SPATIOTEMPORAL MODEL FOR LANDSCAPE ECOLOGICAL ASSESSMENT IN LANDSCAPE PLANNING

WAN YUSRYZAL BIN WAN IBRAHIM

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Specially dedicated to all.

Al-Fatihah

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ABSTRACT

Ecological landscape area is rich with biodiversity and ecosystem are two important factors that balance the serenity of the environment through its ecological function and services. However, landscape change especially rapid urbanization has led to extensive land use and land cover (LULC) transformation that degrades the ecological landscape area and ecosystem services. The limitation of integration analysis in LULC change with ecological interaction has caused detrimental impact on natural landscape area and environmental quality. Analysing the spatiotemporal characteristics of landscape changes and ecological response in a multidisciplinary research is necessary to extend the understanding of spatial change behaviour and ecological consequences. Thus, the aim of this research is to study the integration of spatiotemporal dimension of landscape change with ecological landscape sensitivity consideration in Iskandar Malaysia region (Johor Bahru). The spatiotemporal dimension of historical and future LULC change is analysed to identify the direction and characteristics of the landscape structure and function change. Logistic regression model, analytical hierarchical process, markov chain model and cellular automata were used to identify the spatiotemporal LULC change in the study area. A series of landscape matrices in landscape index at class and landscape levels were used to analyse the spatiotemporal dimension of the landscape change pattern. It includes measurement of the ecological integrity and function responses towards spatiotemporal landscape change by using Core Area Model. Satellite images of 1994, 2000, 2007 and 2013 were used to understand the historical landscape changes and as a basis for future projection. Geographic Information System and Remote Sensing were utilized to evaluate the temporal landscape characteristics and spatial pattern changes. The results indicate that rapid urbanization of Iskandar Malaysia region from 2007 to 2013 has substantially changed the structure and function of the ecological area. The urban area significantly increased from 8,031.6 hectares (3.84%) in 1994 to 42,972.94 (20.1%) in 2013, and expected to increase to 112,224.6 hectares (53.59%) in 2030. As a consequence, the natural ecological areas reduced from 55,201.77 hectares (26.37%) in 1994 to 19,011.5 hectares (9.08%) in 2013. Due to the landscape mosaic change, the core ecological areas are affected from 21,465.9 hectares (38%) reduced to 9,317.61 hectares (49%) and expected to further reduce at 8,416.71 hectares (41%) in 1994, 2013 and 2030, respectively. It shows the response of ecological condition in natural landscape areas towards the landscape changes which subsequently disturb the ecological values and services. As a conclusion, the findings of this research could provide decision makers with better understanding on the environmental consequences of the landscape changes. In addition, it contributes to enhancement of methods in multidisciplinary research and finally increases the capability of the process in adaptive management for the spatiotemporal landscape change.

ABSTRAK

Kawasan landskap ekologi yang kaya dengan kepelbagaian biologi dan ekosistem adalah dua faktor penting untuk mengimbangi kedamaian alam sekitar melalui fungsi dan perkhidmatan ekologi. Walau bagaimanapun, perubahan landskap terutama proses pembandaran yang pesat telah membawa kepada perubahan penggunaan dan liputan tanah *(LULC)* yang besar dan merosakkan kawasan landskap ekologi dan perkhidmatan ekosistem. Keterbatasan analisis dalam mengintegrasikan analisis *LULC* dengan interaksi ekologi telah menyebabkan kesan buruk kepada kawasan landskap semulajadi dan kualiti alam sekitar. Analisis ciri-ciri perubahan reruang *(spatiotemporal)* landskap dan tindak balas ekologi dalam penyelidikan pelbagai disiplin adalah penting untuk memahami secara mendalam tentang corak perubahan reruang dan kesan kepada ekologi. Dengan itu, tujuan kajian ini adalah untuk mengintegrasi perubahan dimensi reruang landskap dengan pertimbangan sensitiviti landskap ekologi di dalam wilayah Iskandar Malaysia (Johor Bahru). Dimensi reruang terdahulu dan perubahan *LULC* masa depan dianalisis untuk mengenalpasti arah perubahan ciri-ciri struktur landskap dan perubahan fungsinya. *Logistic regression model, analytical heirarchical process (AHP), markov chain (MC)* dan *cellular automata (CA)* telah digunakan untuk mengenal pasti perubahan *LULC* di kawasan kajian. Satu siri landskap matrik di dalam indeks landskap di peringkat kelas dan landskap telah digunakan untuk menganalisis dimensi reruang bagi corak perubahan landskap tersebut. Ia termasuk pengukuran tindak balas integriti dan fungsi ekologi terhadap perubahan landskap reruang dengan menggunakan *Core Area Model*. Imej satelit pada tahun 1994, 2000, 2007 dan 2013 telah digunakan untuk memahami perubahan landskap terdahulu dan sebagai asas untuk unjuran perubahan pada masa depan. Sistem maklumat geografi *(GIS)* dan penderiaan jauh *(Remote Sensing)* telah digunakan untuk menilai perubahan ciri-ciri landskap dan corak perubahan reruang. Hasil kajian menunjukkan bahawa proses pembandaran pesat wilayah Iskandar Malaysia dari 2007 hingga 2013 telah mengubah struktur dan fungsi kawasan ekologi dengan ketara. Keluasan kawasan bandar meningkat dengan ketara daripada 8,031.6 hektar (3.84%) pada tahun 1994 kepada 42,972.94 (20.1%) pada tahun 2013 dan dijangka mencapai 112,224.6 hektar (53,59%) pada tahun 2030. Akibatnya kawasan landskap ekologi semulajadi telah berkurang daripada 55,201.77 (26.37%) pada tahun 1994 kepada 19,011.5 (9.08%) pada tahun 2013. Disebabkan oleh perubahan mozek landskap, kawasan teras ekologi semulajadi *(core area)* telah terjejas daripada 21,465.9 hektar (38%) berkurangan kepada 9,317.61 hektar (49%), dan akan terus berkurang kepada 8,416.71 hektar (41%) pada 1994, 2013 dan 2030 tersebut. Ia menunjukkan tindak balas keadaan ekologi bagi kawasan-kawasan landskap semulajadi terhadap perubahan persekitaran yang seterusnya mengganggu nilai-nilai dan perkhidmatan ekologi. Kesimpulannya, hasil kajian ini dapat menyediakan pemahaman yang lebih baik kepada pembuat keputusan mengenai kesan alam sekitar daripada perubahan landskap. Di samping itu, ia menyumbang kepada memperkukuhkan kaedah-kaedah penyelidikan yang melibatkan kepelbagaian disiplin dan akhirnya meningkatkan keupayaan proses penyesuian pengurusan untuk perubahan landskap reruang.

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AHP	-	Analytical Hierarchical Process
ARSM	-	Agensi Remote Sensing Malaysia
CA	-	Cellular Automata
CAI	-	Core Area Index
CBD	-	Central Business District
CDP	-	Comprehensive Development Plan
CPLAND	-	Core Area Percentage of Landscape
DEI	-	Depth of Edge Influence
DCAD	-	Disjunct Core Area Density (DCAD)
ED	-	Edge Density
ESA	-	Environmental Sensitive Area
GIS	-	Geographic Information System
IF	-	Inland Forest
IJI	-	Interspersion and Juxtaposition Index
IRDA	-	Iskandar Region Development Authority
LPI	-	Largest Patch Index
MBJB	-	Majlis Bandaraya Johor Bahru
MC	-	Markov Chain
MCA	-	Multi-criteria Analysis
MCE	-	Multi-criteria Evaluation
MPPG	-	Malis Perbandaran Pasir Gudang
MPJBT	-	Majlis Perbandaran Johor Bahru Tengah
MPS	-	Mean Patch Size
NCA	-	Number of Core Area
NP	-	Number of Patches
LULC	-	Land Use and Land Cover
PCM	-	Pairwise Comparison Method
PD	-	Patch Density

PLAND	-	Percentage of Landscape
PRD	-	Patch Richness Density
PSS	-	Planning Support System
RSO	-	Rectified Skewed Orthomorphic
SHDI	-	Shahnon's Diversity Index
SHEI	-	Shannon's Evenness Index
SHI	-	Shape Index
TCA	-	Total Core Area
LEA	-	Landscape Ecological Assessment
MAUT	-	MultiAttribute Theory
WF	-	Wetland Forest

CHAPTER 1

INTRODUCTION

1.0 Introduction

Landscape change is a spatial consequence that is the result of the complex dynamic land use change process and it is related to human activities, urban expansion and natural area loss. The dynamic land use and land cover (LULC) change for development is influenced by the rapid growth of the population as well as economic activities. The concentration of the population and economic activities in our urban areas creates demands for more land to be made available for development for new housing areas, commercial and industrial land, and public infrastructure. As a consequence, unexploited areas in and around urban areas are often likely to be converted into urban landscapes. The trade-off is a significant issue where many urban areas are expanding their boundaries and removing spaces that were previously open and natural landscape areas. In relation to the issue, the global urban population will increase in future with almost fifty percent of the world's population living in urban areas by 2025 (United Nation, 2009). Thus, urbanization will continue to modify the structure and function of natural landscape areas.

Our past experience shows that rapid landscape change has a significant negative impact on the environment. The environmental problems associated with the dynamic change of urbanization are biodiversity loss (Zhao *et al.,* 2005;

Matsushita *et al.*, 2006; Li *et al.*, 2010 and Nguyen, 2014), natural forest fragmentation (Abdullah and Nakagoshi, 2007; Li *et al.*, 2009), agriculture land loss (Pattanavibool and Derden, 2002; Gasparri *et al.*, 2009 and Su *et al.*, 2011), pollution (Nedeau *et al.*, 2003), microclimate degradation and ecosystem disturbance (Cumming *et al.*, 2012). From the perspective of ecological importance, land use and land cover change are deteriorating the ecological service and value at regional and local levels (Walters *et al.*, 2008). It is becoming increasingly difficult to ignore the issues of natural landscape degradation while urban development is in progress and degrading the serenity of our natural landscape.

The character of our natural landscape structure is related to the performance of ecological services (human's benefit) and values (ecosystem's benefit). The presence of the planet's natural areas provide ecosystem services and values, such as, carbon dioxide storage, stabilize microclimate, erosion protection, water catchment and, food resources and shelter for natural habitat (Tuan Vo *et al.*, 2012). However, natural area loss and fragmentation affect the structure of natural areas which consequently disrupt those ecological functions especially within the human dominated landscape area (Glennon and Kretser, 2013). Moreover, with rapid urbanization in the recent decades, a complex landscape mosaic between urban and natural land creates a more critical situation for the ecological landscape areas. The interaction between land use activities and natural landscape areas do not only represent a certain restructuring of the physical element of our natural landscape areas, it also affects the quality of core ecological areas in the remaining natural landscape patches. Natural areas adjacent to urban land uses are exposed to the edge effect and the depth of influence from complex external activities which subsequently reduce their core area through the deposition of species and the mortality of natural elements (Pattanavibool *et al.*, 2002 and Baker *et al.*, 2008).

Moreover, the fragmentation of natural areas reduces the size and connectivity of ecological zones and disturbs the meta-population process of species, prohibits energy transfer, instability of habitat, and increases competition in ecosystem (Hess and Fischer, 2001; Hersperger, 2006 and DeClerck, 2010). It is more critical because it impedes by the built up areas and could seriously deteriorate various ecological elements. As a result a certain depth of negative influence restructures the core ecological zone (Cancino, 2005 and Lee *et al.*, 2008) which will harm the sustainability of the ecosystem. It can be considered as having a hidden impact towards a complex landscape mosaic that is not easy to interpret with the limited knowledge about the ecological response resulting from human land use activities. The quality of ecological function as it relates to the natural landscape has been seriously highlighted in the past and some theoretical frameworks were developed to resolve this challenge. Nevertheless the integration of these two components is not a simple matter without the combination of good knowledge and tools in terms of the decision-making process (Jogman, 2002; Corry *et al.,* 2005; Mortberg *et al.,* 2007; Reino *et al.,* 2009 and Llausas *et al.,* 2012). While in the process of considering and dealing with the issue, the different levels of knowledge on spatial land use change behaviours and specific ecological responses tend to increase the knowledge gap.

Many studies have been conducted around the world that highlight the issues of fragmentation of natural landscape and highlight the awareness of the changing landscape as it relates to the urbanization issue and the resulting ecological effect it has in terms of the spatiotemporal changes. However, a limited number of past studies integrate the spatiotemporal landscape change with the ecological function analysis. They revealed the spatiotemporal aspect of the landscape structure change but not been completely adequate to integrate the ecological response in regard to the LULC activities. This is an important information to justify the serenity of the patches of natural landscape and the capability of ecological areas to sustain their service and value. The different levels of knowledge on spatial land use and land cover change behaviours with specific ecological response increase the gap in addressing and dealing with the issue. Thus, a further understanding of the ecological consequences of the land use and land cover change area remains an important issue in term of the landscape change.

The issues highlighted above and past research experienced shows an apparent gap on the subject of land use planning with ecological consideration and its effect. Issues on the natural landscape structure change with the quality of the natural landscape patches should be carried out holistically in terms of landscape planning. Structure, function and change are three of the important components in landscape ecology that must be integrated for any consideration in the urbanization process. Thus, this study is conducted to identify the approach and method to enhance the landscape ecological consideration by integrating spatiotemporal landscape change with an assessment of the ecological structure and function. While the ecological structure consequence refers to the natural landscape composition and configuration. Meanwhile the ecological function considers the natural landscape structure quality due to the interaction with its surrounding land use activities. The framework applied in this research is in response to the current environmental issues.

1.1 Research Background

Landscape can be defined as important resource components that consist of tangible (spatial elements) and intangible elements (human observer response) related to the characteristics of its spatial features (Sung *et al.*, 2001). Naveh (1995) and Jongman (2002) defined landscape resources as natural and cultural landscape components with regard to their interaction through economic condition, technical and social aspects, planning and policy. Based on this, it shows the changes of the global spatial dimension are highly related to the interaction and response between the natural landscape resource and spatial human development. The exploitation and degradation of ecological areas are part of the development process that restructures the physical form of the natural landscape areas. However, the ecological elements have been neglected as part of the ecosystem in development where most of the urbanization studies only consider the natural landscape structure dimension without having an understanding of their deteriorated functions (Rafiee *et al.,* 2009 and Stoate *et al.,* 2009).

Rapid urban development is growing and there is no sign of slowing down especially in the developing countries. It is becoming one of the most significant current discussions globally due to its impact towards landscape change and the resulting environmental degradation. On a global basis, almost 1.2 million kilometres square of forest and woodland, and 5.6 million kilometres square of grassland and pasture have been converted to other uses (Prato, 2005). This is followed by the expansion of agricultural land that removed one part of the natural forest area in the world (Jongman, 2002) and reduced the diversity of natural landscapes; biotopes have either disappeared or have been isolated (Vuillemuire and Droux, 2002) with loss of heterogeneity (Gurrutxaga *et al.*, 2010). Wilderness areas have been encroached and river channels have been altered, and represent significant changes in terms of the important agriculture land and loss of forest areas that are rich with ecological services and values. The uncontrolled development and lack of consideration of the ecological importance of the development in the past have significantly caused a series of environmental problems, such as, the appearance of urban heat island, the altering of the hydrological characteristic, limited on carbon dioxide absorption, and the reduction of biodiversity which impacted on the ecological structure, function and dynamics (Han, 2009 and Yang *et al.*, 2011). In addition, it is expected that the urban population will be about 3.8 billion and predicted to reach 5.0 billion in 2030 (United Nation, 2009). The massive expansion of urban areas in the future will result in a tremendous change of the landscape structure and the function of the ecological areas (Jongman, 2007; Solon, 2009; Gurruxtaga *et al.*, 2010 and Vimal *et al.*, 2012).

The issues have been brought to the forefront in terms of the status of the current approaches with respect to understanding and awareness the ecological response in landscape change. The current decision- making process seems difficult to consider holistically in regard to the ecological response that result from the spatiotemporal landscape change interaction. The development of such model is one of the most important challenges as the urban areas are growing and restructuring the natural ecological areas. The limitation of the authority and platform for an ecologist to contribute in the decision planning process also creates a significant gap of understanding the ecological consequences related to landscape change. The stability and quality of ecological patches are neglected as it is challenging and difficult to measure in the development process and eventually the output plan negatively affects the natural landscape areas (Gattie *et al.*, 2007). The complex relationships between the dynamic land use change and ecological stability pose another question regarding how a different understanding of the various disciplines can be integrated along with the decision making process (Hazell *et al.*, 2000 and Musacchio *et al.*, 2005).

The interaction between land use planning and the ecological response becomes an obvious conflict since both disciplines present different levels of study. In land use planning exercise, while it is normally conducted at the macro-scale, an ecological study focuses on the specific habitat and site. Different perceptions on ecological areas and difficulty in translating the different techniques to a standard approach cause a conflict to achieve the integration (de Koning *et al.*, 2007 and Bishop, 2011). The landscape ecology however attempts to close the gap between ecological sustainability and urban landscape change, and serves to link the detailed characteristics of both components with the landscape changes. Nevertheless, since most of the past studies focus only on the effect of the structure of the natural landscape, it is difficult to describe the quality of the ecological function in response to change in the urban landscape. Specifically, the edge effect from the surrounding land use activities and the stability of the core ecological area in the remaining natural landscape areas have not been thoroughly considered in previous landscape change studies.

The shortcomings of the existing approach in terms of sustainable landscape planning attract the attention of and require decision makers to identify an achievable method. In order to maintain the ecological importance of the natural landscape, the modeling and enhancement of the approach ought to be considered in the landscape planning. This study is conducted to identify the approach and model to integrate the change of the landscape more in alignment to respond to the ecological aspect. It considers several spatial dimensions of the natural landscape structure change, such as, patch quality, patch context, boundaries, connectivity and landscape mosaic (land use activities in the surrounding area). Furthermore, the study evaluates the serenity and stability of the fragmented natural landscape areas by considering the composition and configuration of the landscape pattern. Landscape mosaic it also considers the relationship between the composition and configuration of the landscape pattern. This involves integrating the knowledge from the perspective of different disciplines and associating the knowledge into a standard platform. This is for the purpose of extending a more in-depth understanding of the landscape change scenario.

1.2 Problem Statement

In regard to the degradation of the natural landscape as temporal landscape change there is increasing concern that it has transformed the spatial patterns which has had an influence on the ecology and biological structure. Fragmentation, homogenization and the shrinking size of the natural areas are consequences from spatiotemporal LULC change particularly for urban development and agriculture expansion. Although many landscape change research studies have been conducted in the past it is difficult to understand of the ecological response due to the limited knowledge and approach (Sun *et al.*, 2012). In fact, past studies of landscape ecology have mostly focused on the impact of urban development and evaluate the static pattern of the consequences related to the natural landscape (landscape structure; composition and configuration). However, the ecological function degradation due the natural landscape structure change is been difficult to translate. The impact is apparent to the ecologist however it is difficult to explain to professionals of other disciplines, for example, designers or land use planners. Thus, in the process of urban development, attention to ecological sensitivity is not always given serious consideration.

The existing applications have limitations to incorporate ecological stability assessment in land use plan development such as the existing landscape planning and ecological assessment applications. The spatial cohesion of dynamic urban landscape change is difficult to translate the ecological responses (Ferreira *et al.*, 2013). Although many studies have successfully simulated the potential of future urban development and landscape changes, for example spatiotemporal urban landscape studies in Rome (Frondoni *et al.*, 2011), Wisconsin (Weng, 2007), North Carolina (Kirk *et al.*, 2012) and Shenzhen (Li and Yang, 2015), in the spatial changes of structure and function of the natural landscape present another topic for research. The interaction between the ecological responses of the LULC cover change is challenging to integrate in a similar platform. This is because the areas that remain fragmented natural landscape areas face immense pressure to sustain their quality whilst urban areas continue to expand their boundaries.

Then, poor consideration regarding the sensitivity of the ecological area in the landscape change leads to the degradation of the ecological value. Most of the current spatial planning applications only consider the natural landscape areas as a descriptive data without taking into account the biodiversity assets (Huang *et al.*, 2009; Li, *et al.*, 2010 and Miras *et al.*, 2014). The consideration of the urban expansion along with ecological sensitivity must be on a similar platform and requires the development of a better model. This main issue defines a requirement for the identification of the platform particularly engaging with the multidisciplinary expertise in the landscape change study. Any limitation in analyzing the ecological function in relation to its structure characteristics impairs the stability of the ecological area and consequently disturbs the quality thereof (Paudel and Yuan, 2012). Thus, consideration of the ecological function with structure characteristics is necessary to improve on the understanding of the ecological sensitivity and maintain their quality.

Ecological sensitivity and quality assessment in landscape change study requires an integrated model as a tool for holistic landscape change. Yet there is a gap between the methods and techniques in land use change analysis and ecological assessment where the parameter and measurement techniques are at different levels and it is difficult to support the holistic assessment of spatiotemporal landscape change and ecological response (Yue *et al.*, 2011 and He *et al.*, 2011). Moreover, the existing methods in ecological modeling are too specific and difficult to combine with other models especially at the landscape level (Table 3.2, Section 3.2.1). The probability of parameter and technique needs to be identified and should focus on how the ecological function assessment could fit in with a landscape change interaction study. This issue ought to be considered taking into account several technical aspects, such as, the spatial data integration, the accumulation of the input of experts, and the appropriate medium of analysis for output presentation.

Furthermore, landscape change is a dynamic process of human-driven land use change that requires continuity assessment in regard to the way it works. Temporal interpretation is essential for a better understanding of the planning and management of future landscape change (Giam *et al.,* 2010). It is a powerful method that visualizes the characteristic of landscape change where historical experiences and future landscape scenarios are important to explain the quality status of natural landscape areas. Nevertheless, there is a dearth of knowledge to explain the rules and variables involved in landscape change and ecological response (Vreese *et al.,* 2016). Thus, the identification of the rules and variables is investigated in spatiotemporal landscape change and is outlined to predict the landscape change scenario.

The problem statements above form the direction for the research that attempts to improve spatiotemporal landscape change assessment. For this reason, the motivation for the study is to develop a method that incorporates urban development study with ecological structure and function assessment in order to extend an understanding of ecological stability and quality in dynamic landscape change. The effort of this research coupled with individual based analysis in a new platform comprises a different input knowledge. It is believed that the study will bridge the gap of LULC change with ecological interaction for the enhancement of the tool in consideration of the landscape change.

1.3 Research Questions

The problem statements highlighted above raise several research questions which reflect the approach and method involved in this research. The research questions are listed as follows:

i. Which are the best measurements and indicators to evaluate the natural ecological landscape interaction and stability besides the natural landscape pattern analysis in spatiotemporal landscape change?
ii. How to develop the approach and method in visualizing the temporal changes of ecological landscape to achieve a better interpretation and understanding?

iii. What data are required and how might the database design be established to support the spatial dynamic modeling of land use and land cover change analysis and ecological sensitivity assessment?
iv. What is the best platform for the landscape planning study that integrates the various multidisciplinary experts in regard to land use change interaction with ecological consequence?

1.4 Research Aim and Objectives

The aim of this study is to develop spatiotemporal landscape change model that integrates the assessment of the interaction between the spatiotemporal landscape change characteristics with ecological function.

Objectives:

i. To design and establish a spatial dynamic model that incorporates both dynamic landscape change and ecological interaction
ii. To identify the approach, technique and parameters that can be engaged for the integration of the landscape change model
iii. To define the rules and variables involved in the spatial dynamic modelling of the landscape change and ecological function assessment
iv. To formulate the database design and structure to support the parameters and techniques employed in the analysis of the spatiotemporal landscape change with deliberation of the ecological elements

1.5 Significance of Research

This research improves the understanding of spatiotemporal LULC landscape change with ecological area interaction. The visualization of the spatiotemporal landscape pattern and further assessment on the quality of ecological patches are important for adaptive management in landscape planning. The size, shape, connectivity, composition and configuration of the natural landscape scenario within the development area reveal the quality of the ecological aspect in the environment. The information then provides a better understanding of the ability of the fragmented natural areas as it relates to sustaining their services and values.

In addition, this research attempts to connect one of the important theoretical parts in landscape ecology. It instills ecological area function stability assessment through statistical analysis and expert knowledge in both ecology and land use planning. The method and technique used in this research are complementary to each other in order to strengthen the urban change analysis and ecological evaluation. This spatiotemporal landscape change with ecological function analysis is a time series assessment that improves the landscape planning method in adaptive management.

On the technical aspect, this research enriches the ability of spatial modeling by deploying the integration of GIS and Remote Sensing with related techniques that contribute to more intelligent application in landscape change analysis. Information technology used in this research provides a good basis for environmental modeling that can be implemented and upgraded for other environmental applications. Overall the study demonstrates and shows how important and significant of model development, information technology integration and ecological approach enhancement.

1.6 Scope of Research

Several aspects are considered in this research, such as, the level of the attributed detail in urban and ecological landscape change, the involvement of expertise, and the scale of spatiotemporal dimension. This study focuses on the spatiotemporal landscape change as it highlights the LULC change, such as, built up areas, bare soil, agriculture land, water body, and natural forest areas that are divided into forest land and wetland area. Those spatial elements temporally represent the characteristics of landscape pattern in the study area.

The second aspect considered in this research is input from experts on the elements of urban landscape change and ecological sensitivity. The input contributes to the analysis for projecting future landscape change and ecological response. The input in the ecological aspect is transformed at the same level of the urban landscape change environment. With respect to the ecological aspect, this research collects ideas from the experts about the interaction of natural landscape with other land use activities. In this study, edge effect evaluation and core ecological zone determination are utilised and are based on the input from the experts.

On a spatial and time scale, this spatiotemporal landscape change study includes historical experience and future LULC. The selected durations for landscape change assessment are related to policy evolution in the study area. It refers to significant milestones of development policy in the past and in the projection of future landscape change that is based on the prospect of future development. The result of simulation indicates the spatial character of urban development behaviour and the ecological consequences of the landscape as they relate to the existing development policy.

The scope of this study fosters the ability of this research to be conducted in order to increase the understanding of ecological impact in landscape changes. The method used in this research could be a platform in order to extend knowledge for better landscape planning.

1.7 Research Outline

This study comprises several stages which involve various sub-activities in each stage. It includes the identification of the research framework, the model selection and development, the database design and development, the data analysis and recommendations. The outline of the overall process in this study is identified and illustrated in Figure 1.1.

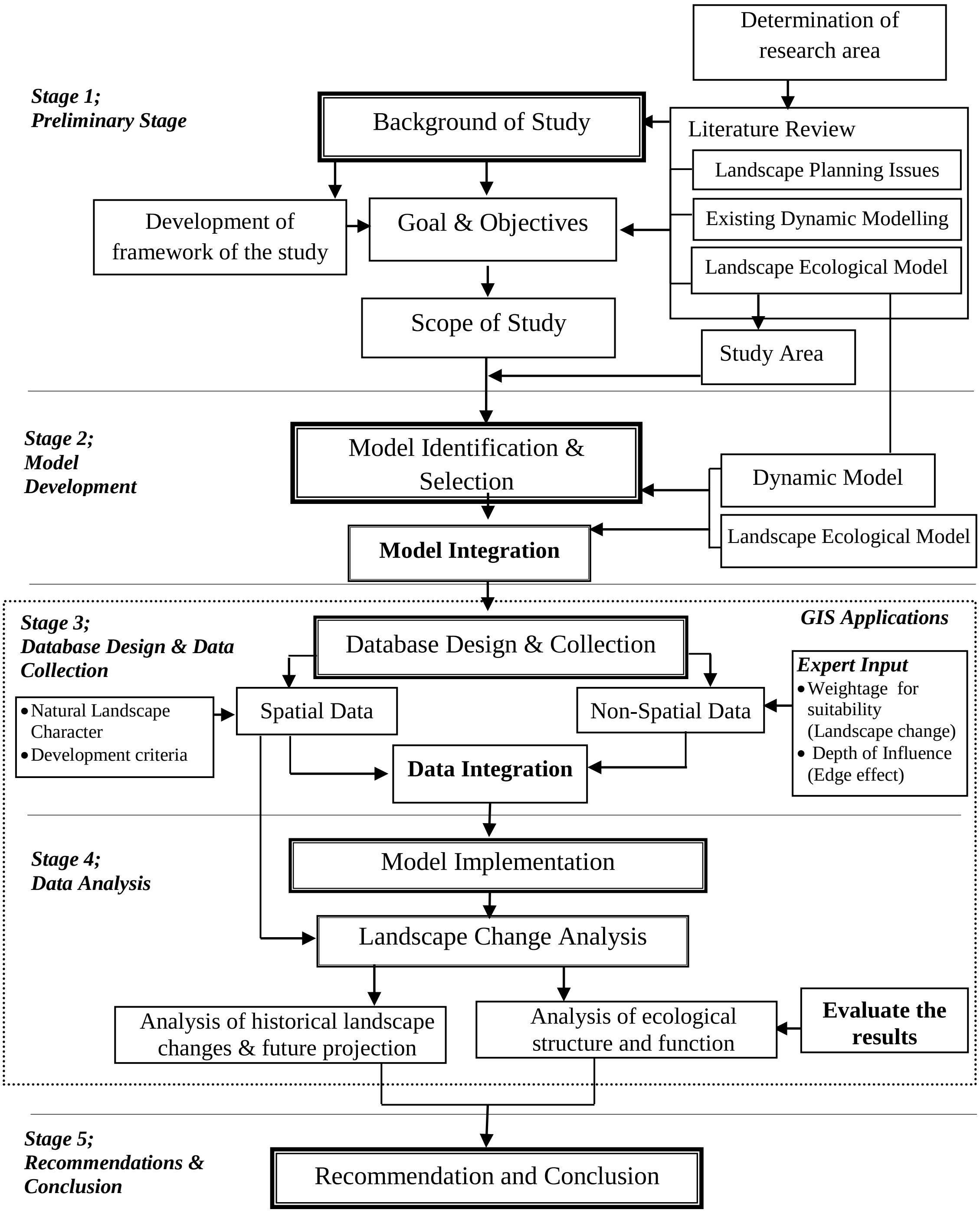

Figure 1.1: The study process

Stage 1 - Preliminary Stage, Finalizing Framework

The first stage of the study focuses on the current situation of landscape change underpinning the theory of sustainable development and landscape ecological assessment. The trend of the urbanization process with ecological impact consideration is analysed to identify the limitation of current applications in landscape change studies. The existing approaches and methods used in ecological modelling are reviewed in relation to the landscape ecological structure and function change due to the interaction with the urban development. The identification of approaches to evaluate the relationship between ecological elements and other land use interaction is conducted to define the possibility of future integration in landscape change study. A comprehensive review based on referred journal, articles, theses, development plan documentation, government publication and books forms the idea of the research and supports the development of the goal and the objectives of the study.

Stage 2 - Model identification and integration

An analysis of the approaches and methods that are currently available, that have been applied in landscape change and landscape ecology studies in the past serves to highlight an approach that could be possibly be used in the integrated landscape change study. Specifically, the methodologies used in past studies are evaluated by taking into account their capabilities in managing multidisciplinary input and spatiotemporal landscape change. The advantages and disadvantages of previous methods and techniques are analysed that refer to the landscape ecological consideration in landscape change study. Although various methods have been used in land use planning and ecology assessment, it is a challenge to identify the possibility to integrate them in the dynamic process of urbanization and ecological quality assessment.

Nevertheless, several models are selected based on the requirement of the research, such as, Cellular Automata (CA), Logistic Regression, Markov Chain and Analytical Hierarchical Process (AHP) for the landscape change study. Meanwhile landscape ecological assessment employs the landscape index as a tool to analyse the ecological structure and function in landscape change. There are several sub-models involved to analyse the ecological landscape structure change in terms of composition and configuration as well as ecological patches response due to the interaction with the surrounding land use. The quality of the ecological patches is evaluated utilising the Core Area Model that considers the edge effect of the surrounding land use activity. This model is useful to define the quality of remaining fragmented natural landscape areas within other land uses and land covers.

Those models are considered based on their capabilities in the integration with the spatial appearance of the landscape change analysis. Further, the data format is determined and designed to fit the models used in this study. GIS and Remote Sensing are the main tools utilized in this study and all of the data is transformed into their environments. The types and levels of the spatial and non-spatial data are identified in regard to the requirement of the models and research objectives.

Stage 3: Database design and collection

The next step of the study is designing the database for the spatial and non-spatial data. The design of the database is referred to as the requirement of the selected models used and the level of ecological consideration in this study. LULC maps are the main data where the input is derived from a series of satellite images to show the extent of landscape changes. Spatial topographic data is another important component that is used in the analysis and it would be in a standard spatial geo-reference and time period. The collection and development of the spatial data mostly from secondary sources, such as, the Department of Town and Country Planning, the local authorities and the Agencies of Remote Sensing Malaysia (ARSM). Some of the data should be updated and validated in order to increase the accuracy of the data and ensure it suits the requirement of the analysis models. While the Erdas Imagine software is used for processing the satellite images, ArcGIS 10.2 is utilized to analyse other geophysical data.

Since expert input is another component of the data that is important to support the models, therefore a questionnaire is prepared to acquire the input (Chapter 5, Appendix E and Appendix F). That input emphasizes the suitability and probability analysis of future urban growth areas where the projection of landscape changes is guided by their opinion. At the same time, the experts deliberate on the ecological impact of natural landscape areas in relation to the implication of the interaction between the urban landscape change and ecological sensitivity. This input is an important input because experts describe the depth of the influence of the ecological patches within the complex landscape mosaic. This input is normalized to ascertain a standard value of edge effect which is finally used to assess the quality of natural areas through the core ecological area. This is the loose-coupling method that is used within the GIS environment in this research.

Stage 4: Model Implementation and Data Analysis

At this stage, there are three major analytical processes involved in this study where the established model is implemented in regard to the case study area. The preliminary stage explores the trend of historical landscape change in the study area. The urban expansion pattern and natural landscape area degradation are analysed from 1994 to 2013. Furthermore, the degree of influence of spatial variables involved in the past landscape change is measured through the logistic regression model. The analysis highlights and ranks the criteria that have had a strong influence on the past changes. The historical experiences will serve as a basis for the next stage of the analysis to project the probability of future landscape change in the study area.

The following analysis extends the previous results to predict the future landscape change. Based on the logistic regression results, input from experts then consider strengthening the model of suitability analysis to define the suitability land for future urban land development. The Analytical Hierarchical Process (AHP) identifies the weightage for all significant variables in preparing the suitability map. The Pairwise Comparison Method is used in AHP and the Expert Choice software is used to run the model. At the similar stage, the probability of future changes is identified through the Markov Chain model. The historical experience in each period is set up as a basis for the future projection of the landscape change. The simulation projects the probability of landscape changes in 2020, 2025 and 2030 by using the appropriate historical path. The interpolation of future spatial characteristics is translated using the Cellular Automata model.

In the final part of the analysis, the composition and configuration of the natural landscape area changes are measured using the selected landscape index. Several landscape matrices are utilised to evaluate the condition of natural landscape areas at class and landscape levels. The analysis focuses on the landscape ecological structure changes along the study period. The result shows the loss and fragmentation pattern of the natural landscape due to the spatiotemporal landscape changes in the study area. Moreover, the ecological stability of the remaining natural areas is evaluated based on the landscape structure, mosaic and edge effect from the adjacent land use activities. The edge effect from the surrounding land use activities towards natural areas is considered to delineate the ecological core zone in the natural areas. Input from experts on the depth of influence determines the quality function of ecological elements in the natural landscape areas. The FRAGSTATS software is used to run the analysis and the indexes indicate the condition of natural landscape structure and function within the dynamic landscape changes. The outcome of the analysis is discussed further in relation to LULC change pattern and ecological area consequences. The interpretation of the results emphasizes several aspects of land use planning, policy evolution and the most important aspects in landscape ecology.

Stage 5: Recommendation and Conclusion

Finally, as part of the contribution of the study, the recommendation for the application of this model is stated to enhance future landscape change studies with concern on the ecological elements. The recommendation also includes suggestions for improvement of the model for better application in future research. It could enhance better knowledge integration particularly in the process of analyzing a complex dynamic landscape change.

1.8 Thesis Organization

This thesis consists of seven chapters. The first chapter addresses the background of the study and highlights the issue of landscape change and ecological interaction. It describes the direction and focus of the research through the development of the goal and objectives of the study. The significance of the study is emphasized in this chapter and then the strategy to conduct the study follows.

The next chapter, Chapter 2 discusses the related literature about LULC change in urbanization studies as well as the landscape ecology approach and assessment in landscape change applications. Issues on past landscape change studies are highlighted and critiqued via the underpinning theories of landscape planning and landscape ecology. Then, the existing approaches, methods and techniques are discussed in Chapter 3 with regard to the spatiotemporal landscape change behaviors. Likewise, the discussion on the role of information technology in particular the geographic information system in spatial modeling is highlighted. It is the approach that is used in simulating landscape change in the study area. The established models and techniques with their spatial capabilities are deliberated upon towards the possibility of integration in the landscape change and ecological assessment. All the process involved is determined by formulating the framework of the study. At the end, this chapter formulates the concept and approach used in this study.

The Chapter 4 then discusses the methodology of the research. The development of the framework of the study is explained in the early part of the chapter. This is followed by an explanation of the detailed process involved in the study. Every single process is discussed starting from the data preparation to the analysis stage. The integration of the spatial and non-spatial data is displayed in the data preparation process and in the analysis stage. It is followed by the sequence of analysis processes in landscape change simulation and landscape ecology consideration.

Chapter 5 discusses the first part of the analysis in this study where it explains the implementation of the spatial dynamic model in landscape change at the study area. Every output within this stage is discussed in order to clarify the spatiotemporal landscape change behaviors. The relationship of variables with the historical landscape change is highlighted as a basis to support input from experts in the preparation of suitability areas for future landscape change. Apart from that, further discussion on the result of the probability of future landscape changes shows the future character landscape change. It relates to the selected rules from the historical experience. The patterns of future landscape changes are visualized in this chapter particularly the landscape ecological area changes.

Meanwhile, the discussion in Chapter 6 focuses on the landscape ecological consequences due to the landscape changes in the past periods and future projection. The discussion emphasizes the landscape ecology structure and function changes. The composition and configuration of the natural landscape changes are justified and then related with the ecological function situation. It reveals the scenarios of the landscape ecological situation for the entire study period through spatial visualization. Graphs and statistical tables support the information of landscape ecological change behavior in the study.

A comprehensive discussion in Chapter 7 deliberates the output from Chapter 5 and Chapter 6 towards improving the landscape change analysis. It relates to achieving the goal of the research and the objectives wherein the landscape ecological function is now highly considered in dynamic landscape change. Furthermore, the results of the study are linked to the implication of policy changes in the study area. It reveals detailed aspects of the ecological consequences from rapid urban development not considered before. This final chapter then synthesizes the findings of the entire study by discussing the achievements of the study approach, the methodology applied and the techniques used in this study. The advantages and disadvantages of the spatial modeling in this research are deliberated upon excluding the limitations of the study. At the end, the chapter suggests possible future research that could be conducted by applying the spatial dynamic modeling method from this study along with improvements.

Decision makers are confronted with many issues in landscape change as demand for spatial development are increasing and reducing significant ecological areas. Even though there are theoretical frameworks that have been established, it seems that due to the limitation of knowledge and technical support it hinders a better comprehensive decision that could be made. It is vitally important that information on the phenomena in regard to the urbanization and ecological impacts be understood at all levels of the decision-making process. And the prediction in regard to the probability concerning the way it happens must be considered by decision makers in landscape planning. It requires advance technology from information system and the appropriate spatial modelling to manage, organise and address the issues. Thus, this research explores the use of spatial modelling in the LULC change with better landscape ecological assessment. It is hoped that the significance of this study will be able to improve the decision-making process in landscape planning and consequently enable it to sustain ecological values and services in the environment.

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