UNIVERSITI PUTRA MALAYSIA

LAND SUITABILITY EVALUATION FOR RUBBER IN GIS PLATFORM AND MULTICRITERIA DECISION-BASED MODEL

GOMA BEDAWI AHMED ALSALHIN

LAND SUITABILITY EVALUATION FOR RUBBER IN GIS PLATFORM AND MULTICRITERIA DECISION-BASED MODEL

By

GOMA BEDAWI AHMED ALSALHIN

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

March 2018

DEDICATION

I dedicate this thesis to my family, and to all the people that contributed toward the successful completion of my PhD programme.

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

LAND SUITABILITY EVALUATION FOR RUBBER IN GIS PLATFORM AND MULTICRITERIA DECISION-BASED MODEL

By

GOMA BEDAWI AHMED ALSALHIN

March 2018

Chairman : Professor Abdul Rashid Mohamed Shariff, PhD
Faculty : Engineering

To sustain the growing population and the competitive demand for land, there is the need to develop optimal land evaluation approach to identify suitable locations for rubber crop that can provide high yield. Proper match of land quality requirements, crop growth and land capabilities will allow achieving maximum yield, and eventually high economic returns. The aim of this study is to develop a land suitability evaluation model to identify optimal locations for rubber farming using Geographic Information System (GIS) and Multi-Criteria Decision Method (MCDM).The land suitability assessment is based on FAO (Food and Agriculture Organization) framework of 1976; with some modifications to comply with the Malaysian rubber crop land specifications. The model is based on a classification structure rather than a set of guidelines provided in the FAO framework. Land characteristics, grouped into nine land qualities and their threshold values were considered using datasets (soil type, soil productivity and drainage, rainfall data, elevation and slope) obtained from different national agencies. Each of the data with their associated sub-criteria represents input layer integrated into GIS environment and analyzed using multi-criteria decision making (MCDM) technique. Weighting factors for the input layers were determined based on expert opinions through analysis of the feedback from the questionnaire administered to the experts at the Malaysian Rubber Board (MRB). The result is a model, rubber land suitability evaluation model (RLSEM), that produces rubber land suitability map of Seremban district, an administrative unit in Negeri Sembilan, Peninsular Malaysia. Performance and fitness analysis of the model shows that the model is sensitive to detecting suitable and non-suitable land for rubber cultivation with sensitivity and specificity values of 84.14% and 76% respectively. Overall, assessment of the detection accuracy using the area under the ROC curve yielded (80%) and p-value <0.0001. For performance evaluation using regression models, the corrected Akaike's information criteria agrees at both the global ordinary least square (OLS) model and local geographically weighted regression (GWR) model with AICc of 521. Also, the adjusted R^2 measures of both the OLS and GWR models produced

the same value, 0.802811. Correlation of the generated and the predicted land suitability models shows high positive relationship with correlation coefficient of 0.99. This implies that the land suitability model developed remained consistent from global to local model. Quantitatively, a total of 35575 hectares, distributed among the three suitability classes: highly suitable 45% (16048 hectares), moderately suitable 43% (15399 hectares), and marginally suitable 12% (4128 hectares) was obtained. Based on the World Bank monthly rubber market price projection at national level of 1.858 USD per kilogram for the month of June 2017 (for Singapore/Malaysia), it is estimated that ~28.9 million USD can be generated annually, if the available suitable land is put to use.

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

PENILAIAN KESESUAIAN TANAH BAGI TANAMAN GETAH MENGGUNAKAN PLATFORM GIS DAN MODEL BERASASKAN KEPUTUSAN PELBAGAI KRITERIA

Oleh

GOMA BEDAWI AHMED ALSALHIN

Mac 2018

Pengerusi : Profesor Abdul Rashid Mohamed Shariff, PhD
Fakulti : Kejuruteraan

Untuk melestarikan populasi yang kian bertambah dan tuntutan tanah yang berdayasaing, terdapat keperluan untuk membangunkan pendekatan penilaian tanah yang optima untuk mengenalpasti lokasi-lokasi yang sesuai untuk menanam getah dan seterusnya memberi hasil yang banyak. Padanan sempurna keperluan kualiti tanah, pertumbuhan tanaman dan kemampuan tanah Akan membenarkan pencapaian hasil yang maksima, dan lama-kelamaan memberikan pulangan ekonomi yang tinggi. Tujuan kajian ini adalah untuk membangunkan satu model kesesuaian tanah dalam mengenalpasti lokasi yang sesuai untuk penanaman tanah menggunakan Sistem Maklumat Geografi (GIS) dan Metod Keputusan Pelbagai Kriteria (MCDM). Penilaian kesesuaian tanah adalah berdasarkan kepada kerangka kerja FAO (Organisasi Makanan dan Pertanian) tahun 1976; dengan beberapa pengubahsuaian mengikut spesifikasi tanah getah Malaysia. Model tersebut adalah berdasarkan kepada struktur klasifikasi dan bukan kepada satu set garis panduan yang disediakan dalam kerangka kerja FAO. Ciri-ciri tanah, dikelaskan mengikut sembilan jenis kualiti tanah dan nilai ambang dipertimbangkan menggunakan set-set data (jenis tanah, produktiviti tanah dan perparitan, data taburan hujan, ketinggian dan kecerunan) diperolehi daripada pelbagai agensi kebangsaan. Setiap data dengan sub-kriteria yang berkaitan mewakili lapisan input atau masukan yang digabung dengan persekitaran GIS dan dianalisa menggunakan teknik pembuatan keputusan pelbagai kriteria atau *multi-criteria decision making (MCDM) technique*. Faktor-faktor pemberatan untuk lapisan input ditentukan berdasarkan pendapat pakar melalui analisa maklumbalas dari soal-selidik yang dijalankan ke atas pakar-pakar Lembaga Getah Malaysia atau *Malaysian Rubber Board (MRB)*. Keputusannya adalah satu model, model penilaian kesesuaian tanah getah (RLSEM), yang menghasilkan peta kesesuaian tanah getah di daerah Seremban, satu unit pentadbiran di Negeri Sembilan, Semenanjung Malaysia. Analisis prestasi dan kesesuaian model menunjukkan bahawa model ini begitu peka dalam mengesan tanah yang sesuai atau tidak sesuai untuk penanaman getah dengan

nilai sensitiviti dan kesesuaian 84.14% dan 76% masing-masing. Secara keseluruhannya, penilaian ketepatan menggunakan kawasan di bawah lengkuk ROC menghasilkan 0.80 (80%) dan nilai-p <0.0001 pada sela masa keyakinan 95%. Untuk penilaian prestasi menggunakan model regresi, kriteria maklumat Akaike adalah konsisten pada kedua-dua model *global ordinary least square* (OLS) dan model lokal *geographically weighted regression* (GWR)) dengan AICc 521. Seterusnya pengukuran berlaras R^2 kedua-dua model OLS and GWR menghasilkan nilai yang Sama, 0.802811. Korelasi kedua-dua model menunjukkan perhubungan positif yang tinggi dengan pemalar korelasi 0.99. Ini menunjukkan bahawa model kesesuaian tanah yang dibangunkan kekal konsisten dari model gloal ke lokal. Secara kuantitatifnya, sejumlah 35575 hektar, diagihkan di kalangan tiga kelas kesesuaian: sangat sesuai 45% (16048 hektar), agak sesuai 43% (15399 hektar, dan tidak begitu sesuai 12% (4128 hektar). Berdasarkan kepada projeksi harga pasaran getah bulanan dari Bank Dunia 1.858 USD se kilogram for untuk bulan November 2017 (untuk Singapura/Malaysia), dianggarkan bahawa ~28.9 juta USD boleh dijana setiap tahun jika tanah sedia ada yang sesuai digunakan.

ACKNOWLEDGEMENTS

I am most thankful to almighty Allah for giving me the patience and making it possible for me to produce this work. I am grateful to many people who have made this thesis possible and have given their encouragement, assistance, and support throughout the whole process of my studies.

I would like to express my deepest appreciation to my supervisor, Associate Professor Dr. Abdul Rashid Mohamed Shariff for his kind help during my study, from the very beginning of the research, to the very end of editing the wording of the thesis. I shall always remember all the phrases and words learned throughout the meetings. It has been an enjoyable education.

I am also grateful to my committee member, Associate Professor Dr. Siva Kumar Balasundram and Dr. Ahmad Fikri Bin Abdullah for their guidance, insightful comments and valuable suggestions.

Finally, I am grateful to my family and friends for their encouragement, understanding, and tolerance during the study.

I certify that a Thesis Examination Committee has met on 29 March 2018 to conduct the final examination of Goma Bedawi Ahmed Alsalhin on his thesis entitled "Land Suitability Evaluation for Rubber in GIS Platform and Multicriteria Decision-Based Model" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Hasfalina binti Che Man, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Aimrun Wayayok, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Zelina Zaiton Ibrahim, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Internal Examiner)

Armando A. Apan, PhD
Professor
University of Southern Queensland
Australia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 28 June 2018

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

Abdul Rashid Mohamed Shariff, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Siva Kumar Balasundram, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Ahmad Fikri Bin Abdullah, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice- Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- There is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ______________________ Date: ______________________

Name and Matric No: Goma Bedawi Ahmed Alsalhin, GS38477

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________

Name of Chairman of Supervisory Committee: Professor Dr. Abdul Rashid Mohamed Shariff

Signature: ______________________

Name of Member of Supervisory Committee: Associate Professor Dr. Siva Kumar Balasundram

Signature: ______________________

Name of Member of Supervisory Committee: Dr. Ahmad Fikri Bin Abdullah

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

C	Celsius
AHP	Analytic Hierarchy Process
ALES	Automated Land Evaluation Systems
ALSE	Agricultural Land Suitability Evaluator
CEC	Cation Exchange Capacity
Cm	Centimeter
CR	Consistency Ratio
DID	Department of Irrigation and Drainage
DOA	Department of Agriculture
E	East
FAO	Food and Agriculture Organization
GIS	Geographic Information System
LCC	Land Capability Classifications
LEIGIS	Land Evaluation using an Intelligent Geographical Information System
LECS	Land Evaluation Computer System
LESA	Land Evaluation and Site Assessment
LMU	Land Mapping Unit
LUT	Land Utilization Type
m	Meter
m^2	Square meter
MADM	Multi Criteria Decision Method
MC	Multi Criteria
MCA	Multi Criteria Analysis
MCDA	Multi Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
MCE	Multi Criteria Evaluation
mm	Millimeter
MOA	Ministry of Agriculture

N	North
N1	Currently not suitable
N2	Permanently not suitable
OM	Organic Mater
PH	Soil Reaction
RI	Random Consistency Index
S1	High Suitability
S2	Medium Suitability
S3	Marginally Suitable
USBR	U.S. Bureau of Reclamation
OLS	Ordinary Least Square
GWR	Geographically Weighted Regression

CHAPTER 1

INTRODUCTION

1.1 Introduction

Increase in population growth has put pressure on the demand for land; thus, devising means for productive use of land is has become inevitable (Gómez Delgado, et al, 2004). There have been protracted efforts to evaluate land use change across time, from land-use planning to project development purposes including agriculture, forestry, recreation, and engineering applications. Today, application of geo-technology has become a standard tool for assessing land suitability for agricultural use (Bunruamkaew & Murayama, 2012). The condition of the land, its natural environment, and social issues are prominent factors put into consideration to examine the quality of the land use (Mashayekhan et al., 2011).

Land suitability assessment is multifaceted and multidisciplinary in nature, comprising of two aspects. The first aspect focuses on environmental conditions and potential use while the second emphasizes on the suitable level for resource appropriation (Ukaegbu et al.,2012). In this context, various approaches have been undertaken by researchers around the world, Malaysia inclusive, to deal with the challenges to assessing land suitability for agricultural purposes (Olaleye et al., 2015). More recently, application of Geographic Information Systems (GIS) and Multiple-Criteria Analysis (MCA) have made land suitability assessment more accessible to economically disadvantaged nations/organizations. And has also enable researchers to make rapid progress in the analysis of interactions between land resources and agriculture land use (Prakash , 2003).

GIS-based MCA provides rational, objective and non-biased decisions making in agriculture land suitability evaluation (Bunruamkaew & Murayama, 2012). Localized agricultural land suitability evaluation model for rubber crop cultivation in Malaysia has come of age due to competing use of land for oil palm tree and rubber plantation. Such tool will allow decision makers and rubber entrepreneurs to quickly determine the quality of potential land for such purposes.

1.2 Background

Rubber (*Hevea brasiliensis*) is a fast growing tropical crop cultivated extensively in south-east Asia, particularly in Malaysia, Thailand, Indonesia, Vietnam, China and India (Elaalem et al., 2010). The importance of this cash crop is evidence in the current global ranking of Malaysia as the sixth largest producer of rubber in the world. But recently, a report provides an alarming state of natural rubber production in Malaysia which has dropped to 0.7 million tons (12.5%) in 2015 from 0.8 million tons in 2014

(Natural Rubber Statistics 2016). Likewise, exports was reported to have dropped by 10.5% for the same period (Natural Rubber Statistics 2016). From 1990 to 2014, Malaysia produced only between 825,000 tons to 1.3 million tons of natural rubber a year (Wahid Murad et al., 2009). The implication of this is that Malaysia is facing drastic decline in world production rating.

According to a World Bank report (cited in Natural Rubber Statistics 2016), rubber production globally expanded in the country from the 1960s to the 1980s. Estates' contribution to national rubber production fell from about 60% in 1965 to about 29% in 1988; but, the contribution of the rubber smallholder sector increased from 40% to about 71% over the same period (Kato, 1991). This shift occurred while the total output, globally, was on the upward trend until 1980s. There are two main reasons behind this shift: one is the fact that older trees at the end of their productive cycles were still being tapped in the estates and, two, rubber prices remained volatile. This explains why most rubber estates decided to switch to oil palm cultivation. In the light of these findings, a comprehensive and well-funded program was deployed to encourage new planting and replanting to improve rubber varieties in the smallholding sector. For the purpose of comprehension, any rubber plantation less than 10 hectares is categorized as smallholder (Noguchi et al., 2003). The agency established to administer the replanting program in the 1950s was later rebranded as Rubber Industry Smallholder Development Authority (RISDA). The federal Land Development Authority (FELDA) and Federal Land Consolidation and Rehabilitation Authority (FELCRA) presently control 94% of rubber land (Table 1.1.) and produce over 80% of the total rubber in Malaysia.

Table 1.1 : Productivity of smallholders

Years	Area (ha)	Production (tons)
2010	956.18	939,241
2011	962.84	996,210
2012	975.25	922,798
2013	979.86	826,421
2014	985.51	668,613
2015	992.51	722,122
2016	998.61	187,690

Department of Statistics Malaysia 2016

1.3 Problem Statement

Malaysia is facing a decline in world ranking as one of the key producers of natural rubber. From 1990 to 2016, Malaysia produced only between 825,000 tons to 1.3 million tons of natural rubber annually (Arshad et al., 2013) in which 93% of the productions comes from 400,000 rubber smallholders. Although it is possible for a farmer to produce 500 kg/ha/year and even up to 3,000 kg/ha/year (Hassan et al., 2013) but decrease in the market demand for natural rubber has consequential effect on the zeal for rubber cultivation, especially among the smallholders entrepreneurs who have shifted interest to oil palm plantation which is considered to be more lucrative.

- This development has affected the total land area available for rubber farming as most lands previously used have been converted to oil palm plant which offer early production time than latex.

- With this competing interest, identifying suitable locations for rubber growth with maximum yield is essential for adequate planning for the rubber industry in Malaysia.

- Currently, most lands for rubber cultivation are arbitrarily determined based on accessibility or affordability, rather than suitability for maximum yield.

- None of the previous land suitability studies consider soil productivity as a one of the key criteria to evaluate the land; all of them focus on climate criteria, and/or physical criteria.

GIS and Remote Sensing (RS) technologies have been widely used to assist in the monitoring and mapping of the growth of rubber plantation area in Malaysia.

1.4 Motivations behind this research

Malaysia has witnessed drastic loss of rubber land during the past four decades to conversion of rubber plantation to oil palm and to other physical developments (Natural Rubber Statistics 2016). This has resulted in a plummeting natural rubber production. In Malaysia, rubber smallholders produce over 80% of total rubber production. But in a space of one year (between 2014 and 2015), for example, the volume of rubber production has reduced by 20.7%. Similarly, export has reportedly dropped by 10.5% for the same period of time (Malaysia, 2014). Bringing the study area into focus provides a synoptic view of the extent to which the district has lost rubber lands (Figure 1.1).

Despite the establishment of bodies such as the Rubber Industry Smallholder Development Authority (RISDA), Federal Land Development Authority (FELDA), and the Federal Land Consolidation and Rehabilitation Authority (FELCRA) tasked with engaging the rubber smallholding sector, most of the farmers have succeeded in converting their lands to oil palm plantations without consequences. With the government’s renewed efforts to take back rubber production into the mainstream of agricultural export commodities, there is need to have a scientific means of providing useful information to the stakeholders for informed decision making process, starting from the choice of location for future rubber farms.

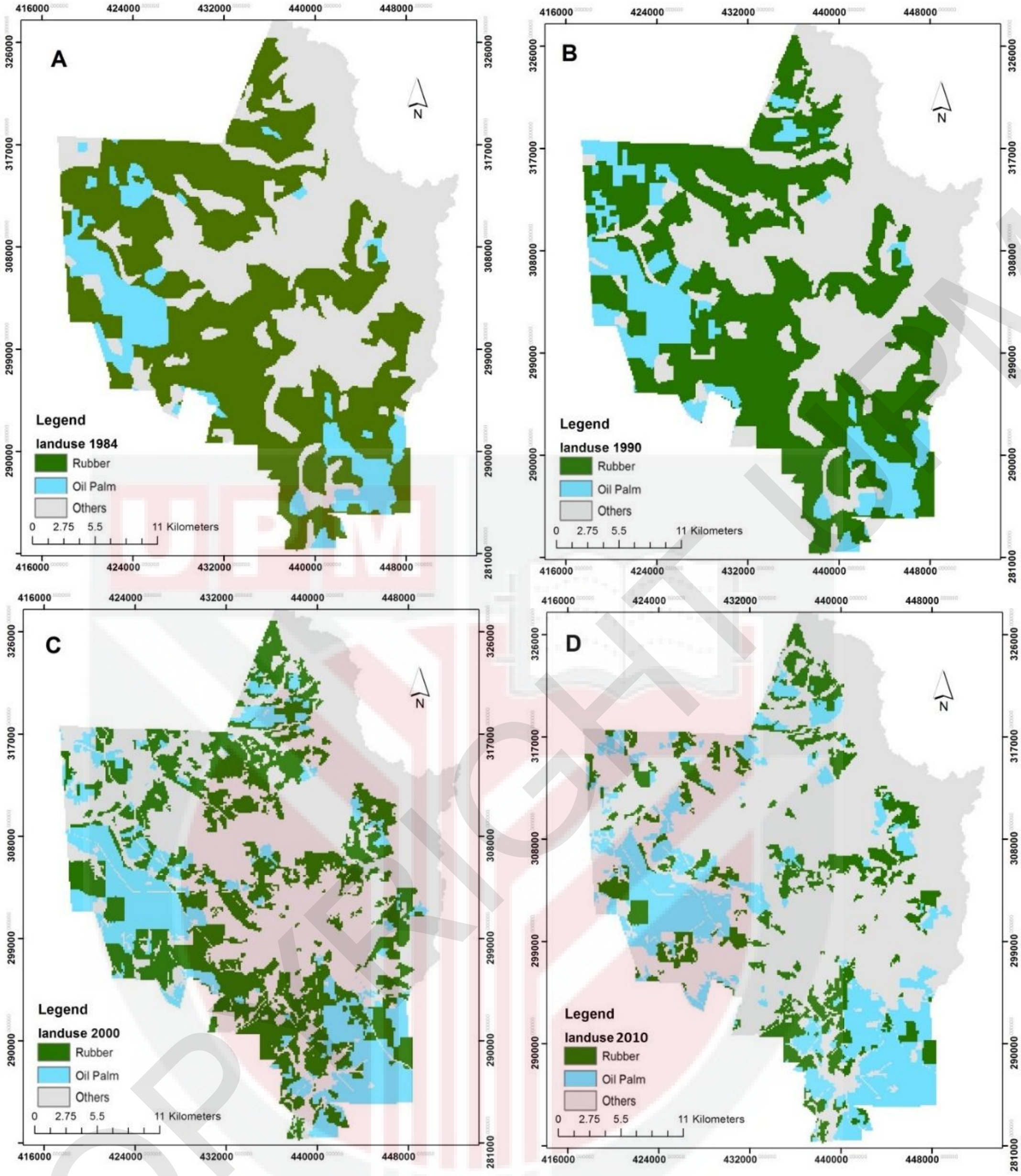

Figure 1.1 : Trend of rubber and oil palm plantation distribution in Seremban district forth years (a) 1984, (b) 1990, (c) 2000, and (d) 2010

1.5 Research Objectives

The main objective of this study is to develop a model for evaluating land suitability for rubber crop cultivation in Seremban district in Negeri Sembilan, Peninsula Malaysia.

The following are the specific objectives of the thesis:

1) To develop a comprehensive land suitability assessment model to support rubber cultivation and to estimate the amount of land area currently available for rubber cultivation.
2) To identify and determine optimal criteria of model development and assess the model performance/fitness
3) To estimate the potential annual productivity and economic return on investment.

1.6 Research questions

This thesis comprehensively addresses the following research questions:

1) Is the existing choice of land for rubber plantation optima for maximum yield?
2) What is the pattern of spatial distribution of suitable land in Seremban district?
3) What is the percentage of suitable land for rubber cultivation in Seremban?
4) Are the current rubber land use areas fit for rubber cultivation?
5) How economically viable is the available land?

1.7 Scope of Research

This study is aimed at developing test a model based on MCA to evaluate land suitability in Seremban district taking into account different parameters including, topography, soil, climate and environmental data datasets of the study area. The model will be implemented based on FAO framework (1976) with necessary modifications to suit the conditions of the local environment for agricultural needs, specifically rubber cultivation. Multi-criteria is vital to the issue at hand; therefore, priority is given to criterion weightage. Combined in a GIS environment, Knowledge-Based Rubber Land Suitability Evaluator model (RLSEM) will be developed.

1.8 Research Limitation

The research provides physical suitability evaluation of rubber (*Hevea brasiliensis*) cultivation as a single landuse type case. Due to the limited availability of the varieties of data requirement for complete assessment, the study does not consider all the qualities proposed by FAO. Rather, it basically focuses on the three criteria: a) effect on land quality upon use; b) the occurrence of the critical value of land quality within the study area; and c) the practicality of obtaining information on individual land quality.

1.9 Thesis organization

There are five chapters in this thesis. Chapter One contains a brief introduction and general background of the study, problem statement, and its objectives. The chapter further highlights the research questions and scope of the study. It draws the curtain with the road map of the thesis by providing the structure of the thesis. Chapter Two gives detail description of issues and concepts of land evaluation, focusing on historical profile of past land suitability methods. It also looks at the limitations and the preliminary steps required for land suitability evaluation with respect to integrative use of GIS and multiple criteria decision approach. It further discusses land suitable for cultivation, decision support systems, and identification of the strengths and weaknesses of the techniques used for land suitability evaluation. In Chapter Three, detail description of the study area, data used and methods involved in attaining the objectives of the study is provided. This include data preparations, integration in GIS environment, criteria and their weightage, model development and testing. Chapter Four presents and discusses the results obtained and their implications. Chapter Five sums up the thesis with concise but complete notes on the conclusion (general and specific), strengths/weaknesses and finally hint on further studies in the future.

REFERENCES

Ab Majid, A. H., & Ahmad, A. H. (2013). Termite infestation associated with type of soil in Pulau Pinang, Malaysia (Isoptera: Rhinotermitidae). *Tropical Life Sciences Research*, *24*(2), 91–95.

Abawi, K. (2008). Qualitative and Quantitative. *Geneva Foundation for Medical Education and Research*, 3–12.

Adon, R., Bakar, I., Wijeyesekera, D. C., & Zainorabidin, A. (2013). Overview of the Sustainable Uses of Peat Soil in Malaysia with Some Relevant Geotechnical Assessments. *International Journal of Integrated Engineering*, *4*(4), 38–46.

Ahmed, G. B., Shariff, A. R. M., & Idrees, M. O. (2015). Adaptation of Land Suitability Evaluation for the Malaysian Agricultural Land Use. *Asian Journal of Applied Sciences*, *3*(5), 528–535.

Ahmed, G. B., Shariff, A. R. M., Idrees, M. O., Balasundram, S. K., & Fikri, A. (2017). GIS-Based Land Suitability Mapping for Rubber Cultivation in Seremban , Malaysia. *International Journal of Applied Engineering Research*, *12*(20), 9420–9433.

Akinci, H., zalp, A. Y., & Turgut, B. (2013). Agricultural land use suitability analysis using GIS and AHP technique. *Computers and Electronics in Agriculture*, *97*, 71–82. https://doi.org/10.1016/j.compag.2013.07.006.

Al-Harbi, K. M. A. S. (2001). Application of the AHP in project management. *International Journal of Project Management*, *19*(1), 19–27. https://doi.org/10.1016/S0263-7863(99)00038-1.

Al-shalabi, M. a., Mansor, S. Bin, Ahmed, N. Bin, & Shiriff, R. (2006). GIS Based Multicriteria Approaches to Housing Site Suitability Assessment. *XXIII FIG Congress. Shaping the Change. Munich, Germany, October 8-13*, 1–17.

Arshad, A. M., Armanto, M. E., & Adzemi, A. F. (2013). Evaluation of Climate Suitability for Rubber (Hevea brasiliensis) Cultivation in Peninsular Malaysia. *Journal of Environmental Science and Engineering A Formerly Part of Journal of Environmental Science and Engineering*, *2*, 293–298.

Bacic, I. L. Z., Rossiter, D. G., & Bregt, A. K. (2003). The use of land evaluation information by land use planners and decision-makers: a case study in Santa Catarina, Brazil. *Soil Use and Management*, *19*, 12–18. https://doi.org/10.1079/SUM2002154.

Bagheri Bodaghabadi, M., Martínez-Casasnovas, J. A., Khakili, P., Masihabadi, M. H., & Gandomkar, A. (2015). Assessment of the FAO traditional land evaluation methods, A case study: Iranian Land Classification method. *Soil Use and Management*, *31*(3). https://doi.org/10.1111/sum.12191.

Baniya, N. (2008). Land Suitability Evaluation Using Gis for Vegetable Crops in Kathmandu Valley / Nepal. *Thesis*, 1–259. Retrieved from https://www.deutsche-digitale-bibliothek.de/binary.

Bell, J. C., Cunningham, R. L., & Havens, M. W. (1992). Calibration and validation of a soil-landscape model for predicting soil drainage class. *Soil Science Society of America Journal*, *56*, 1860. ttps://doi.org/10.2136/sssaj1992.03615995005600060035xh

Bell, J. C., Cunningham, R. L., & Havens, M. W. (1994). Soil Drainage Class Probability Mapping Using a Soil-Landscape Model. *Soil Science Society of America Journal*, *58*(2), 464. https://doi.org/10.2136/sssaj1994.03615995005800020031x

Brunsdon, C., Fotheringham, S., & Charlton, M. (1998). Geographically Weighted Regression. *Journal of the Royal Statistical Society Series D The Statistician*, *47*(3), 431–443. https://doi.org/10.1111/1467-9884.00145.

Bunruamkaew, K., & Murayama, Y. (2012). Land use and natural resources planning for sustainable ecotourism using GIS in Surat Thani, Thailand. *Sustainability*, *4*(3), 412–429. https://doi.org/10.3390/su4030412.

Cardozo, O. D., García-Palomares, J. C., & Gutiérrez, J. (2012). Application of geographically weighted regression to the direct forecasting of transit ridership at station-level. *Applied Geography*, pp. 548–558. https://doi.org/10.1016/j.apgeog.2012.01.005.

Ceballos-Silva, A., & López-Blanco, J. (2003a). Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: A case study in Central Mexico. *Agricultural Systems*. https://doi.org/10.1016/S0308-521X(02)00103-8.

Ceballos-Silva, A., & López-Blanco, J. (2003b). Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: A case study in Central Mexico. *Agricultural Systems*, *77*(2), 117–136. https://doi.org/10.1016/S0308-521X(02)00103-8.

Chandio, I. A., Matori, A. N., Yusof, K., Talpur, M. A. H., & Aminu, M. (2014). GIS-basedland suitability analysis of sustainable hillside development. In *Procedia Engineering* (Vol. 77). https://doi.org/10.1016/j.proeng.2014.07.009.

Chandio, I. A., Nasir, A., Matori, B., Wanyusof, K. B., Aftab, M., & Talpur, H. (2013). Validation of Multi - Criteria Decision Analysis Model of Land Suitability Analysis for Sustainable Hillside Development. *European Journal of Scientific Research*, *109*, 342–349.

Chen, Y., Yu, J., Shahbaz, K., & Xevi, E. (2009). A GIS-Based Sensitivity Analysis of Multi-Criteria Weights. *18Th World Imacs Congress and Modsim09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation With Mathematical and Computational Sciences*, (July), 3137–3143.

Clement, F., Orange, D., Williams, M., Mulley, C., & Epprecht, M. (2009). Drivers of afforestation in Northern Vietnam: Assessing local variations using geographically weighted regression. *Applied Geography*, *29*(4), 561–576. https://doi.org/10.1016/j.apgeog.2009.01.003.

D'Angelo, M., Enne, G., Madrau, S., Percich, L., Previtali, F., Pulina, G., & Zucca, C. (2000). Mitigating land degradation in Mediterranean agro-silvo-pastoral systems: A GIS-based approach. *Catena*, *40*(1), 37–49. https://doi.org/10.1016/S0341-8162(99)00063-6.

de Neergaard, A., Magid, J., & Mertz, O. (2008). Soil erosion from shifting cultivation and other smallholder land use in Sarawak, Malaysia. *Agriculture, Ecosystems and Environment*, *125*(1–4), 182–190. https://doi.org/10.1016/j.agee.2007.12.013

Delgado, M. G., & Sendra, J. B. (2004). Sensitivity Analysis in Multicriteria Spatial Decision-Making: A Review. *Human and Ecological Risk Assessment: An International Journal*, *10*(6), 1173–1187. https://doi.org/10.1080/10807030490887221.

Department of Statistics Malaysia. (2015). Department of Statistics Malaysia Official Portal. *Department of Statistics, Malaysia*, (November), 1–5. https://doi.org/2016-08-11.

Elaalem, M., Comber, A., & Fisher, P. (2010). Land Evaluation Techniques Comparing Fuzzy AHP with TOPSIS methods.

Elsheikh, R., Mohamed Shariff, A. R. B., Amiri, F., Ahmad, N. B., Balasundram, S. K., & Soom, M. A. M. (2013a). Agriculture Land Suitability Evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops. *Computers and Electronics in Agriculture*, *93*, 98–110. https://doi.org/10.1016/j.compag.2013.02.003.

Elsheikh, R., Mohamed Shariff, A. R. B., Amiri, F., Ahmad, N. B., Balasundram, S. K., & Soom, M. A. M. (2013b). Agriculture Land Suitability Evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops. *Computers and Electronics in Agriculture*, *93*, 98–110. https://doi.org/10.1016/j.compag.2013.02.003.

Emadi, M., Baghernejad, M., Pakparvar, M., & Kowsar, S. A. (2010). An approach for land suitability evaluation using geostatistics, remote sensing, and geographic information system in arid and semiarid ecosystems. *Environmental Monitoring and Assessment*, *164*(1–4), 501–511. https://doi.org/10.1007/s10661-009-0909-6

ESRI (Environmental Systems Resource Institute). (2012). ArcGIS Desktop: Release 10.1. *Redlands CA.*

FAO. (1976). *A framework for land evaluation*. *FAO Soils Bulletin n.32*. https://doi.org/M-51.

FAO. (2012). FAO Statistical Yearbook 2012. *FAO Statistical Yearbook 2012. World Food and Agriculture*, 18–31. https://doi.org/ISBN 978-92-5-107426-8.

FAO. (2015). *FAO Statistical Pocketbook 2015*. *Food and Agriculture Organization of the United Nations*. https://doi.org/978-92-5-108802-9.

Fischer, M. M., Getis, A., Wheeler, D. C., & Páez, A. (2010). Geographically Weighted Regression. *Handbook of Applied Spatial Analysis*, *47*(3), 461–486. https://doi.org/10.1111/1467-9884.00145.

Fotheringham, A. S. (2009). Geographically Weighted Regression. *The SAGE Handbook of Spatial Analysis*, *47*(3), 243. https://doi.org/10.1198/tech.2006.s356.

García, J. L., Alvarado, A., Blanco, J., Jiménez, E., Maldonado, A. A., & Cortés, G. (2014). Multi-attribute evaluation and selection of sites for agricultural product warehouses based on an analytic hierarchy process. *Computers and Electronics in Agriculture*, *100*, 60–69. https://doi.org/10.1016/j.compag.2013.10.009.

Gómez Delgado, M., Joaquín, &, & Sendra, B. (2004). Human and Ecological Risk Assessment: An International Journal Sensitivity Analysis in Multicriteria Spatial Decision-Making: A Review. *Human and Ecological Risk Assessment: An International Journal*, *10*(6), 1173–1187. https://doi.org/10.1080/10807030490887221.

Griffith, D. A. (2008). Spatial-filtering-based contributions to a critique of geographically weighted regression (GWR). *Environment and Planning A*, *40*(11), 2751–2769. Retrieved from http://journals.sagepub.com/doi/abs/10.1068/a38218.

Hassan, N., Mohamed Hamzah, H. H., & Md Zain, S. M. (2013). A goal programming approach for rubber production in Malaysia. *American-Eurasian Journal of Sustainable Agriculture*.

Hassan Zaki, P., Zaki Hamzah, M., Hasmadi Ismail, M., Wahidin Awang, K., & Abd Hamid, H. (2010). Malay customary tenure and conflict on implementation of colonial land law in Peninsular Malaysia. *Journal of Law and Conflict Resolution*, *2*(2), 33–45. Retrieved from http://www.academicjournals.org/JLCR.

Henson, I. E., & Harun, M. H. (2007). Responses of oil palm to an interrupted dry season in North Kedah, Malaysia. *Journal of Oil Palm Research*, *19*(July 2000), 364–372.

Ho, C. C., Newbery, D. M., & Poore, M. E. D. (1987). Forest composition and inferred dynamics in Jengka Forest Reserve, Malaysia. *Journal of Tropical Ecology*, *3*(1), 25–56. https://doi.org/10.1017/S0266467400001103.

Howell, C. J., Schwabe, K. A., Haji Abu Samah, A., Graham, R. C., & Taib, N. I. (2005). Assessment of Aboriginal Smallholder Soils for Rubber Growth in Peninsular Malaysia. *Soil Science*, *170*(12), 1034–1049.

https://doi.org/10.1097/01.ss.0000187346.30201.40.

Ishaq, U. M., Umara, B., Edi Armanto, H. M., & Adzemi, M. A. (2014). Assessment and Evaluation of Bris Soil and its Implication on Maize Crop in Merang-Terengganu Region of Malaysia. *Journal of Biology, Agriculture and Healthcare*, *4*(5), 69–76.

Ivajnšič, D., Kaligarič, M., & Žiberna, I. (2014). Geographically weighted regression of the urban heat island of a small city. *Applied Geography*, *53*, 341–353. https://doi.org/10.1016/j.apgeog.2014.07.001.

Jabatan Perangkaan Malaysia. (2011). Jabatan Perangkaan Malaysia. *Statistics of Graduates in the Labour Force Malaysia*, 77.

Jankowski, P. (2015). International Journal of Geographical Information Systems Integrating geographical information systems and multiple criteria decision-making methods Integrating geographical information systems and multiple criteria decision-making methods. https://doi.org/10.1080/02693799508902036

Kalogirou, S. (2002). Expert systems and GIS: An application of land suitability evaluation. *Computers, Environment and Urban Systems*. https://doi.org/10.1016/S0198-9715(01)00031-X.

Kasperczyk, N., & Knickel, K. (2004). Analytic hierarchy process (AHP). *IVM Institute*, 1–6. https://doi.org/10.1108/13683040210451697.

Kato, T. (1991). When Rubber Came : The Negeri Sembilan Experience, *29*(2).

Kennedy, E., & Davis, C. (1998). US department of agriculture school breakfast program. *American Journal of Clinical Nutrition*, *67*(4).

Krajewski, W. F., & Smith, J. A. (2002). Radar hydrology: Rainfall estimation. *Advances in Water Resources*, *25*(8–12), 1387–1394. https://doi.org/10.1016/S0309-1708(02)00062-3.

Kutter, A., Nachtergaele, F. O., & Verheye, W. H. (1997a). The new FAO approach to land use planning and management, and its application in Sierra Leone. *ITC Journal*, *3*(4).

Kutter, A., Nachtergaele, F. O., & Verheye, W. H. (1997b). The new FAO approach to land use planning and management , and its application in Sierra Leone. *Itc Journal*.

Lu, B., Charlton, M., & Fotheringham, A. S. (2011). Geographically Weighted Regression using a non-Euclidean distance metric with a study on London house price data. *Procedia Environmental Sciences*, *7*(0), 92–97. https://doi.org/10.1016/j.proenv.2011.07.017.

Malaysia, L. G. (2014). Natural rubber statistics 2014, 1–26. Retrieved from http://www.lgm.gov.my/nrstat/nrstats.pdf.

Malaysian, R. B. (2009). *RUBBER PLANTATION & Processing Technologyies* (FIRST 2009). KUALA LUMPUR: MALAYSIA RUBBER BOARD.

Mansor, S. B., Pormanafi, S., Mahmud, a. R. B., & Pirasteh, S. (2012). Optimization of Land Use Suitability for Agriculture Using Integrated Geospatial Model and Genetic Algorithms. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *I-2*(September), 229–234. https://doi.org/10.5194/isprsannals-I-2-229-2012.

Mashayekhan, A., Mahiny, A. S., & Ir, W. S. (2011). A Multi-Criteria Evaluation approach to Delineation of Suitable Areas for Planting Trees (Case Study: Juglans regia in Gharnaveh Watershed of Golestan Province). *Journal of Rangeland Science J. of Range. Sci*, *1*(3).

Mir, S. I., Gasim, M. B., Rahim, S. A., & Toriman, M. E. (2010). Soil Loss Assessment in The Tasik Chini Catchment, Pahang, Malaysia. *Bulletin of the Geological Society of Malaysia*, *56*, 1–7. https://doi.org/10.7186/bgsm2010001.

Moghaddam, A., & Nowrouzi, F. (2000). New Approaches to Land-use Planning Impact of Land Utilization Systems on Agricultural Productivity Report of the APO Seminar on Impact of Land Utilization Systems on Agricultural Productivity. *Islamic Republic of Iran*, 4–9. Retrieved from www.apo-tokyo.org.

Mohamad Rasidi, M. N., Sahani, M., Othman, H., Hod, R., Idrus, S., Mohd Ali, Z., … Rosli, M. H. (2013). Application of Geographical Information System for spatial-temporal Mapping: A case study of dengue cases in Seremban, Negeri Sembilan, Malaysia . *Aplikasi Sistem Maklumat Geografi Untuk Pemetaan Reruang-Masa: Suatu Kajian Kes Denggi Di Daerah Seremban, Negeri Sembilan, Malaysia*, *42*(8), 1073–1080.

Nakaya, T., & Fotheringham, A. (2009). Semiparametric geographically weighted generalised linear modelling in GWR 4.0. *Proceedings of GeoComputation*, 1–5.

NATURAL RUBBER STATISTICS 2016. (2016).

Navarro-Hellín, H., Martínez-del-Rincon, J., Domingo-Miguel, R., Soto-Valles, F., & Torres-Sánchez, R. (2016). A decision support system for managing irrigation in agriculture. *Computers and Electronics in Agriculture*, *124*, 121–131. https://doi.org/10.1016/j.compag.2016.04.003.

Noguchi, S., Kasran, B., Yusop, Z., Tsuboyama, Y., & Tani, M. (2003). Depth and physical properties of soil in a forest and a rubber plantation in Peninsular Malaysia. *Journal of Tropical Forest Science*, *15*(4), 513–530.

Nwer, B. A. B. (2005). The Application of Land Evaluation Technique in the north-east of Libya. *National Soil Resources Institute , Faculty of Environment*, *PhD Thesis*, 340.

Olaleye, A. O., Akinbola, G. E., Marake, V. M., Molete, S. F., & Mapheshoane, & B. (2015). Communications in Soil Science and Plant Analysis Soil in Suitability

Evaluation for Irrigated Lowland Rice Culture in Southwestern Nigeria: Management Implications for Sustainability. https://doi.org/10.1080/00103620802432824.

Olaniyi, A. O., Ajiboye, A. J., Abdullah, A. M., Ramli, M. F., & Sood, A. M. (2015). Agricultural land use suitability assessment in Malaysia. *Bulgarian Journal of Agricultural Science*, *21*(3), 560–572.

Ossadnik, W., & Lange, O. (1999). AHP-based evaluation of AHP-Software. *European Journal of Operational Research*, *118*(3), 578–588. https://doi.org/10.1016/S0377-2217(98)00321-X.

Páez, A., & Wheeler, D. C. (2009). Geographically Weighted Regression. In *International Encyclopedia of Human Geography* (pp. 407–414). https://doi.org/http://dx.doi.org/10.1016/B978-008044910-4.00447-8.

Paramananthan, S., & Zauyah, S. (1986). Soil landscapes in Peninsular Malaysia. *Geol. Soc. Malaysia, Bulletin*, *9*(April), 565–583.

Pourkhabbaz, H. R., Javanmardi, S., & Sabokbar, H. A. F. (2014). Suitability Analysis for Determining Potential Agricultural Land Use by the Multi-Criteria Decision Making Models SAW and VIKOR-AHP (Case study : Takestan-Qazvin Plain), *16*, 1005–1016.

Prakash TN. (2003). Land Suitability Analysis for Agricultural Crops: A Fuzzy Multicriteria Decision Making Approach.

Qing, L., Yunxiang, L., & Zhangcheng, Z. (2004). Effects of moisture availability on clonal growth in bamboo Pleioblastus maculata. *Plant Ecology*, *173*(1), 107–113. https://doi.org/10.1023/B:VEGE.0000026334.40661.06.

Qureshi, M. E., Harrison, S. R., & Wegener, M. K. (1999). Validation of multicriteria analysis models. *Agricultural Systems*. https://doi.org/10.1016/S0308-521X(99)00059-1.

Radiarta, I. N., Saitoh, S. I., & Miyazono, A. (2008). GIS-based multi-criteria evaluation models for identifying suitable sites for Japanese scallop (Mizuhopecten yessoensis) aquaculture in Funka Bay, southwestern Hokkaido, Japan. *Aquaculture*, *284*(1–4), 127–135. https://doi.org/10.1016/j.aquaculture.2008.07.048.

Rendana, M., Rahim, S. A., & Lihan, T. (2014). Spatial Modeling Based Analysis of Land Suitability for Rubber Crop in Ranau District of Sabah , Malaysia, *14*(10), 1019–1025. https://doi.org/10.5829/idosi.aejaes.2014.14.10.12418.

Rosa, D. De. (2002). MicroLEIS 2000 : Conceptual Framework Agro-ecological Land Evaluation *. *Instituto de Recursos Naturales Y Agrobiologia, CSIC, Avda. Reina Mercedes 10, 41010 Sevilla, Spain*.

Rossiter, D. G. (1996). A theoretical framework for land evaluation. *Geoderma*, *72*(3–4), 165–190. https://doi.org/10.1016/0016-7061(96)00031-6.

Rusli, A., & Ali, N. A. (2004). Performance appraisal decision in Malysian public service. *The International Journal of Public Sector Management*, *17*, 48–64.

Saaty, R. (1996). The Analytic Hierarchy Process.

Saaty, T. L. (2004). Decision making — the Analytic Hierarchy and Network Processes (AHP/ANP). *Journal of Systems Science and Systems Engineering*, *13*(1), 1–35. https://doi.org/10.1007/s11518-006-0151-5.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83. https://doi.org/10.1504/IJSSCI.2008.017590.

Selby, B., & Kockelman, K. M. (2013). Spatial prediction of traffic levels in unmeasured locations: Applications of universal kriging and geographically weighted regression. *Journal of Transport Geography*, *29*, 24–32. https://doi.org/10.1016/j.jtrangeo.2012.12.009.

Sharififar, A. (2012). Assessment of different methods of soil suitability classification for wheat cultivation. *J Agrobiol*, *29*(2), 47–54. https://doi.org/10.2478/v10146-012-0008-0.

Streutker, D. R., Glenn, N. F., & Shrestha, R. (2011). A Slope-based Method for Matching Elevation Surfaces. *Photogrammetric Engineering & Remote Sensing*, *77*(7), 743–750. https://doi.org/10.14358/PERS.77.7.743.

Sujaul, I. M., Muhammad Barzani, G., Ismail, B. S., Sahibin, A. R., & Mohd Ekhwan, T. (2012). Estimation of the Rate of Soil Erosion in the Tasik Chini Catchment, Malaysia using the RUSLE Model Integrated with the GIS. *Australian Journal of Basic and Applied Sciences*, *6*(12), 286–296.

Tanasă, I. C., Niculită, M., Roşca, B., & Pîrnău, R. (2010). Pedometric Techniques in Spatialisation of Soil Properties for Agricultural Land Evaluation, *67*(1), 1843–5246.

Tu, J. (2011). Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. *Applied Geography*, *31*(1), 376–392. Retrieved from http://www.sciencedirect.com/science/article/pii/S0143622810000846.

Ufes, L. D. T. E. C. (2012). Apostila de ArcGIS. In *Apostila de ArcGis* (p. 159).

Ukaegbu, E. P., Akamigbo, F. O. R., & Asadu, C. L. A. (2012). Suitability Rating of Soils of Owerri Agricultural Zone, Nigeria, for Rainfed Monocropping of Maize. *Journal of Agriculture Biotechnology & Ecology*, *5*(2), 55–66.

van Beveren, I. (2012). Total factor productivity estimation: A practical review. *Journal of Economic Surveys*. https://doi.org/10.1111/j.1467-6419.2010.00631.x.

Velasquez, M., & Hester, P. T. (2013). An Analysis of Multi-Criteria Decision Making Methods. *International Journal of Operations Research*, *10*(2), 56–66.

Wahid Murad, M., Siwar, C., Hashim Nik Mustapha, N., Fuad Nik Mohd Kamil, N., Muhamad, S., & Abdul Aziz, A. (2009). Emergence to Develop an Appraisal System for Agricultural Practices in Malaysia. *J Hum Ecol*, *28*(3), 191–198.

Wheeler, D., & Tiefelsdorf, M. (2005). Multicollinearity and correlation among local regression coefficients in geographically weighted regression. *Journal of Geographical Systems*, *7*(2), 161–187. Retrieved from http://link.springer.com/article/10.1007/s10109-005-0155-6.

Yaacob, O., & Sulaiman, W. H. W. (1992). The Management of Soils and Fertilizers for Sustainable Crop Production in Malaysia. *Sustainable Agriculture for the Asian and Pacific Region; Papers Delivered at the 11th Meeting of the Technical Advisory Committee of the Food and Fertilizer Technology Center for the Asian and Pacific Region, Suwŏn, Korea Republic, 18-24 May 1992.*, 23–32.

Yusof, M. F., Abdullah, R., Azamathulla, H. M., Zakaria, N. A., & Ghani, A. A. (2011). Modified Soil Erodibility Factor, K for Peninsular Malaysia Soil Series. *3rd International Conference on Managing Rivers in the 21st Century: Sustainable Solutions for Global Crisis of Flooding, Pollution and Water Scarcity*, 799–808.

Yusof, M. F., Azamathulla, H. M., & Abdullah, R. (2014). Prediction of soil erodibility factor for Peninsular Malaysia soil series using ANN. *Neural Computing and Applications*, *24*(2), 383–389. https://doi.org/10.1007/s00521-012-1236-3.

Zabel, F., Putzenlechner, B., & Mauser, W. (2014). Global agricultural land resources - A high resolution suitability evaluation and its perspectives until 2100 under climate change conditions. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0107522.

Zhang, M., Fu, X. H., Feng, W. T., & Zou, X. (2007). Soil organic carbon in pure rubber and tea-rubber plantations in South-western China. In *Tropical Ecology* Vol. 48, pp. 201–207.