UNIVERSITI PUTRA MALAYSIA

ANALYSIS AND MODELLING OF URBAN SPRAWL PROCESS AND ITS SPATIOTEMPORAL PATTERNS IN TRIPOLI METROPOLITAN AREA, LIBYA

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ABUBAKR ALBASHIR ABDULHADI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

December 2014

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DEDICATION

I dedicate this work to humanity, to my great nation, to my family,

and to the soul of Professor Dr. Jamalueddin Noorzaie.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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December 2014

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Urban development is a spatially dynamic phenomenon that indicates population increase, expansion of built-up areas, economic growth, increased importance level of cities, and so on. Urban expansion is characterized and affected by the interactions of many factors in time and space at various scales; for instance, political, economic, social, and cultural. In recent years, urban development in developing countries has been faster than that in developed countries. Hence, controlling the urbanization process and creating sustainable development in emerging countries require accurate information about urban expansion processes and their spatial patterns. Moreover, urban expansion (sprawl/growth) analysis using current and historical data is a necessary process in urban spatial studies and future urban planning. Tripoli metropolis, which has not been studied before, was chosen as the area in which to conduct this research, discover its urban sprawl patterns, and assess well-established urban modeling techniques in such North African city. Several data were used to conduct spatial analysis, modeling, and predictions for urban expansion such as Land-Sat image 1984, Land-Sat image 1996, Spot 5 image 2002, Spot 5 image 2010, road networks, population data, digital contour map, and topographic map. The general aim of this research is to spatiotemporally analyze, assess, and simulate the urban sprawl of Tripoli metropolis by using remotely sensed data through geographic information systems GIS. This study adopted several techniques to investigate, analyze, and assess urban sprawl as a process and as a pattern from different perspectives(such as overall urban development, urban expansion in each district, urban expansion direction, urban expansion in time periods and variations) to provide a comprehensive picture about urban expansion situations in the study area. The techniques used for urban sprawl detection and assessment were as follows: (1) Built-up area and population measures, (2) Comparison of observed and theoretical expected built-up area expansion,(3) Urban Expansion Intensity Index,(4) Shannon's entropy model, (5) Degree of freedom model, and (6) Landscape metrics. In the context of urban sprawl analysis, this research also presents a perspective that considers the effect of growth direction and distance from the central business district (CBD). To simulate the urban sprawl process and predict probable sprawl patterns in the future, several modeling approaches were applied, including (1) bivariate statistical model of Frequency Ratio (FR), (2) a novel bivariate statistical urban model of Evidential Belief Functions (EBF), (3) Multivariate Logistic Regression (LR) Model, and (4) Common Integrated Cellular Automata Markov Chain (CA-Markov) model. Furthermore, this study proposed a novel integrated

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hybrid model based on Multivariate Decision-Tree-based Chi-squared Automatic Interaction Detection (CHAID-DT), Markov Chain (MC), and Cellular Automata (CA) models. Results showed that the FR and EBF models provide good understanding of the role of every class within each individual urban driving factor in the urban sprawl progression process. The approach used in both models was based on net real urban expansion rather than on the whole built-up area, and it successfully reflected the urban sprawl behaviors and the dynamicity of the urbanization process. The overall influence of each urban driving factor affecting the sprawl in Tripoli was also effectively determined by the LR model. However, modeling results showed that the main drawback of the FR, EBF, and LR models is that they cannot determine exactly where the urban expansion will occur and its quantity. The common CA–Markov chain model predicted the future quantitative demand of urbanized areas and explicitly presented the spatial patterns of urban land-use changes, but it could not consider the urban driving factors. On the contrary, the novel hybrid model incorporated many urban driving factors, such as social, economic, and biophysical factors, and the modeling results clearly explained the interactions of urban factors and probable urban expansions. Moreover, the proposed integrated model overcame the shortcomings of each individual model. The well-known robust Relative Operating Characteristic (ROC) technique was used to validate all the generated probability maps. The validation results of ROC for the applied models of FR, EBF, LR, and CHAID-DT were 84.5%, 83.2%, 86%, and 94.9%, respectively. Kappa statistic index of agreement technique was also used to check the validity of the CA–Markov chain model and the proposed hybrid models in terms of quantity and location. The validation demonstrated the following accuracy levels: Kappa standard index of 0.8584, Kappa location index of 0.886, and Kappa no index of 0.881 for the CA–Markov chain model, while the novel hybrid models had a Kappa standard index of 0.8941, Kappa location index of 0.9227, and Kappa no index of 0.9110. Finally, this research provided a comprehensive spatiotemporal analysis and simulation of urban sprawl from different aspects in Tripoli metropolitan area, Libya. The techniques used and their outcomes provide a good understanding of urban sprawl in Tripoli and will enrich the literature on spatial urban studies as well as urban sprawl modeling and analysis. The proposed hybrid model shows robust behavior in urban simulation and a higher accuracy level than that of currently used models.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra
Malaysia sebagi memenuhi keperluan untuk ijazah Doktor Falsafah

ANALISIS DAN PEMODELAN TERHADAP PROSES BANDAR TERKAPAR DAN CORAK-CORAK SPATIOTEMPORALNYA DI TRIPOLI METROPOLITAN CITY, LIBYA

Oleh

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Pembangunan bandar adalah satu fenomena dinamik secara spatial yang menunjukkan peningkatan penduduk, pengembangan keluasan kawasan, pertumbuhan ekonomi, peningkatan tahap kepentingan bandar-bandar dan sebagainya. Perkembangan bandar dikategori dan dipengaruhi oleh interaksi-interaksi antara pelbagai faktor seperti masa dan ruang contohnya, politik, ekonomi , sosial, dan faktor budaya. Kebelakangan ini, pembangunan bandar di negara-negara membangun adalah lebih cepat berbanding negara-negara maju. Oleh itu, pengawalan proses perbandaran dan pengwujudan pembangunan mampan di negara-negara baru muncul memerlukan maklumat yang tepat mengenai proses-proses perkembangan bandar dan juga corak-corak spatialnya. Malahan, analisis perkembangan bandar (rebakan/pertumbuhan) dengan menggunakan data semasa dan data bersejarah adalah satu proses yang dikehendaki dalam kajian spatial bandar dan perancangan bandar berjangka panjang. Tripoli metropolis yang merupakan suatu kawasan yang belum dikaji sebelum ini telah dipilih sebagai kawasan untuk menjalankan kajian ini untuk menemui corak terkapar bandarnya dan juga menilai teknik-teknik pemodelan bandar yang mantap di bandar-bandar Afrika Utara. Beberapa bahan-bahan data telah digunakan untuk menjalankan analisis spatial, pemodelan, serta ramalan-ramalan untuk corak perkembangan bandar di kawasan Tripoli metropolitan. Data yang digunakan termasuk imej Landsat 1984, imej Landsat 1996, imej Spot 5 2002, imej Spot 5 2010, rangkaian jalan raya, data populasi, peta digital kontur, dan peta topografi. Tujuan kajian ini adalah untuk mengkaji, menilai, dan mensimulasikan bandar terkapar secara spatial dan temporal di Tripoli metropolis dengan menggunakan remotely sensed data melalui sistem maklumat geografi GIS. Kajian ini mengguna beberapa pendekatan untuk menyiasat, menganalisis, dan menilai rebakan bandar sebagai suatu proses dan sebagai corak dari perspektif yang berlainan serta menyediakan gambaran yang menyeluruh mengenai keadaan perkembangan bandar dalam tempoh masa yang berbeza di kawasan kajian ini. Teknik-teknik yang digunakan untuk pengesanan dan penilaian rebakan bandar adalah seperti berikut: (1) keluasan kawasan dan pengukuran populasi, (2) perbandingan antara permerhatian dan jangkaan secara teoritikal di perkembangan kawasan keluasan, (3) Indeks Intensiti Perkembangan Bandar, (4) model Shannon's entropy, (5) Degree of freedom model, dan (6) metrik Landskap. Dalam konteks analisis rebakan bandar, kajian ini juga menunjukkan perspektif yang mempertimbangkan kesan arah pertumbuhan dan jarak dari kawasan pusat perniagaan (CBD). Untuk mensimulasikan proses rebakan bandar dan meramalkan

corak jangkaan rebakan pada masa depan, beberapa pendekatan pemodelan telah digunakan, iaitu (1) bivariate statistical model of Frequency Ratio (FR), (2) a novel bivariate statistical urban model of Evidential Belief Functions (EBF), (3) Multivariate Logistic Regression (LR) Model, and (4) Common Integrated Cellular Automata Markov Chain (CA-Markov) model. Tambahan pula, kajian ini mencadangkan satu model hybrid bersepadu yang novel dengan berasaskan Multivariate Decision-Tree-based Chi-squared Automatic Interaction Detection (CHAID-DT), Markov Chain (MC) dan model-model Cellular Automata (CA). Keputusan menunjukkan model FR dan model EBF memberi pemahaman yang baik tentang faktor terhadap peranan setiap kelas dalam kalangan setiap individu menuju bandar dalam proses perkembangan rebakan bandar. Pendekatan yang digunakan dalam kedua-dua model ini adalah berdasarkan perkembangan bandar sebenar bersih tetapi bukan pada keseluruhan keluasan kawasan. Ia berjaya mencerminkan tingkah laku rebakan bandar dan dinamik proses pembandaran. Pengaruh secara keseluruhanan bagi setiap faktor pendorong bandar menjejaskan kepadatan di Tripoli dan ia juga ditentukan secara berkesan oleh model LR. Walau bagaimanapun, keputusan pemodelan menunjukkan bahawa kelemahan utama model FR, EBF, dan LR adalah model-model itu tidak boleh menentukan dengan tepat di mana perkembangan bandar akan berlaku dan juga kuantitinya. Model rantaian CA-Markov yang umum meramalkan permintaan kuantitatif masa depan di kawasan bandar dan memaparkan corak spatial perubahan penggunaan tanah di bandar dengan jelas, tetapi ia tidak diambil kira sebagai faktor pendorong bandar. Sebaliknya, model hibrid yang novel menggabungkan banyak faktor pendorong bandar, seperti faktor-faktor sosial, ekonomi, dan biofizik , serta keputusan pemodelan juga menjelaskan faktor interaksi bandar dan pengembangan-pengembangan bandar kemungkinan. Selain itu, model bersepadu yang dicadangkan mengatasi kelemahan bagi setiap model individu. Teknik Relative Operating Characterstic (ROC) yang terkenal telah digunakan untuk mengesahkan semua peta kebarangkalian yang dihasilkan. Keputusan pengesahan ROC untuk model-model FR, EBF , LR, dan CHAID -DT yang telah digunakan adalah 84.5%, 83.2 % , 86 %, dan 94.9 % masing-masing. Teknik perjanjian indeks Kappa statistik juga digunakan untuk menyemak kesahihan model rantaian CA- Markov dan model hibrid yang dicadangkan dari segi kuantiti dan lokasi. Penemuan pengesahan menunjukkan tahap ketepatan berikut: Indeks standard Kappa 0,8584 , indeks lokasi Kappa 0.886, dan indeks Kappa 0,881 bagi model rantaian CA- Markov, manakala model hibrid novel mempunyai indeks standard Kappa daripada 0,8941, lokasi Kappa indeks 0,9227, dan indeks Kappa 0,9110. Akhir sekali, kajian ini menyediakan analisis spatiotemporal yang komprehensif dan simulasi rebakan bandar dari aspek yang berbeza di kawasan Tripoli metropolitan, Libya. Teknik-teknik yang digunakan dan hasil-hasilnya memberi pemahaman yang baik terhadap bandar terkapar di Tripoli dan ia juga memperkayakan kesusasteraan bagi kajian bandar spatial serta pemodelan dan analisis rebakan bandar. Model hibrid yang dicadangkan menunjukkan tingkah laku yang teguh dalam simulasi bandar dan tahap ketepatan yang lebih tinggi berbanding dengan model-model yang kini digunakan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

CBD	Central Business District
FR	Frequency Ratio Model
EBF	Evidential Belief Functions Model
LR	Multivariate Logistic Regression Model
CA–Markov	Integrated Cellular Automata Markov Chain Model
CHAID-DT	Decision-Tree-Based Chi-Squared Automatic Interaction Detection Model
ROC	Relative Operating Characteristic Technique
RS	Remote Sensing
GIS	Geographic Information Systems
UPA	Urban Planning Agency, Libya
MAUP	Modifiable Areal Unit Problem
CLUE	Conversion of Land-use and its Effects
ABM	Agent-Based Model
ANN	Artificial Neural Network
UEII	Urban Expansion Intensity Index
ED	Edge Density
LPI	Largest Patch Index
SHAPE	Shape Index
LSI	Landscape Shape Index
PD	Patch Density
SIEI	Simpson's Evenness Index
MC	Markov Chain Model
CA	Cellular Automata Model

CHAPTER 1

INTRODUCTION

1.1   General

Cities or urban areas are the symbols of civilization and modernization. Urban expansions are considered one of the most important causative factors of environmental problems. Although the total quantity of urban land still covers a minimal percentage of the earth's land surface, the influence of the urbanization process on ecosystem fluxes, biodiversity, and environment quality are pervasive and profound. The urban development process also has various effects on the ecology of metropolises, such as fragmenting and destroying native habitats, generating anthropogenic pollutants, and changing local climate conditions.

A common feature among developing countries in the last century is rapid urban development. The rate of population growth in developing countries is unprecedented. Unfortunately, this population increase has evolved into a process unmatched by urban growth. To achieve sustainable urban development and planning, efficient urban land-use management and scientific understanding of urban expansion processes are critically required, especially in developing countries facing rapid sprawling urban growth processes and uncontrolled spatiotemporal urban patterns.

In the context of sustainable urban planning, one of the significant issues is how to simulate and predict the changes in land use and their spatial trends. The lack ofa clear understanding on the urban system under study leads to a degree of uncertainty because of several unknown and uninvolved urban factors, which makes predicting future urban expansions difficult. This uncertainty may result in serious urban development decisions. Hence, to understand the characteristics of any urban expansion system, its complexity, and its problems, the proper analysis and modeling techniques are necessary.

The great evolution in Geographic Information Systems (GIS) and Remote Sensing (RS) techniques has produced huge prospects, and significant achievement has been attained in monitoring and managing rapid urban expansions and their impact. Nonetheless, these techniques still need further development to support decision makers and urban planners. However, this research is focused on Tripoli metropolitan area, Libya, a capital which has not been studied yet.

Tripoli faced unexpected urban growth these past decades. Moreover, the implementation of urban plans in the area was affected by corruption, political situations, and economic conditions (UPA, 2009).These issues resulted in undesirable urban growth behaviors and complex situations. Hence, realistic assessment and modeling systems that can be used to explore, assess, and predict different spatiotemporal urban patterns are required. Furthermore, in related literature, no urban study has been performed to highlight and analyze the spatial patterns of Libyan cities. Therefore, understanding the driving forces and dynamics of the urban system and

evaluating the impact of urban growth on the environment are necessary in these regions. Generally, the present study analyzes, assesses, and identifies the spatiotemporal patterns of urban expansions in Tripoli and simulates the area's urban expansion process to understand its behaviors as well as to predict its future urban development.

1.2   Problem Statement

Despite the existence of government plans for urbanization, during the past decades, Tripoli underwent rapid urban expansion, and urban growth and development were spontaneous, uncontrolled, and haphazard. Moreover, the implementation of urban plans is affected by political situations, and economic conditions, resulting in urban expansions that depend on the trends of citizens regardless of the urban plans.

However, the main study area urban development requirement is housing, where demand is rising rapidly (representing 67% of the urbanized area in the past decade)with the total absence of governmental intervention based on reports by the Urban Planning Agency, Libya (UPA) in 2009.The main concern over urban expansion in Tripoli is the conversion of fertile and green lands and environmental reserve areas, which results in urban, socioeconomic, and physical problems. Hence, realistic spatial analysis and modeling systems that can be used to explore and assess the future of different regions are crucial to present clear and urgent assessments as well as to provide wise guidelines for future urban development. Lastly, no urban study has been performed before on such North African city. Therefore, understanding the driving forces and dynamics of urban systems and evaluating the environmental impact and patterns of urban growth are essential.

1.3   Research Objectives

1- To analyze, assess, and quantify urban sprawl in Tripoli metropolis city as a process and as a pattern during the period of 1984 to 2010 from different perspectives.

2- To evaluate the driving factors of the urban expansion process and measure their interactions as well as contributions in the formation of spatiotemporal patterns of urban growth and sprawl.

3- To simulate and predict probable urban trends and their spatial patterns by using appropriate models, evaluate and improve the performance of applied models, and suggest a new statistical model.

4- To propose a hybrid model that overcomes the shortcomings of other models, and to present a new vision of urban expansion modeling.

1.4   Scope of the Study and Limitations

This study aims only to investigate, analyze, and assess the spatiotemporal patterns of the urban expansion process from 1984 to 2010, and to predict future urban trends for the years 2020 and2025.Three classes of land use are considered for analysis and assessment in this research, namely, built-up area, non-built up (agriculture) area, and restricted area. For urban modeling and prediction,12 urban expansion factors are adopted as follows: distance to active economy centers, distance to central business districts (CBD), easting coordinate, northing coordinate, slope, restricted areas, distance

to nearest urbanized area, population density, distance to educational area, urban area, distance to roads, and distance to coastal area. The validation of results is limited to two techniques: Relative Operating Characteristic (ROC) and Kappa Statistic Index of Agreement. The urbanization process studied in this research considers only major spatial urban driving factors of urban expansion at macro scales. In this study, urban development is defined as physical change due to the conversion of non-built-up area to built-up area. Urban redevelopments and urban land use restructuring is not the concern of this research. Furthermore, this study limited to the horizontal dimension of urban development.

1.5   Thesis Organization

This thesis is organized into five chapters. The first chapter includes the introduction, which gives a brief description of the urbanization process, its analysis, its modeling, and its spatial impact. It also discusses the problem statement, objectives, and scope of the study. The second chapter covers the literature review and presents in-depth urban modeling theories, forms of urban expansion, definitions of urban growth and sprawl, and urban expansion modeling and assessments. The third chapter presents the materials used, study area, and models employed in analysis and simulations. The fourth chapter covers the results and discussions of the study. The fifth chapter concludes this thesis with a summary of the work and suggestions for future research.

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