**UNIVERSITI PUTRA MALAYSIA**

***DEVELOPMENT OF OPTIMIZED MODEL BASED ON EVIDENTIAL BELIEF FUNCTION FOR GROUNDWATER MAPPING***

**HALEH NAMPAK**

DEVELOPMENT OF OPTIMIZED MODEL BASED ON EVIDENTIAL BELIEF FUNCTION FOR GROUNDWATER MAPPING

By

HALEH NAMPAK

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia in fulfillment of the requirements for Degree of Master of Science

September 2014

*I would like to dedicate my thesis to my beloved parents*

*Ali and Nahid*

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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**HALEH NAMPAK**

**September 2014**

**Chairman: Assoc. Prof. Biswajeet Pradhan, PhD**

**Faculty: Engineering**

Groundwater is one of the most important natural resources in any nation serving as a major source of water to communities, industries and agricultural purposes. In recent years, groundwater resources in Malaysia due to high demands of local water system and especially prolonged drought period has become a serious issue in the Klang Valley, Malaysia.

Spatial data integration and analysis for prediction of groundwater potential were conducted on the available datasets of Langat basin, Malaysia. In the search of groundwater potential areas, borehole data are essential as an indicator for directing exploration activities. Geographic information system (GIS) is a rapid, useful and low cost technique tool for implementing of groundwater mapping. The main objective of this study is to identify an optimized model for groundwater potential mapping. For that reason, some statistical methods including both bivariate and multivariate models, such as frequency ratio (FR), logistic regression (LR) and evidential belief function (EBF), were applied and tested. Evidential belief function model has not been applied in groundwater mapping. This contribution is novelty of this study. Then the developed model was compared and validated with well-known techniques such as FR and LR models.

The processes of the method application include (i) identification of groundwater conditioning factors using data which obtained from available maps, remotely sensed imagery and related databases. The conditioning parameters are, elevation, slope, curvature, topographic wetness index, stream power index, river density, lineament density, lithology, land use, normalized difference vegetation index, soil and rainfall. (ii) The probabilistic of each conditioning factor was estimated using statistical weighting methods and a thematic map was produced for each conditioning factor.

The optimized groundwater conditioning factors were then integrated to produce groundwater potential map. Then, the most indicative groundwater potential map was validated using the groundwater occurrence locations that were not used for generating the map. The resultant maps derived from integration of each method separately, were verified by the groundwater well locations for the study area. The AUC for the prediction curve of the groundwater potential map through three type of modelling was at 0.720, 0.720, and 0.779 of prediction accuracy for, FR, LR and EBF methods, respectively. The validation results demonstrate that integration of all evidential maps give satisfactory result for groundwater potential mapping.

Both advantages and drawbacks of implementation for the proposed prescriptive approach are illustrated in the thesis. Recommendations for the study area are indicated within the perspective of the existing water supply systems. In summary, the results of this study suggests a comprehensive evaluation of groundwater exploration development and environmental management for future planning by related agencies in Malaysia which provided an effective method and reduce cost as well as less time consuming.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**PEMBANGUNAN MODEL DIOPTIMUMKAN BERDASARKAN FUNGSI KEPERCAYAAN KETERANGAN UNTUK PEMETAAN BAWAH TANAH**

Oleh

**HALEH NAMPAK**

**September 2014**

**Pengerusi:** **Prof. Madya. Biswajeet Pradhan, PhD**

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Air bawah tanah merupakan salah satu sumber semula jadi yang terpenting bagi mana-mana negara sebagai sumber utama air kepada masyarakat, industri, dan kegunaan pertanian. Dalam tahun-tahun kebelakangan ini, sumber air bawah tanah di Malaysia telah menjadi satu isu yang serius di Lembah Klang, Malaysia kerana ia mendapat sambutan yang menggalakkan bagi sistem air tempatan dan disebabkan tempoh kemarau yang panjang.

Integrasi dan analisis data spatial untuk ramalan potensi air bawah tanah telah dijalankan ke atas set data yang ada bagi kawasan tadahan Langat, Malaysia. Dalam proses pencarian kawasan potensi air bawah tanah, data telaga gerudi adalah penting sebagai petunjuk untuk mengarah aktiviti carigali. Sistem maklumat geografi (GIS) adalah teknik yang pesat, bermanfaat, dan mempunyai kos yang rendah untuk melaksanakan pemetaan air bawah tanah. Objektif utama kajian ini adalah untuk mengenal pasti model yang optimum bagi pemetaan potensi air bawah tanah. Oleh sebab itu, beberapa kaedah statistik termasuk model bivariate dan model multivariate, seperti nisbah kekerapan (FR), regrasi logistik (LR), dan fungsi kepercayaan keterangan (EBF) telah digunakan dan diuji. Model fungsi kepercayaan keterangan telah tidak digunakan dalam pemetaan air bawah tanah. Sumbangan ini adalah suatu yang baru dalam kajian ini. Kemudian, model yang dibangunkan telah dibandingkan dan disahkan dengan teknik terkenal seperti model FR dan LR.

Proses permohonan kaedah termasuk (i) mengenal pasti faktor-faktor penyaman air bawah tanah dengan menggunakan data yang diperolehi daripada peta-peta yang ada, imej penderiaan jauh, dan pangkalan data yang berkaitan. Parameter penyaman adalah ketinggian, cerun, kelengkungan, indeks kelembapan topografi, indeks kuasa aliran, ketumpatan sungai, ketumpatan ciri khas, litologi, penggunaan tanah, indeks ternormal

perbezaan tumbuhan, tanah, dan hujan. (ii) Kebarangkalian setiap faktor penyaman dianggarkan menggunakan kaedah pemberat statistik dan peta tematik yang telah dihasilkan bagi setiap faktor suasana. Faktor penyaman air bawah tanah yang optimum telah dirangkumkan untuk menghasilkan peta potensi air bawah tanah. Kemudian, peta air bawah tanah yang paling berpotensi yang ditunjukkan telah disahkan dengan menggunakan lokasi kejadian air bawah tanah yang tidak digunakan untuk menjana peta. Peta-peta yang terhasil yang diperolehi daripada integrasi setiap kaedah secara berasingan, telah disahkan dengan lokasi telaga air bawah tanah bagi kawasan kajian. AUC bagi lengkung ramalan bagi peta potensi air bawah tanah melalui tiga jenis model iaitu masing-masing pada 0.720, 0.720, dan 0.779 ketepatan ramalan dengan kaedah FR, LR, dan EBF.

Kelebihan dan kelemahan pelaksanaan pendekatan preskriptif yang dicadangkan adalah seperti yang digambarkan dalam tesis. Cadangan untuk kawasan kajian ditunjukkan dalam perspektif sistem bekalan air yang sedia ada. Ringkasnya, hasil kajian ini menunjukkan pembangunan penerokaan dan pengurusan alam sekitar bagi air bawah tanah perlu penilaian yang komprehensif bagi perancangan masa hadapan oleh agensi-agensi berkaitan di Malaysia untuk menyediakan kaedah yang berkesan dan dapat mengurangkan kos serta tidak memakan masa yang panjang.

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I certify that a Thesis Examination Committee has met on ... 2014 to conduct the final examination of Haleh Nampak on his thesis entitled "Spatial Data Analysis and Data Integration for Groundwater Potential mapping, Langat Basin, Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Pertanian Malaysia [P.U.(A) 106] 15 March 1988. The Committee recommends that the candidate be awarded the Master of Science.
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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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| | |
|---|---|
| AHP | Analytical Hierarchy Process |
| ARSM | Malaysian Remote Sensing Agency |
| Bel | Belief |
| CAD | Computer-aided design |
| CI | Consistency Index |
| CR | Consistency Ratio |
| DEM | Digital Elevation Model |
| DOA | Department of Agriculture Malaysia |
| Dis | Disbelief |
| EBF | Evidence Belief Function |
| ETM+ | Landsat Enhanced Thematic Mapper Plus |
| FR | Frequency Ratio |
| GIS | Geography Information System |
| GPS | Global Positioning System |
| GWPI | Groundwater Potential Index |
| IDW | Inverse Distance Weighted |
| JMG | Jabatan Mineral Dan Geosains (Minerals and Geoscience Department) |
| JPBD | Jabatan Perancangan Bandar Dan (Federal Department of Town and Country Planning, Peninsular Malaysia) |
| JUPEM | Jabatan Ukurdan Pemetaan Malaysia (Department of Survey and Mapping Malaysia) |
| Landsat | Land Remote Sensing Satellite |

| | |
|---|---|
| LR | Logistic Regression |
| MINGEOSIS | Minerals and Geoscience Information System |
| MCDM | Multi Criteria Decision Methods |
| MMD | Malaysian Meteorological Department |
| MOA | Ministry of Agriculture |
| MOH | Ministry of Health |
| MOSTI | Ministry of Science, Technology and Innovation |
| NRE | Ministry of Natural Resources and Environment |
| Pls | Plausibility |
| RADARSAT | Radar satellite |
| RI | Random Index |
| RS | Remote Sensing |
| RSO | Malayan Rectified Skew Orthomorphic |
| SPC | Specific Capacity |
| SPOT | Systeme Probatoired Observation de la Terre |
| TIN | Triangulated Irregular Network |
| Unc | Uncertainty |
| WAM | Weighted Aggregation Method |
| WIOA | Weighted Index Overlay Analysis |
| WLC | Weighted Linear Combination |

# CHAPTER 1

# INTRODUCTION

## 1.1 Research background

Groundwater is the most crucial source of water that provides to the needs in all climatic regions in the world and is the most dependable and valuable source of water (Todds and Mays, 2005). The population growth, agricultural requirements, urbanization (Ettazarini, 2007) and rapid industrialization (Pradhan, 2009) has meant that the demand for groundwater is increasing as well. In comparison to the surface water, groundwater has many benefits. Groundwater has a better quality, is less exposed to seasonal and perennial fluctuations and is more protected from the pollutants and infections. Groundwater is much uniformly spread over large areas. In the absence of surface water, groundwater fulfils the need. Hydro-technical facilities for surface water require a large investment in comparison to the groundwater facilities that can be developed gradually.

More than 40% of the global population suffers from water shortage. It is estimated that about 1.8 billion people will be living in areas with scarcity of water by 2025, while two-thirds of the population will be living under critical conditions of water scarcity (FAO, 2012). In developing countries, withdrawal of water is expected to increase by 50% and in developed countries by 18% till 2025 (GEO, 4).

The water situation is expected to deteriorate by 2030, as about 47% of the population is expected to live in water stressed conditions (UNDP, 2006). Regions already under water stress will also be subjected to an increase in population. These areas with a population growth will have a limited access to safe drinking water and sanitation facilities (Unesco, 2012). Groundwater contains about 30% of the world's freshwater reserve. This 30% accounts for the 97% of all the freshwater that is potentially available to humans for usage (UNEP). Groundwater is being used at a faster rate than its replenishing rate in 60% of the European cities with a population of more than 100,000 people (WBCSD, 2007).

In areas with insufficient surface water supply, more dependence is upon groundwater source, such as in Malaysia (Rakan Sarawak, 2003). It is estimated that from 2000 to 2050, the water demand in Malaysia will increase by 63% (Bernama, 2007). Groundwater sources are accounting to 10% of the water supply in Malaysia. Groundwater usage for domestic purposes is about 70%, for industrial purposes is about 25%, while for agricultural purposes is about 5% (Karim, 2006). The states of Kelantan and Perlis are only using groundwater for public usage. 70% of the total water system in Kelantan is obtained from groundwater wells in Kota Bharu (Suratman, 2004). In addition, Selangor state recently faced water crisis which was worst tension after water crisis in 1998 in Klang Valley due to the El Niño phenomenon. This water crisis forced Malaysian government to control water shortage by rationing of water in Selangor state.

## 1.2 Problem statement

To delineate the groundwater resources, it is important to gain reliable geosciences data in the form of geological and hydro-geological applications. Several sectors such as, estates, farms, factories and private production for commercially produced mineral water is using the groundwater sources in Malaysia (Ocned, 2008). The demand for groundwater is higher than the groundwater resource exploitation in Malaysia. Groundwater status in Malaysia shows that less than 10 % of the water usage being developed from groundwater resources with 70 % used for domestic supply, 25 % for industrial supply, and 5 % for agricultural purpose.

Groundwater demand is also increasing due to the insufficient surface water supply (Rakan Sarawak, 2003). There are various reasons for considering Selangor state as a study area. The presence of hard rock aquifer in the region was a primary factor, which have a low to medium potential to store groundwater (JMG, 2007).Igneous rocks also are primarily hard and compact in nature and do not have the porosity (Dar et al., 2011). Groundwater movement is not easy in these rocks, thus this rock is poor in retaining groundwater (Thakur and Raghuwanshi, 2008). In addition, traditionally groundwater exploration of hard rock aquifer is mostly done using the wild cat methods. Apart from that, the ad hoc studies areas are generally based on demands arise and where sources of groundwater are not developed.

The El Nino effect has also contributed to the shortage of water in the region (Bachik et al., 1998). Lately, in February 2014 Selangor state encountered water crisis which should make Malaysian government to attempt a long-term solution. Another reason is also the presence of an electrical hydro project in the area and the supply of daily water to the surrounding communities by Empangan Sungai Langat. Various states of Peninsular Malaysia are experiencing shortage of groundwater during the hot and dry seasons.

The groundwater statistics in Malaysia by the Ministry of Natural Resources and Environment (NRE) reveal the underutilized exploitation of groundwater (only 2%) as compared to other nationssuch as Thailand (80%) and China (70%). The potential of the groundwater sources has not been recognized and hence has not been exploited to its potential. To provide a sustainable water resource, it is important to utilize this water source (The Star, 2012). The conventional method used for the analysis of groundwater for alluvial and fractured rock aquifers in Malaysia was termed by Karim (2006) as inadequate and not systematic. Lithological properties were only used to assess the potential of groundwater map by JMG in 2007. The growing demand of groundwater implies new techniques which can optimize traditional approaches for groundwater potential assessment using data mining and statistical methods for current practice. The conventional methods compared to new methods were mostly based on local information and expert opinion.

## 1.3 Main objective

The general objective of this research is to apply GIS and remote sensing based techniques for interpretation and integration of various hydrogeological datasets for the development of data-driven models to delineate potential zones of groundwater source at Langat Basin, Selangor, Malaysia.

### 1.3.1 Specific objectives

i. To identify and establish of groundwater conditioning factors by using GIS.

ii. To estimate and integrate spatial evidences through various bivariate and multivariate statistical models to quantify the spatial association between groundwater productivity and conditioning features.

iii. To validate the results of various approaches for groundwater potential map and make comparison for final output verification.

## 1.4 Research questions

This research endeavored to answer the following research questions:

i. How many conditioning factors are going to be collected in this research?

ii. What kind of methodology will be used in order to prepare the input data for groundwater potential mapping?

iii. How many methods of data driven techinques are going to use in this research?

iv. Which data driven model is the most suitiable and more accurate for groundwater exploration?

v. Which hydro-geological and conditioning factors have correlation and significant with the groundwater occurrence ?

## 1.5 Hypothesis

It is possible to interpret and integrate diverse groundwater conditioning factors, and known groundwater occurrence data in order to produce groundwater potential map using RS and GIS. To anticipate where these occurrences of interest might occurs, it is required to study spatial interdependence between known groundwater occurrences and certain groundwater conditioning factors that govern the occurrence. GIS-based predictive modelling such as frequency ratio (FR), logistic regression (LR) and evidential belief function (EBF), implicates the analysis of spatial association between multi-layered groundwater conditioning factors and known groundwater occurrences to predict where the wells might have been mostly extracted.

## 1.6 Theoretical framework

A large part of the study area is formed by hard rock and since this study aims to delineate groundwater potential need to prepare groundwater controlling factors which included lithology, lineament density, river density, elevation, slope, curvature, stream power index, topographic wetness index, soil, land use and rainfall. Using three different types of data driven method of GIS modelling techniques included FR, LR and EBF was carried out in order to produce groundwater potential map. These were selected to compare the predicted groundwater potential map produced using data driven approach.

## 1.7 Scope of the study

Twelve groundwater conditioning factors were selected for this study including; elevation, slope, curvature, topographic wetness index, stream power index, drainage density, lineament density, lithology, normalized difference vegetation index, soil, land use and rainfall. Three type of groundwater potential map would be generated using statistical methods such as frequency ration, logistic regression and evidential belief function model. The groundwater potential map were optimized using Dempster-Shafer theory which allows modelling of the degrees of uncertainty in the prediction. Each final output were compared and validated using borehole well data which were not used within analysis.

## 1.8 Significant contribution

This study applied various statistical approaches to evaluate the importance and association of several groundwater conditioning factors. The hypothesis of the study can be proved by verified results through groundwater occurrence in the study area. The methodologies of integration of GIS and remote sensing provide a rapid, powerful tool and low cost technique in the search for groundwater compared to the current practice of conventional method of groundwater exploration and assessment projects.

### 1.9 Outline of the thesis

This thesis is divided into five chapters, including;

**CHAPTER 1: INTRODUCTION**. This chapter mentioned briefly about the problem statement of the study, goal, objectives and scope of the study.

**CHAPTER 2: LITERATURE REVIEW**. This chapter provides an overview of groundwater status in Malaysia and previous work of using GIS and remote sensing for groundwater potential mapping. Next, discussion about satellites imageries and sensors applied by the researchers in groundwater resources exploration and assessment. Then, discussion describing the methodology used for identification and extraction of groundwater controlling factors and type of GIS modelling technique applied for generation of groundwater potential maps. Finally, validation methods were used to assess the accuracy of maps produced are summarized.

**CHAPTER 3: METHODOLOGY.** This chapter describes in detail about the characteristics of the study area. Then followed by the materials, methodology, GIS modelling and model validation used for delineation of groundwater potential zones using data-driven GIS technique and remote sensing.

**CHAPTER 4: RESULTS AND DISSCUSSION.** This chapter concentrates on the outcomes of the study including results of integration GIS modelling techniques which supported by diagrams, tables, equations and charts. Next, this chapter also discussed on the comparative analysis of data-driven GIS modelling techniques in groundwater potential mapping.

**CHAPTER 5: SUMMARY, CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH.** This chapter provides the overall conclusion from this study, recommendation and further research for the study area.

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