management and Valuation at the University of Sri Jayewardenepura, Sri Lanka for encouraging me and sharing the burden of my work among them so that I could finish my studies within the allotted three and a half years. I would like to express my sincerest appreciation to my husband Jagath, eldest daughter Prabhani, other daughters, and my parents for their understanding and love when I was focusing more on my studies and less on my family responsibilities.

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LIST OF ABBREVIATIONS

AWMSI	Area Weighted Mean Shape Index
AWMPFD	Area Weighted Mean Shape Index
ANN	Artificial Neural Network
ABM	Agent Based Modelling
AUSEI	Annual Urban Spatial Expansion Index
CMP	Colombo Master Plan
CMRSP	Colombo Metropolitan Regional Structure Plan
CA	Cellular Automata
ED	Edge Density
GND	Grama Niladari Division
GIS	Geographic Information System
IDW	Inverse Distance Method
KMC	Kaduwela Municipal Council
LEI	Landscape Expansion Index
MAUP	Modifiable Areal Unit Problem
MC	Municipal Council
MPS	Mean Patch Size
MSI	Mean Shape Index
PS	Pradesheeya Sabha
PGI	Population Growth Index
PDCI	Population Density Change Index
PSCoV	Patch Size Coefficient of Variance
LUCI	Urban Land use Change Index
RS	Remote Sensing
SDI	Shannon's Diversity Index
SEI	Shannon's Evenness Index
UC	Urban Council
UDA	Urban Development Authority

UNDP	United Nations Development Programme
USEI	Urban Spatial Expansion Index
WRMP	Western Region Megapolis Plan
MPFD	Mean Patch Fractal Dimension
MC	Municipal Council

POLA RUANG-MASA PERTUMBUHAN PENDUDUK DI PINGGIR BANDAR COLOMBO, SRI LANKA

ABSTRAK

Pertumbuhan bandar dan urbanisasi yang pesat, khususnya, dalam dunia sedang membangun memerlukan satu kefahaman saintifik tentang pola pertumbuhan di bandar mengikut aspek ruang-masa. Ilmu ini sangat penting untuk pengurusan tanah lestari dan perancangan pembangunan bandar. Teknologi GIS moden telah membuka peluang yang besar dalam memantau dan menguruskan pertumbuhan bandar yang pesat. Namun demikian, teknik-teknik ini mempunyai beberapa kekangan dalam membuat keputusan untuk pembangunan yang lestari. Pertumbuhan bandar mengikut ruang-masa berlaku mengikut perubahan sistem bandar utama terdiri daripada sub-sistem fizikal, sosio-ekonomi dan pembangunan. Dengan perubahan faktor-faktor pemacu dalam setiap sub-sistem, ia mempengaruhi sistem bandar utama secara langsung. Oleh itu, mengkaji pertumbuhan bandar mengikut aspek ruang-masa dengan menyatukan semua faktor-faktor pemacu yang wujud dalam tiga sub-sistem yang berbeza menjadi satu landasan adalah penting dan kajian ini membuat sumbangan kepadanya dari aspek teori. Tren pertumbuhan yang lalu, kekurangan tindakan kawalan dan ketiadaan ilmu tentang pemacu pertumbuhan yang lepas adalah jurang kajian yang wujud dalam kajian bandar di Sri Lanka. Kajian ini bertujuan menjurus jurang kajian dengan menganalisa pola pertumbuhan ruang-masa. Untuk mencapai objektif ini, kajian telah merangka tiga objektif. Objektif pertama menjurus kepada menganalisa dan menyorot pertumbuhan bandar yang lepas di daerah Colombo untuk mengenalpasti pinggir bandar Colombo. Pendapat pakar, rekod sejarah dan tinjauan lapangan digunakan untuk mengumpul

data untuk tujuan ini. Analisis pola spatial berasaskan GIS, analisis perubahan struktur penggunaan tanah dan analisis gradien bandar telah digunakan sebagai kaedah analisis. Objektif kedua menjurus kepada membangunkan satu kerangka kerja berkonsep untuk pemodelan GIS. Pendapat pakar, pandangan penduduk, dan data lapangan telah digunakan untuk mendapatkan faktor-faktor pemacu yang dikaitkan dengan tiga sub-sistem berbeza. Objektif terakhir ialah memodelkan pertumbuhan pinggir bandar di Colombo. Kajian menggunakan pemodelan regresi spatial sebagai kaedah analisis, oleh kerana ia adalah kaedah yang paling baik untuk menganalisa pembolehubah binari dengan data sosio-ekonomi. Pelbagai peta bertema, fotograf dari pandangan atas, dan imej satelit digunakan untuk mencipta peta kriterion, dan persampelan spatial digunakan untuk memilih sampel untuk dianalisis. Hasil kajian menunjukkan bahawa terdapat satu bentuk spatial baru di Colombo, bernama "Model Nagara-Grama" yang terhasil daripada perubahan dalam pertumbuhan bandar ruang-masa (spatio-temporal) dalam masa tiga dekad. Tambahan lagi, model konseptual menunjukkan di mana wujud pinggir bandar dan perhubungannya dengan alam sekitar. Seterusnya, kajian menunjukkan hala tuju pertubumhan pinggir bandar dan faktor-faktor positif dan negatif yang mempengaruhinya. Kajian menunjukkan bahawa faktor-faktor kepadatan dan proksimiti mempengaruhi secara negatif pertumbuhan bandar ruang-masa, sementara faktor-faktor sosio-ekonomi dan alam sekitar mempengaruhi secara positif pertumbuhan di pinggir bandar.

SPATIO-TEMPORAL URBAN GROWTH PATTERNS IN THE COLOMBO URBAN FRINGE, SRI LANKA

ABSTRACT

Rapid urbanisation and urban growth, in particular, in the developing world require a scientific understanding of spatio-temporal urban growth patterns. This knowledge is highly essential for sustainable land management and urban development planning. Modern GIS technologies have opened up great opportunities in monitoring and managing fast urban growth. However, these techniques have some limitations in decision making for sustainable development. Spatio-temporal urban growth occurs due to changes of the main urban system comprising physical, socio-economic, and environmental subsystems. With changes of the driving factors in each subsystem, directly influencing the main urban system. Therefore, analysing the spatio-temporal urban growth by amalgamating driving factors that exist in three different subsystems into one platform is vital and this research contributes to it theoretically. Indistinct past growth trends, lack of control measures and absence of knowledge about past growth drivers in the Colombo urban fringe are research gaps that exist in Sri Lankan urban studies. This research aims to address this research gap by analysing its spatio-temporal growth pattern. To accomplish this, the research framed three objectives. The first objective focused on analysing and reviewing past urban growth in the Colombo district in order to identify the Colombo urban fringe. Expert opinions, historical records, and field surveys were used to collect data for this purpose. GIS based spatial pattern analysis, land use structure change analysis and urban gradient analysis were used as analysis methods. The second objective

focused on developing a conceptual framework for GIS modelling. Expert opinions, residents' views, and field data were used to derive driving factors linked with three different subsystems. The final objective was to model the Colombo urban fringe growth. The study used spatial logistic regression modelling as the analysis method, as it is a reliable method for analysing binary variable with socio-economic data. Various thematic maps, aerial photographs, and satellite images were used to create criterion maps, and spatial sampling was used to select the sample for analysis. The research outcomes revealed a new spatial form of Colombo, namely "Nagara-Grama Model" that resulted from changes in spatio-temporal urban growth over the past three decades. In addition, the conceptual model shows where the urban fringe exists and the relationship it has with its surroundings. Further, the research revealed the fringe growth directions and the negative and positive factors influencing it. The research showed that density and proximity factors negatively influenced spatio-temporal urban growth whereas socio economic and environmental factors positively influenced fringe urban growth.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Research

Urbanisation and urban growth are common phenomena throughout the Western and the Eastern worlds. In 2014, the world's urban population amounted to 54% of its total population. In the developed countries, 78% of the population lived in urban areas while in the developing countries the figure is around 52%. This indicates that currently more than half of the world's population is urbanised (United Nations, 2014) and the current decade shows higher urban densities in the mega cities of the world compared to previous decades. "Close to half of the world's urban dwellers reside in relatively small settlements of less than 500,000 inhabitants, while only around one in eight live in the 28 mega-cities with more than 10 million inhabitants" (United Nations, 2014 p2). These high urban densities occur due to urban growth fuelled by migration and this is the ultimate result of urbanisation. Globally, all regions are responsible for accommodating and adjusting to their urban growth in a sustainable manner. Crookes in 2010 mentioned, "Cities play a critical role in our lives, providing habitats for more than half the world's population (p.1)." Though the urban population figures of the developing countries are not fully verified, they indicate with reasonable certainty that nearly half of the population live in densely populated urban areas.

The Asian urban population is 48% of the total population of the region but this represents 53% of the urban population of the world. The continuing urbanisation and overall growth of the world's population is projected to add 2.5

billion people to the urban population by 2050, with nearly 90 per cent of the increase concentrated in Asia and Africa (United Nations, 2014). This rapid growth has led to massive urban agglomerations in Asia that threaten sustainable development. Ultimately, this high urban concentration gradually expands outwards, in either a haphazard or a planned manner. Theoretically, urbanisation, urban growth, and urban development are basic processes in urban studies that cannot be considered separately. Clark (1982), as cited by Bhatta (2010) stated urban development as the process that links with the other two main processes of urban growth and urbanisation. The process occurred in a general pattern but the implications were so extensive that continuous changes occurred in urban areas. These spatial changes happened due to physical processes which occurred over a long duration showing continuous spatial changes in a temporal manner. Therefore, urban growth can be considered as a spatial-temporal process. In addition, urban growth is considered as a spatial and demographic process, as over a long period, it can lead to an increase in the number of towns and cities with high urban densities and brisk economic activities. Research by Adepeju et al. (2016) described urban growth as a physical sociological process that represented discrete events in time and space. In many instances, this growth is uncontrolled and dispersed and this is likely to impede sustainable development (Bhatta et al., 2010). Hence, urban growth analysis should take into consideration spatial and temporal aspects as they are interrelated with the demographic process.

A theoretical review of this spatio-temporal process leads to the conclusion that this is indeed a complex urban system as so many scholars have observed (Kim & Batty, 2011; Cheng & Masser, 2003; Jat et al., 2008). This complex urban system can be understood by studying the interactions of the different sub-systems. Some of

the scholars (Cheng, 2003; Deka et al., 2012; Banzhaf et al., 2009) attempted to show urban growth as a phenomenon that occurs as a result of interactions among the sub-systems, by using physically and functionally different scales.

"An urban landscape may be viewed as a system that integrates physical, social, economic, ecological, environmental, infrastructural, and institutional sub-systems, where urban growth and sprawl is the outcome of changes in performance/ functioning of these sub-systems" (Bhatta, 2010, p. 6).

The concepts of land use change management (Kaiser et al., 1995), and the highest and best use of land in the social and commercial sense (Barlow, 1978), provide good theoretical explanations about the sub-systems interrelated to land use planning. Those concepts opened up a broad debate about the factors affecting land use change from the physical, social and environmental points of view. These three domains are considered as sub-systems in the holistic functioning of the overall urban system. All growth drivers interrelated to these three sub-systems exerts their influences to change the urban growth of the main system on a certain scale.

The analysis of spatial formation and the dynamics of urban growth are one of the currently debated topics in urban studies. Several scholarly works focuses on the spatial formation and dynamics of urban growth patterns in the west using a diverse range of theories and models. In the 20^{th} century, scholars developed different theoretical models to explain urban growth. Most of the models describe the way of expanding urban growth from centre to the periphery. Centre dominant model (Myrdal, 1957), central place theory (Christaller, 1933), Gibbs model (Gibbs, 1963), core periphery model (Friedmann, 1965), are some of the examples of explanations in urban spatial pattern. A theoretical explanation for the process of urbanisation that

takes place in a city-based pattern would be that it occurred due to advantages of agglomeration economics and the economies of scale. In addition to that rural-urban separation has been widely accepted in classical urban theories. In contrast to conventional western theories of the urbanisation process, in the 1970s Asian urban scholars presented a new type of urban form in Asia (McGee et.al., 1991). They differentiated the Asian urbanisation process from the western process in three respects. Firstly, the spatial separation of rural-urban activities is lacking in Asia; secondly, inadequate operation of agglomeration economies have not fully facilitated the concentration of the population to linked urban places; and finally, the profound western historical influence of the industrial revolution is not directly applicable to Asia. The common character of Asian urbanisation is densely populated rural regions surrounding big cities, occurring without any significant rural to urban migration. As a result, the economic transformation of heavily populated areas from agricultural activities to non-agricultural activities takes place and this change often stretches along the corridors between large city hubs as a ribbon development with high growth fringes surrounding major town centres.

The rapid economic growth of cities created fresh employment opportunities and that attracted an additional commuting population to the city. The development of road networks and public transport facilities encouraged the influx into the city of a commuting population that was accommodated in the urban fringe areas. This process created new demand for housing and other services in the fringe and the fringe responded by increasing the supply of land by the simple expedient of converting agricultural land to non-agricultural uses without proper planning. The fringe gradually merged into the urban sphere of influence by rapid amalgamation but this has not stopped the high intensity of ongoing land development (Perera,

2008). This continuous growth process creates an uneven growth pattern. Hence, planners faced continuous challenges in planning a livable environment for the inhabitants while simultaneously attempting to mitigate this uneven growth. As their efforts did not achieve much unevenly scattered settlements along the road network interspersed with some sprawl pockets have become common features seen in the Asian urban fringe (Bhatta et al., 2010; Sudhira et al., 2004). The type and scale of unplanned development is dissimilar among the countries within the region, in both the spatial and the temporal aspects. Measurement of this dispersed urban growth is a challenging task. Weak planning regulations as well as the diverse social and cultural backgrounds of Asia have affected their growth patterns. Therefore, western experiences would not directly apply to the measurement of the urban growth in Asian countries. Sri Lankan urban studies too have faced this limitation.

Traditional urban planning approaches suffered some limitations when attempting to measure these different interactions using a spatio-temporal scale. However, presently the Geographic Information System (GIS) can be integrated with dynamic urban modelling techniques to provide a consistent platform for calibrating such growth patterns and interrelations accurately. Many scholars have conducted studies on the spatial formation and dynamics of urban growth patterns using a diverse range of techniques integrated with GIS, such as analysis of urban growth patterns (Fan & Fan, 2014), modelling of urban growth patterns (Allen & Lu, 2003; Hu & Lo, 2007), and measurement of urban growth patterns (Aljoefie, 2012), to mention a few. Urban growth is a result of influences of different physical socio-economic and environmental factors and identification of these influences are significant for urban planning. GIS based statistical modelling include a wide range of tools to measure the level of influences in different factors, and various scholarly

works have used GIS modelling to clarify urban expansion from the physical and socio-economic points of view (Lu & Wei, 2009; Hu & Lo, 2007). This research mainly focuses on applying the GIS integrated statistical modelling techniques for portraying all aspects of the urban growth pattern with reference to the Colombo urban fringe in Sri Lanka.

Sri Lanka is an island in the Indian Ocean and administratively divided into nine provinces or regions. The country is facing urbanisation and is continuously in the process of transforming from a rural economy to a services and manufacturing oriented economy. Urbanisation in Sri Lanka shows a slow growth rate compared to the fast urbanisation found elsewhere in South Asia. The country has one of the lowest population growth rates among developing countries (1.0 percent a year). According to official statistics, its urban population growth averaged 0.3 percent a year from 2005 to 2010. While the urbanisation data on Sri Lanka are not accepted by all, there is consensus that the country is urbanising faster than the statistical figures suggest, although more slowly than other South Asian and South East Asian countries. The Western Region has undergone the highest rate of urbanisation in the country and its urban concentration has been accompanied by higher economic density and higher productivity. The population in the western region went up from 3.9 million in 1981 to 5.8 million in 2012, accounting for 35 percent of the national increase (Department of Census & Statistics, 2012). While the western region covers only about 6 per cent of the land area of the country and holds 28 percent of its population, it accounts for 45 per cent of GDP. Per capita income in the western region is 3,808 US dollars p.a., which is 1.6 times the national per capita income (UN Habitat, 2012). Much of Sri Lanka's foreign trade passes through the port of Colombo and the western region generates much of the capital, human resources,

technology, and advanced services to drive economic growth and job creation in the rest of the country. The service sector of the western region is the main economic driver generating 65 percent of the region's GDP as against 58 percent for the service sector nationally (Department of Census & Statistics., 2012,).

When comparing the three districts of the western region, the growth rate of Colombo District is higher. However, the population growth does not mirror the physical growth. Table 1.1 shows the population distribution pattern in the Colombo District.

Table 1.1 Population Distribution in the Colombo District

	Population		Average annual rate of increase
	2001	2012	2001-2012
Colombo City	642,163	555,152	-1.35
Immediate MCs *	493,686	457,146	-0.74
Inner Suburbs	663,805	765,633	1.53
Outer suburbs	451,620	545,895	2.08
Colombo District	2,251,27	2,323,82	0.32

Compiled from Department of Census and Statistics, 2012 census data
*MC – Municipal Council

According to Table 1.1, the 2012 population figures of the city of Colombo and the immediate surrounding municipal councils show negative growth rates. The localities in the inner suburbs show a low growth rate and those in the outer suburbs display a high growth rate. In 2012, the population density of Colombo district was 3438 persons per sq. km., ranking it first in the Island. Hence, this district plays a key role in terms of urbanisation in Sri Lanka.

Transport and communication, wholesale and retail trade, manufacturing, education, and service sectors are the main growth drivers in the Colombo district.

Stimulated by these drivers, the urban growth spreads beyond the city of Colombo in a concentric pattern. During the past four decades in the city of Colombo, the urban growth was high vertically; beyond that, urban growth has spread haphazardly to the countryside and the growth directions were not clearly identified. Wanasingha (1985) observed that ease of travel to workplace through readily accessible public transport and the availability of affordable land were significant reasons for the conversion of the fringe areas from rural to urban in the Colombo fringe. At present, Sri Lanka's urban vision is focused on an accelerated process; most areas of the Colombo urban fringe have been identified as potential zones for new urban developments. Exploring urban growth in spatial-temporal scale is a vital necessity for urban planners and decision makers to set their future planning and developments.

1.2 Statement of Problem

Common growth patterns of Colombo are ribbon development, growth pockets, and infill growth like in other Asian countries. Further, in Colombo the urban fringe shows an uneven growth pattern like its counterparts in other Asian countries. This distribution pattern shows the dynamics of the interaction between population growth and urban growth. There is a strong negative relationship between population growth and urban growth with the population data showing higher growth towards the outer areas in an uneven manner (Table 1.1). For example, the 2012 census shows population densities of some of the small administrative divisions known as Grama Niladari Divisions (GND) in the urban fringe as less than 10 persons per hectare (See Administrative structure of Sri Lanka in Appendix 1). This situation may be due to natural physical constraints, inadequate infrastructure or some other influencing factor, but the decision makers are unable to pinpoint the

exact cause because of the lack of spatio-temporal data or studies about urban growth. Detailed clarification of this unique transformation pattern in terms of a spatial-temporal scale is a vital necessity for urban planners and decision makers to set their future priorities correctly in respect of the locations of establishments and resource allocations. However, South Asian or South East Asian urban forms inappropriate to apply either to the Sri Lankan urban scenario because its unique growth pattern is linked intimately with the social and cultural background of the people.

When considering the past urban growth studies, space and time are seen to be significant factors. Over the last four decades the urban growth pattern has shown considerable changes and the urban fringe has gradually moved outwards. Previous urban studies have paid little attention to this spatial and temporal dimension because of the lack of data and reliable methods. Presently, urban growth modelling in combination with advanced GIS technologies provide advance techniques for observing the spatial and temporal growth patterns. GIS technologies provide extensive methods to review and quantify urban changes and this study will use the same tools to assess the spatio-temporal urban growth pattern.

1.3 Scope and Objectives of the Research

The scope of study for this research is based on several questions. First, how can the spatio-temporal urban growth in the Colombo District be measured in order to identify fringe growth? How can the fringe growth be conceptualised and how do we apply the conceptual pattern on the ground? To answer the above research questions, this study reviewed and analysed urban growth to determine the spatio-

temporal growth in the Colombo urban fringe. To accomplish this task, the following three objectives were formulated:

- To analyse the spatio-temporal urban growth pattern in Colombo urban fringe
- To develop a conceptual framework for the urban growth modelling
- To model urban growth for determining the relationship between fringe growth and its driving forces

1.4 Significance of the Research

Urban growth in developing countries is a complicated phenomenon in relation to two aspects. For example, the government needs to understand how to expand the city outwards and how it could serve the population better with public services, infrastructure development, etc. From an urban planning point of view, the planners need to identify how and where urban growth can occur, and what are the driving forces that cause those changes (Kim & Batty, 2011). Due to lack of data and methods Sri Lankan urban scholars paid minimal attention to that in the past. This research intends to minimise the above gap by developing an urban growth model for Colombo, Sri Lanka. The study attempted to identify the significant driving forces acting on the different sub-systems, and their level of influence at different scales, while focusing on the geographical layout of the Colombo urban fringe. The findings will be useful to planners as it will help them to pinpoint how and where urban growth might be expected to occur in the fringe. Previous Sri Lankan urban studies paid little attention to this, and so this research will offer greater insight and suggest new ways for planners and decision makers to think, analyse, and solve problems relating to urban growth. In addition, urban planning practices in the developing countries have lacked integration and policy formulation has hardly focused on the

urban fringe due to inadequate methods and lack of data. The methodology and findings of this research will provide a new planning approach to tackle uneven growth challenges in the future successfully. The findings of this case study may also become a reference model for future case studies in developing countries through sharing its experiences and the lessons learned.

In the early stages, urban models had suffered some limitations in figuring out the spatio-temporal relationships of urban growth. Over the past two decades the possibilities of urban modelling have expanded through modern innovations, such as blending it with GIS and remote sensing technologies. The integration of the GIS with urban studies has provided an effective tool for detecting urban growth and modelling same in the recent past (Deka et al., 2012). Urban models of land use change blended with GIS have become important tools for city planners, economists, ecologists, and resource managers. The present GIS based urban modelling techniques facilitate decision making in urban planning through analysis, evaluation, forecasting, and simulation (Cheng, 2003). A vast amount of literature has been published on studies of urban growth in its various aspects during the past two decades, such as urban growth system theories and methods (Cheng & Masser, n.d; Batty, 2001.; Sliuzas et al., 2010), and analysis of urban growth (Herold et al., 2003; Sudhira et al., 2004; Bhatta, 2010). Some of the studies were devoted to analysing the pattern of urban growth (Nong et.al.,2014; Liu et al., 2014), monitoring urban growth (Fan & Fan, 2014; Kaya & Curran, 2006) and modelling and predicting the spatio-temporal pattern of urban growth (Ramachandran et al., 2012, Thapa et al., 2011; Jat et al., 2008;). Those studies have made valuable contributions to the analysis of urban growth and its consequences (Aljoufle, 2012).

Although several studies have been conducted on the urban growth phenomenon, a thorough analysis of the mutual interactions among the three urban sub-systems (physical, socio-economic and environmental) has not yet been done. In 2003, Cheng addressed certain complexities that arose during an urban development project but his study was concerned only with certain urban growth areas (developing areas) and not with planned urban development. In 2012, Aljoufle explored urban growth and transport interactions. Although there are many driving factors behind urban growth that tend to influence economic, social, and environmental subsystems, most scholarly works only considered the socio-economic factors (Han et al., 2009) while some researchers considered only the environmental factors. Therefore, the majority of scholarly works have only discussed the separate effect of each driver rather than their combined effect and the interactions between those drivers (Ju et al., 2016). In the developing countries, only a few researchers have focused on urban growth drivers connected to all three sub-systems. This research will offer a new perspective in researching the interactions between a large number of growth drivers related to the socio-economic, physical and environmental sub-systems and therefore points the way forward by incorporating the diverse sub-systems with the main system in urban growth studies.

Simulation models are widely used in urban modelling to predict urban growth but there exist some limitations in amalgamating socio-economic data into the model. Therefore, this study attempts to develop an urban growth model using statistical modelling techniques. Most researchers use logistic regression for urban growth studies and this study too has made use of it. Those studies developed explanatory variables as distance variables and density variables but they were not considered as variables in the socio-economic, physical and environmental domains,

which are sub-systems of the main urban system. This research developed explanatory variables based on the three different sub-systems and this is a new methodological development in performing GIS based urban modelling.

In conclusion, the significance of this study can be stated as follows. Firstly, this study is of value to Sri Lankan urban planners, in understanding former growth patterns so that it can help them to engage in future planning more effectively. It is also significant in that it would encourage Asian scholars to conduct urban research focused on the urban fringe in their cities. Further, it adds to the new vision of GIS based urban modelling as it would enable them to assess urban growth in three different sub-systems. Finally, the results of this study would have much relevance to urban planning studies when blended with GIS.

1.5 Chapter outline

The subject matter of the thesis consists of seven chapters and the chapters have been brought together in one diagram, mentioned in the research framework illustrated in Figure 1.1. In addition to the introductory and concluding chapters, the thesis consists of five core chapters. A brief summary of each chapter follows.

Chapter One provides a general overview of the study. It includes the background of the research, research questions that are addressed scope and objectives, significance, limitations, and conceptual framework of the research.

Chapter Two consists of the literature review. It presents a theoretical review of urban growth in its various aspects. In addition, it discusses the various urban models and modelling approaches.

Chapter Three consists of research methodology, focusing on primary and secondary data, data sources, population, samples, and variables. It also discusses measurements, indicators, and parameters for model development.

Chapter Four systematically records and analyse the spatial and temporal urban growth of Colombo District during the last four decades, focusing on Objective One. This chapter recalls the background knowledge of urban growth in order to produce the conceptual framework of the model. After an introduction to the various urban development policies since 1977, the urban growth patterns including road networks and other land uses were mapped for 1985, 1996, and 2014, and interpreted. Following this, the spatial and temporal patterns were quantitatively evaluated from the perspectives of annual growth rate, spatial pattern, and land use structure change. It helped to better understand the urban fringe and its pattern in the Colombo district. Finally Colombo spatial form is conceptualised using a new model called the Nagara-grama model.

Chapter Five focuses on the second and third objectives. First, it develops the proposed conceptual framework of the urban growth model focusing on the second objective. It shows how to develop the conceptual model by integrating the physical, socio-economic and environmental sub-systems. Secondly, it presents the urban growth model in two spatial scales; urban change (macro scale) and density change (micro scale). The multi-scale analysis provides deeper insight into urban growth patterns. In addition, the method is based on the integration of exploratory data analysis and spatial logistic regression. This framework is tested by analysing the urban growth in the case study area of the urban fringe during the period 1972-2012.

Chapter Six discusses the results of the research, given in chapter four and chapter five, focusing on the research objectives.

Chapter Seven presents the conclusions. It consists of the findings, study implications from the theoretical, methodological and management perspectives, contributions of the study, its limitations and recommendations for further research.

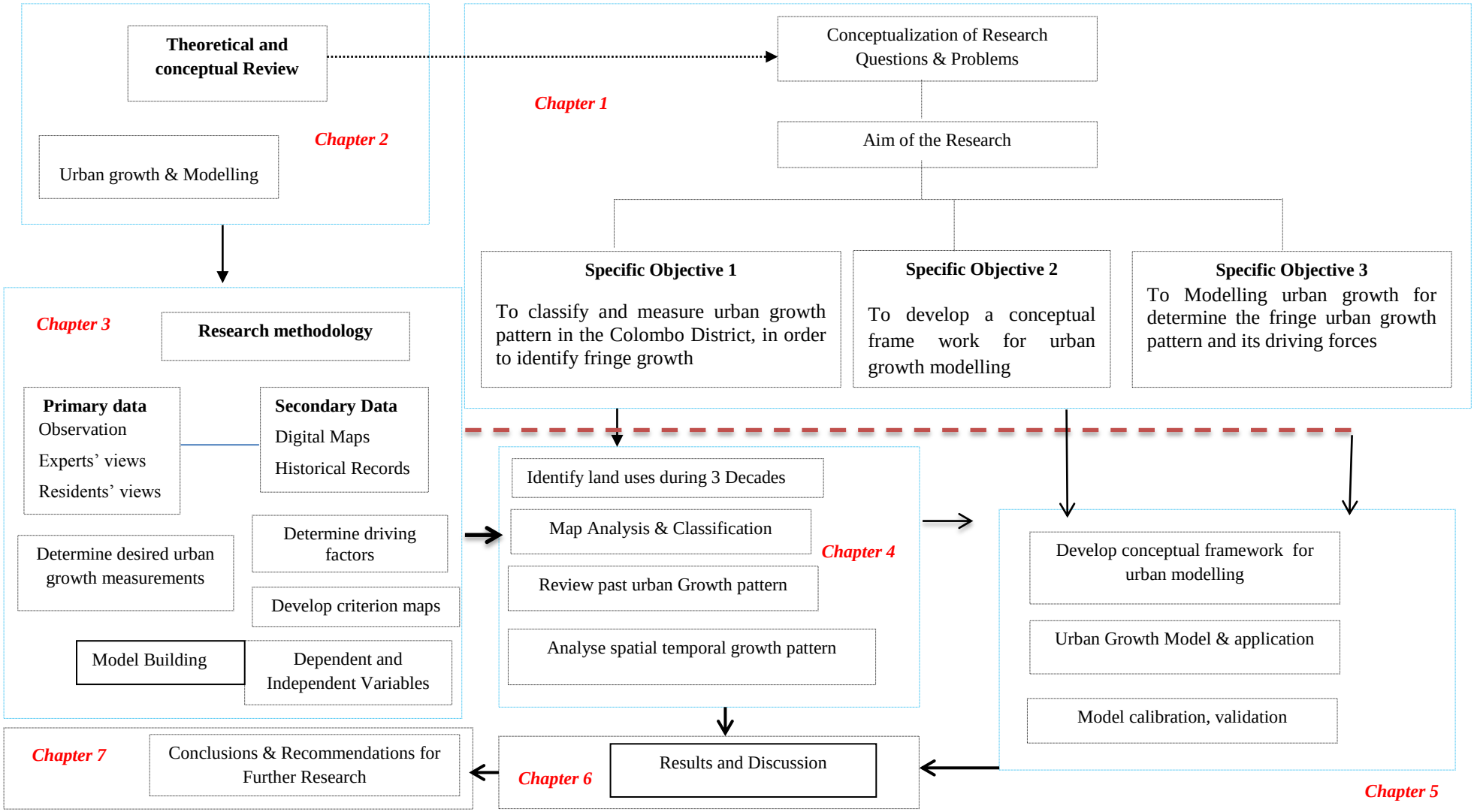

Figure 1.1 Conceptual Framework of the Research

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This section presents a review of relevant literature concerning theories, studies, and scholarly discussions on urban modelling including latest findings. The chapter commences with a brief account of urban growth and related theories, and the different measurements used for measuring urban growth as discussed in various scholarly works. Subsequently, the urban fringe, its delineation and the driving factors that influence growth are discussed. Presented next are previous scholarly works related to urban studies and the different urban development plans, which are used to show past urban directions in Colombo and the Western Region of Sri Lanka for highlighting the research gap.

2.2 Spatio-Temporal Urban Growth

The density and spread of human habitations and the associated physical phenomena on the earth's surface vary from place to place and from time to time; urban geography mainly focuses on locations and spatial arrangements of urban areas. A study of urban growth is one of the components of urban geography and focuses on the urban transformation in terms of physical and demographic expansion. A study of urban geography reveals that urban development, urban growth, and urbanisation are phenomena that closely interact with each other.

Urban development is directly linked with urban growth and urbanisation, and urban development is the process of emergence of a world dominated by cities

and urban values (Pacione, 2005). The emergence of large cities and their rising spatial influence mark a movement of people from sprawling rural areas to predominantly urban places. That has happened in most countries of the world over the last two centuries. This state of affairs not only shows that large numbers of people live in the cities and towns and the surrounding areas, but that whole segments of the population are completely dominated by urban values, expectations and lifestyles (Bhatta, 2010). This has occurred mainly because the non-agricultural nature of employment in the city is more convenient and appealing to the modern urban society which is more socially, culturally and intellectually oriented than the traditional agricultural society.

The term urbanisation currently refers to the physical growth of urban areas. In 2014, the United Nations defined urbanisation as the movement of people from rural to urban areas with population growth equating to urban migration; this inevitably leads to a rise in urban density and an increased demand for urban services. The built-up area of cities in developing countries will increase to more than 600,000 square kilometers by 2030. Those countries expect their populations to increase by 20% and their built-up land areas by 2.5 times by 2030. It is estimated that every new resident will convert, on average, some 500 square meters of non-urban land to urban land (United Nations, 2014). The term ‘urban development’ can be considered as a simple process but its consequences are complex, because this spatial process encompasses changes in the economic, social, and political structure of a region. This rapid and complicated urbanisation process results in the spillover of physical growth to the surrounding areas and this phenomenon is commonly referred to as ‘urban growth’. Thus, urban growth is considered as a spatial,

demographic (Clark, 1982) and non-spatial social process. Spatial process is the process of evolution of non-built up areas to built-up areas, while during the same period demographic changes will occur because the population is attracted to built-up areas. Those two processes affect the behaviour and social relationships among members of the society, and this is considered as a non-spatial social process (Bhatta, 2010). Urban growth is not an instant spatial process but happens over a long period. Hence, urban growth is viewed as a spatial-temporal process. Sinclair, 1978 mentioned "temporally, the sequence of change occurs in one location through a period of time. Spatially, the sequence is distributed throughout an area (or field) at any one point in time*"*(p.34).

Urban growth is a continuous process that keeps changing the spatial structure of cities. Some scholars have considered it as a static phenomenon, whereas some have regarded it as a dynamic phenomenon; however, most researchers have acknowledged both as spatial-temporal processes. In 2010, Andrienko et al. described that everything in the physical world is purely spatial and temporal because everything is a process. Physical change must be seen as a combination of processes that occur along the time scale in the space concerned. Cheng (2003) mentioned that a process is a sequence of changes occurring in space and time, as it initially begins as a spatial process and later transforms into a temporal process. The spatial analysis of spatio-temporal data in the urban context can prove too complex due to the need to study large areas over long periods. Andrienko et al. (2010) have stated that the attributes relating to space and time may be too numerous and pose challenges in two ways. In the first instance geographical space is complex and heterogeneous. But it can be represented by a cartographic

map, which serves as a model and helps to interpret the associated space and the locations. Secondly, it is also a complex phenomenon but it flows in a linear manner. Normally, events happening over time may occur periodically, including overlapping and interacting events. The comprehensive analysis of spatio-temporal data calls for a two pronged approach, as it requires to be considered both as a temporally ordered sequence of spatial situations and as a local temporal variation. It is stressed and emphasised that spatial data processing, integration, and analysis are subject to the fundamental concept of spatial dependence and this is referred to as 'the first law of geography' or 'Tobler's first law', which states "everything is related to everything else, but near things are more related than distant things" (Miller, 2004). As per the law, characteristics of formal locations are correlated negatively or positively and this is named as 'spatial autocorrelation' in statistical terminology. Similar to the spatial concept, the temporal concept was also explained as, "the concept of temporal dependence and temporal autocorrelation exist for relationships in time" (Andrienko et al., 2010, p. 1583). Research by Herold et al. (2005a) supports, a hypothetical schema of the spatial-temporal process of urban growth using a general conceptual representation as shown in Figure 2.1. According to this concept, the urban area expansion starts with a historical core that grows and it then scatters to form new individual development centres. Further Herold et al. (2005a, p.3), described this spatial-temporal process of urban growth as follows:

> "The process continues along a path of organic growth and outward expansion. The continued spatial evolution transitions to the *coalescence* of the individual urban blobs. This phase of transition initially includes development in the open space between the central urban core and peripheral centres. This conceptual growth pattern continues and the system progresses towards a

saturated state. The 'final' agglomeration can be seen as an initial urban core for further urbanisation at a less detailed zoomed-out extent. In most traditional urbanisation studies this 'scaling up' has been represented by changing the spatial extent of concentric rings around the central urban core."

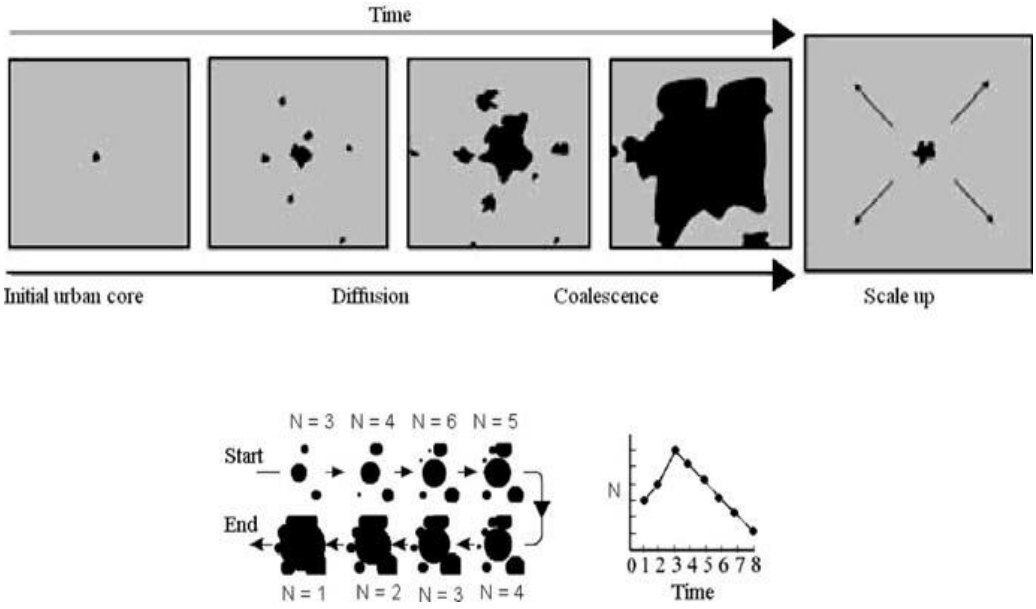

Figure 2.1 Hypothetical schema of urban growth process
Source: Herold et al. (2005)

As a result of the spatial temporal process, physical expansion of urban areas occurred, converting non-built-up areas to built-up areas. This urban expansion can happen in three ways; either with the same population density (persons per square kilometer in existing built-up areas) or with increased density or with reduced density. Changes in the density can arise due to redevelopment of existing built-up areas at higher densities, or through infill of new developments in non-built-up areas. New development can take place adjoining the existing built-up areas or in undeveloped land that is separate from the existing built-up areas.

Wilson et al. (2003) have identified three types of urban growth, which they name as infill, expansion, and outlying. Mostly, outlying growth occurs in open areas and environmentally sensitive lands in and around the city. Bhatta (2010) explained the above growth classes using the semantic diagram depicted in Figure 2.2. He shows that different growth types happen over long periods, namely Time 1 and Time 2. Urban growth cannot be observed in a short period but over a long period and as many as three different types of urban growth can occur.

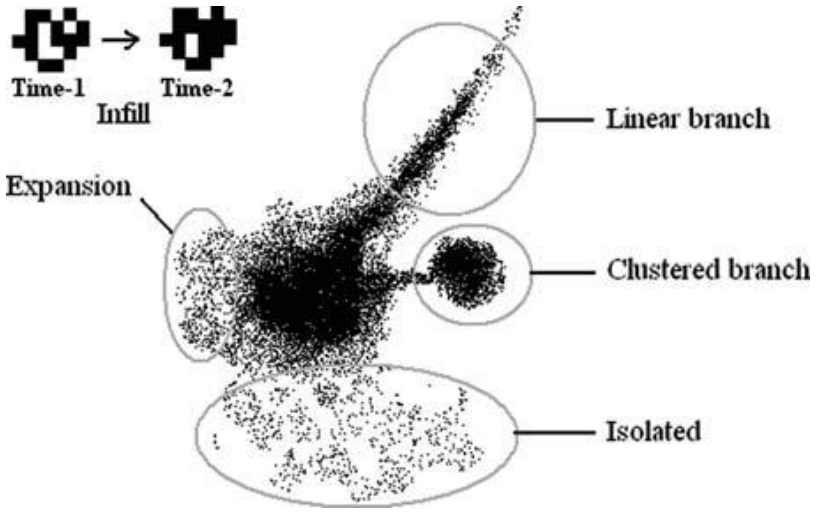

Figure 2.2 Schematic diagram of urban growth pattern
Source: Bhatta (2010, p.11)

As per Figure 2.2, urban growth has occurred during two periods (Time 1 and Time 2). Infill growth is the main growth type and it takes place within a built-up area. Expansion growth is centred around it and directly connected with existing built-up areas whereas the outlying growth occurs separately from existing built-up areas. It can be further divided into isolated, linear branch, and clustered branch growth. Harvey and Clark (1965) had earlier identified the three major forms of urban growth as low-density continuous development, ribbon development, and leapfrog development. These can be regarded as expansion growth, linear branch

growth, and clustered (or isolated) branch growth respectively, as defined by Wilson et al. (2003). Angel et al. (2007) also identified the three basic forms of urban growth as, secondary urban centre development, ribbon development, and scattered development. In addition, physical expansion could spread along roads or development corridors, in a star shaped, linear, or circular pattern, and in an orderly or disorderly manner.

Measuring urban expansion in a meaningful way is a difficult task because of the paucity of reliable data. The average density of population is one of the measurements used, but if the average urban density were derived by dividing the population by the administrative area defined by official boundaries then it could possibly lead to misleading data. Population density is the most reliable indicator of population distribution and this information can be accessed easily because the population density map illustrates the exact locations where population is concentrated in a particular area. Census data are often used to create population density maps but since these data are based on census units they may not be appropriate for all studies. More often than not, arbitrary boundaries are used to delineate census units. Density functions based on areal census units are less accurate at capturing directional and local variations due to problems of aggregation. This measurement creates modifiable areal unit problems (Openshaw, 1984) and it would be a highly unreliable measurement, because actual figures would vary with the official definition. Absence of correct figures related to built-up areas of cities leads to errors when trying to calculate correct urban densities. Hence, this study seeks to calculate average density using the actual built-up area of the city in the denominator, rather than its official urban boundaries. Both average density and

average built-up area per person have now been derived using the classification of built-up and non-built up areas. Classification of urban built-up areas is a major task though because there is no universal guideline for this.

Physically, urban land can be classified according to land use and land cover. Land cover refers to the physical condition of the ground surface and land use refers to classification of the land based on how it is used. Kaiser et al. (1995) mentioned the land use classification system groups land into certain categories depending on use (activities, functions, and amounts) and land cover (vegetation and surface character) for the purpose of planning, analysing, and record keeping. Anderson (1976) described a land use classification system (Appendix 2) for remotely sensed data. The main feature of urban or urban built-up land, which is a component under Anderson's classification system, is the area of intensive use where much of the land is covered by structures. This category includes cities, towns, ribbon developments along highways, transportation, power, and communications facilities. Areas such as those occupied by mills, shopping centres, industrial and commercial complexes, and other institutions that may in some instances be isolated from the urban areas. In addition, land subject to less intensive use, which may be located in the urban areas, is included in this category. However, agricultural land, forest land, wetland, and water bodies located in urban areas are excluded except where they are surrounded and dominated by urban development.

Table 2.1 summarises and further clarifies the categories of urban or built-up land uses mentioned by Anderson (1976).