UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF SUITABLE HOSPITAL LOCATION USING GIS AND MACHINE LEARNING

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By

KHALED Y. M. ALMANSI

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

July 2022

DEDICATION

This thesis is dedicated to:

The memory of my brother Ameer: so that what is dead may never die;

My father and mother who formed part of my vision and taught me good things that matter in life. Their patience and sacrifice will remain my inspiration throughout my life. I am also very much grateful to my sisters for their constant support and encouragement;

My children, I hope the sacrifices you have endured for me to pursue this dream will be repaid to you with many opportunities for joy and success in your future.

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

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July 2022

Chairman: Professor Abdul Rashid Bin Mohamed Sharif, PhD
Faculty: Engineering

Choosing the suitable site for a new hospital is a difficult aspect of decision-making for the decision-makers. Large data availability with challenging features and the proliferation of different methodologies have made it extremely difficult to select the best models that perform for a particular site selection problem. This research provided a comprehensive study for hospital site suitability and introduced machine learning models. The experiment was conducted in two study areas which are Gaza Strip, Palestine and Melaka, Malaysia. First, the conditioning factors were optimized and ranked to identify and select the most correlated factors to predict the suitability of a hospital site by applying the correlation feature selection (CFS) algorithm and the greedy-stepwise search method. Second, to assess the hospital site suitability, three machine learning (ML) models, namely, support vector machine (SVM), multilayer perceptron (MLP) and linear regression (LR) were introduced to predict the suitability of the hospital site. In addition, two multi-criteria decision-making models (MCDM), namely, analytical hierarchy process (AHP) and fuzzy overlay were used to compare the models and verify the results. The ML models Performance were verified using the receiver operating characteristics (ROC) curves and cross-validation with other evaluation metrics; correlation coefficient, root mean square error (RMSE), mean absolute error (MAE), relative absolute error (RAE), as well as root relative squared error (RRSE). The comparison of the model shows that in Melaka and Gaza Strip, MLP (AUC: 92.20%, 84.90%) and AHP (AUC: 91.40% and 83.20%) are more reliable and acceptable for hospital suitability mapping in both locations with consistent and realistic results. The high-level performance and accuracy of the model outcomes supported the conclusion that the proposed methodology in this research can successfully produce a site suitability map for locating new hospitals. Third, an insight into the machine learning models utilized and how their predicted weights affect hospital site suitability mapping was provided. A clear dissimilarity between the ML and MCDM models in terms of the predicted weights characteristics of the conditioning factors in both study areas are discovered. The study has revealed that some conditioning factors are more significant than others because of inherent traits associated with the spatial characteristics of each case study that results in the differences in the weights. Fourth, five location-allocation models were implemented based on the calculus of coverage, mainly implemented in the search

for poor coverage to propose new hospital sites in both study areas. In this research, site suitability from one study area to another was verified using all the implemented methods. Thus, the proposed approaches would be effectively and easily replicated in other regions. Moreover, the results of the proposed approaches provided detailed information that would be useful to decision makers to locate the hospital for effective health delivery planning and implementation.

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

PENILAIAN LOKASI HOSPITAL YANG SESUAI MENGGUNAKAN GIS DAN PEMBELAJARAN MESIN

Oleh

KHALED Y. M. ALMANSI

Julai 2022

Pengerusi: Profesor Abdul Rashid Bin Mohamed Sharif, PhD
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Memilih tapak yang sesuai untuk hospital baharu merupakan aspek yang sukar dalam menentukan rumusan bagi pembuat keputusan. Ketersediaan data yang besar dengan ciri yang mencabar dan percambahan metodologi yang berbeza menyukarkan untuk memilih model terbaik lagi berkesan bagi mengatasi masalah penentuan tapak tertentu. Penyelidikan ini menyediakan kajian komprehensif terhadap kesesuaian tapak hospital dan memperkenalkan model pembelajaran mesin. Eksperimen dijalankan di dua kawasan kajian iaitu Semenanjung Gaza, Palestin dan Melaka, Malaysia. Pertama, faktor penyesuaian telah dioptimumkan dan diberi pentahapan untuk mengenal pasti dan memilih faktor yang paling berkorelasi untuk menjangka kesesuaian tapak hospital dengan menggunakan algoritma pemilihan ciri korelasi (CFS) dan kaedah pencarian mengikut langkah tamak (greedy-stepwise search method). Kedua, untuk menilai kesesuaian tapak hospital, tiga model pembelajaran mesin (ML) iaitu mesin vektor sokongan (SVM), multilayer perceptron (MLP) dan regresi linear (LR) diperkenalkan untuk meramalkan kesesuaian tapak hospital. Di samping itu, dua model membuat keputusan berbilang kriteria (MCDM), iaitu proses hierarki analisis (AHP) dan tindanan kabur digunakan untuk membandingkan model dan mengenal pasti keputusan. Prestasi model ML telah disahkan dengan menggunakan lenkungan receiver operating characteristics (ROC) dan dilakukan pengesahan silang menggunakan metrik penilaian lain; correlation coefficient, root mean square error (RMSE), mean absolute error (MAE), relative absolute error (RAE), dan root relative squared error (RRSE). Perbandingan model menunjukkan bahawa di Melaka dan Semenanjung Gaza, MLP (AUC: 92.20%, 84.90%) dan AHP (AUC: 91.40% dan 83.20%) lebih dipercayai dan diterima untuk kesesuaian pemetaan hospital di kedua-dua lokasi dengan keputusan yang konsisten dan realistik. Prestasi tahap tinggi dan ketepatan hasil model menyokong kesimpulan bahawa metodologi yang dicadangkan dalam penyelidikan ini berjaya menghasilkan peta kesesuaian tapak untuk mencari hospital baharu. Ketiga, cerapan tentang model pembelajaran mesin yang digunakan dan cara bagaimana beratnya diramalkan mempengaruhi pemetaan kesesuaian tapak hospital telah diperolehi.. Perbezaan yang ketara ditemui antara model ML dan MCDM dari segi ciri berat yang diramalkan bagi faktor penyesuaian di kedua-dua kawasan kajian. Kajian mendedahkan bahawa beberapa faktor penyesuaian didapati lebih signifikan daripada yang lain kerana

elemen-elemen yang wujud pada ciri-ciri spatial setiap kajian kes yang membawa kepada perbezaan dalam keberatan. Keempat, lima model peruntukan-lokasi telah dilaksanakan berdasarkan kalkulus liputan, terutamanya dilaksanakan dalam mencari liputan yang lemah untuk mencadangkan tapak hospital baharu di kedua-dua kawasan kajian. Dalam penyelidikan ini, kesesuaian tapak dari satu kawasan kajian ke kawasan kajian yang lain telah disahkan menggunakan semua kaedah yang dilaksanakan. Oleh itu, pendekatan yang dicadangkan akan direplikasi dengan berkesan dan mudah di kawasan lain. Selain itu, hasil pendekatan yang dicadangkan memberikan maklumat terperinci yang berguna kepada pembuat keputusan untuk menempatkan hospital bagi perancangan dan pelaksanaan penyampaian kesihatan yang berkesan.

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

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Declaration by Members of the 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) Rule 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

GIS	Geographic Information Systems
ML	Machine learning
AHP	Analytical Hierarchy Process
ANN	Artificial Neural Network
MLP	Multilayer perceptron
SVM	Support Vector Machine
LR	Linear Regression
DEM	Digital Elevation Model
RBF	Radial Basis Function
TRI	Topographic Roughness Index
TWI	Topographic Wetness Index
SPI	Stream Power Index
ROC	Receiver Operating Characteristic
AUC	Area Under Curve
CV	Cross-Validation
MAE	Mean absolute error
RMSE	Root Mean Squared Error
RAE	Relative Absolute Error
RRMSE	Relative Root Mean Squared Error

CHAPTER 1

INTRODUCTION

1.1 General

Increase in population growth especially in the cities and the need to efficiently manage the available space among competing land use has continue to make spatial location a critical factor in urban planning, business location, transportation and other modern infrastructural facilities for many years. Site selection is an important strategic planning tool for a broad spectrum of public and private establishments. Decision makers are often faced with the difficulty of spatial resource allocation to determine objectively among contending criteria the best locations to site new facilities (Aboulola, 2017).

Over the last decades, site selection has benefited from the capabilities of geospatial technologies for selecting suitable sites. Site suitability assessment has largely been used as the primary method for determining the location of public infrastructure with consideration of criteria such as terrain, land use and various general preferences. For instance, locating some establishments needs that the location is unrestricted by any environmental intervention such as noise, natural hazards, and traffic problems and is also available to current and future residents (LaGro, 2013; Samani et al., 2018). One of such criteria-based decision is health facilities like hospital.

A suitable location for a hospital has many essential societal factors that must be considered for maximum benefit to the society. Among healthcare professionals, there is always mixed opinions and argument about the factors that have the greatest influence – environmental, social, economic, etc. because the whole criteria selection procedure needs interdisciplinary input, including health management personnel, government officials, engineers, environmental scientists and social scientists (Liu et al., 2011). On the part of the government, locating hospitals in the most suitable location will support improving the distribution of the facilities and matching healthcare delivery to socio-economic demands. Additionally, it facilitates the coordination of networks for the development of civil and rural health services and social challenges. From the residents' viewpoint, constructing a healthcare facility in a proper place will enhance healthcare accessibility, reduce emergency response time, enhances resident satisfaction with healthcare service, and eventually improves life quality (Atun et al., 2013). For investors and operators in the field of health services, locating the hospital in the most suitable location can save cost and ensure return on investment. In general, locating the right hospital in the right location enhances competitive advantage, branding, marketing, and human resource provision (Zhou & Wu, 2012).

Determining suitable site for locating hospital requires sophisticated analysis that involves several important considerations - technical, environmental, physical, social, financial, and

so on. Site suitability analysis is the process of determining the best location to site a proposed facility (Abdullahi et al., 2014a; Steiner et al., 2000). The decision to determine the most suitable piece of land to site proposed hospital is influenced by several factors and variables that is impossible to be achieved using the traditional method. So, the process entails critical consideration and weighting of the influencing factors using multi-criteria analysis. This is usually expressed as a function of modelling features with the aid of objectivity-based data mining techniques as decision support systems to arrive at the most profitable choice (Salehi et al., 2016). Since location is the denominator in site suitability, selecting the best location is a geospatial problem; therefore, Geographical Information System (GIS) characterized by the use of various data-related parameters for suitability modelling.

Geographic Information System (GIS) is a dedicated type of information system that has the capability of capturing, storing, updating, analysing and integration of spatially referenced data (Green, 2018). This has made it an indispensable tool in making vital decision related to location using a suit of spatial tools, including data observation and description, analysing, measurement, predicting, etc. to help decision makers in different areas. In the science of location-based decisions, the combination of modelling and mapping with GIS permits efficient utilization of data from multiple sources to build reliable models involving several interrelated constraints or criteria needed to be considered to arrive at the best decisions, ideal location or the best alternative site for future development (Abramovich, 2012). Site suitability analysis is one of the fields with wide application of GIS because it has the advantage of providing alternative choice of location for facility development.

The advent of GIS techniques has given birth to many methods in the site suitability assessment. For site suitability analysis particularly, a number of approaches have been developed integrating Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) such as Analytic Hierarchy Process (AHP) and Fuzzy models (Elmahmoudi et al., 2020). The capability of GIS tools to bring together diverse and complex spatial variables and manipulate them to reach comprehensive technical and administrative decisions makes is the preferred geospatial methodology for selecting suitable sites (Silva et al., 2011). And it has been widely used in regional and urban planning (Kahila-Tani et al., 2019), water resource management (Wang & Xie, 2018), health care resource allocation (Khashoggi & Murad, 2020), and natural hazards (Gorsevski et al., 2012). GIS plays important roles as a spatial decision-making instrument by assigning priority weights to the criteria in order to evaluate feasible alternatives and to visualize the results at different levels of choice for decision-makers (Rojanamon et al., 2009).

In the context of the current study, preparation of dataset factors to assess site suitability for hospital is an essential requirement; therefore, relevant spatial database must first be created comprising of different types of conditioning factors. These factors are selected based knowledge obtained from relevant studies referenced in literatures and field investigations. Conditioning factor selection process is critical because a particular set of factors may not work for every situation – a set of conditioning factors may be effective in

a specific area and the same may not be applicable to other areas – due to environmental heterogeneity. So, the accuracy of derived maps depends not only on the methodology utilised but also on the completeness and quality of the conditioning factors employed. Increase in the quality of the data increases the performance of the resulting suitability map. In many countries, particularly the developing and underdeveloped nations, access to complete datasets containing topographical/geomorphological, environmental, geological, and hydrological information which are vital to holistic evaluation is likely impossible. Nevertheless, it does not mean that suitability assessment is not practicable. This study, therefore, aims to utilise digital elevation model (DEM), land use and population derived conditioning factors to examine the efficiency of the conditioning factors in hospital suitability site modelling.

1.2 Problem Statement

The incessant rural-urban migration and the resulting high concentration of population in urban areas have continue to mount pressure on the utilisation of urban infrastructure with growing potential of urban and man-made crises and disasters such as flooding, slope hazard, fires and insecurity. Therefore, the government and stakeholders in physical and infrastructural planning have been trying to find appropriate model for allocating land resources for appropriate usage so as to improve human safety, welfare and to deliver better living conditions to the inhabitants of urban areas. (Soltani et al., 2019). Since hospitals perform vital functions as assessment index of any society, they are of special importance different from other urban services (Nazarian, 2009). Health is among the most sensitive indicators in relation to sustainable urban development, given its close relationship with human life expectancy, health resources and services deserves being given special attention and made readily available to all people equally and fairly (Moghadam & Ehrampoush, 2004).

Identification of suitable location to site hospital is one of the fields that has been studied using traditional techniques but has not been fully explored giving rise to gaps in the literature as highlighted below:

1. There is a lack in the literature for a systematic review that identifies the hospital site suitability models, methods, and frameworks in recent decades. A review of current and complete models, methods, and frameworks will guide researchers in future research.
2. Suitability of the hospital site using machine learning methods is the most vital gap where no scientific research has been conducted or introduced machine learning in the field of hospital location suitability. Most studies relied on GIS-based multiple-criteria decision analysis for hospital location suitability assessment (Abdullahi et al., 2014; Ahmed et al., 2016; Soltani & Marandi, 2011; Vahidnia et al., 2009).
3. Recognition and mapping of an appropriate set of conditioning factors which are highly correlated with suitably siting hospital require specific knowledge of the main motives for constructing new hospital in addition to the

knowledge of different scientific fields (Abdullahi et al., 2014a; Ahmed et al., 2016).

4. Some conditioning factors, such as altitude, slope, distance from road, TWI, TRI and SPI are more important and effective than others in certain studies (Jebur, 2015; Miller, 2013; Mojaddadi, 2018). However, some conditioning factors may be effective for a specific area, while the same factors may not be influential for other environments (Jebur, 2015). It is important to understand the variability and applicability of different conditioning factors.

Therefore, this research aims to cover the requirements of reliable hospital site suitability modeling using machine learning approaches. The accomplishment of the suggested approaches is expected to improve the traditional methods of the previous studies.

1.3 Motivation Behind this Research

This study is driven by the wide gap in the literature between geohazard modelling and socio-economic studies such as hospital site suitability which has not been fully explored using machine learning methods or introduced into this field. This is the area in which this research contributes by providing a systematic review that identifies the models and methods used for hospital site suitability in order to bridge the gap in the literature. In addition to the curiosity about how machine learning classifications interact to improve and predict the importance of spatial parameters vis-à-vis the interaction of geographic information systems techniques with the predicted results of the machine learning algorithms in this field of hospital site suitability assessment.

1.4 Research Objectives

This thesis proposes and applied a new methodology for hospital site suitability modelling using machine learning method. A major contribution to the literature is to enhance the current techniques used. The following are the main objectives of the thesis:

1. To derive and optimize hospital site suitability conditioning factors by utilizing Correlation based Feature Selection (CFS) along with the Greedy-Stepwise method.
2. To implement recent knowledge-driven GIS techniques of machine learning and multi-criteria decision-making for hospital site suitability modeling.
3. To provide some philosophical reflections concerning the optimal machine learning classifier and the effects of the predicted weights of the machine learning models on GIS mapping.
4. To assess the current hospital sites and identify the areas with poor coverage within a predefined standard distance using location-allocation models and propose new locations.

1.5 Research Questions

To fulfil the overall research objectives, the following research questions are addressed in this research:

1. What are the optimal conditioning factors that contribute to the suitability of the hospital site?
2. What types of machine learning classification method adopted can be employed to perform hospital site suitability analysis, and which conditioning factors are most relevant to the mapping of hospital site suitability? What weights should be given to each factor?
3. Do more conditioning factors increase the accuracy of the resulted prediction map?
4. How reliable and accurate is the knowledge-driven machine learning classification method used in comparison with well-known GIS techniques for the purpose of this study?

1.6 Scientific Contributions

The work presented within this thesis is expected to lead to the following original contributions:

1. Appraisal of conditioning factors, models and methods for spatial location suitability though comprehensive exploration of previous studies as well as proposed machine learning models by strategic planners and opinion of experts from the available models, methods, and frameworks.
2. Optimization of the conditioning factors using CFS and Greedy-Stepwise prior to use for analysis unlike the conventional approach.
3. Implementation of the SVM, MLP and LR machine learning classification algorithms for hospital site suitability, where no similar study has been conducted previously.

1.7 Scope and Limitations

The aim of this study is to predict sites suitable for locating hospital using machine learning and GIS techniques. The proposed methodology was applied in two study areas to test the validity of the conclusions and the applicability of the methodology across a range of areas with dissimilar environmental conditions. For the purpose of prediction, this research introduces machine learning methods to determine the suitability locations for building hospital by optimizing several factors contributing to the suitability of the hospital site. Furthermore, the study implements some of the widely used machine learning GIS-based models in the field of geo-hazards to discover the optimal model for hospital site suitability and compare it with the traditional models of multi-criteria decision-making for validation. As for study limitations, there was no direct contact with local authorities due to data

privacy policies. Field verification was also a limitation so Google Earth and high-resolution satellite imagery were used for verification purposes. In addition, the performance of the methods employed is evaluated by calibrating and verifying the suitability results using ROC curve and Cross-Validation with metrics of MAE, RMSE, RAE and RRSE.

1.8 Thesis Organization

This thesis is organized into five chapters followed by the list of the referenced materials. The summary of each chapter is presented as follows:

i. Chapter One: Introduction

This chapter discussed brief introductory background of the study, the problem statement, objectives, research questions, scope of the study and finally the scientific contribution to the knowledge.

ii. Chapter Two: Literature Review

Chapter Two provides an overview of hospital site suitability using GIS. Generally, the chapter presents the traditional, innovative, and emerging techniques for site suitability, followed by discussion detail description of the methodologies used for qualitative and quantitative analysis of site suitability and finally summarising the different validation methods usually employed for assessing the accuracy of the resulting prediction maps.

iii. Chapter Three: Methodology

In Chapter Three, detail description of the characteristic of the study areas was presented. Thereafter, the materials and dataset, methodology, machine learning classifiers implementation, GIS modelling and model validation were executed in the list to produce the hospital site suitability maps and associated products.

iv. Chapter Four: Results and Discussion

This chapter presents and discusses the results of the study. These include conditioning factors optimization, machine learning prediction, and integration of the GIS models presented in figures (maps), tables, equations, and charts. Furthermore, the chapter discusses the outcome of the comparative analysis of SVM, MLP, and LR with AHP and

Fuzzy overlay for hospital site suitability. Moreover, assessment of location-allocation models to identify the coverage area of the existing hospitals is shown and discussed. Finally, the accuracy obtained from all the models applied is compared and discussed.

v. Chapter five: Conclusion and Recommendations for Future Research

This chapter provides the overall conclusion of the study, including recommendation and direction of future research in the study areas.

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