UNIVERSITI PUTRA MALAYSIA

GOLD POTENTIAL MAPPING USING BIVARIATE AND MULTIVARIATE STATISTICAL MODELS IN GIS AT GUA MUSANG, MALAYSIA

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FK 2015 173

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By

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Thesis Submitted to the School of Graduates Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

JANUARY 2015

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

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January 2015

Chairman: Biswajeet Pradhan, PhD

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Throughout the history of humanity, gold remains as the most desired metals. Due to its small occurrences in the earth's crust, this precious metal acquisition is very difficult. In Malaysia, gold potential map have been generated using conventional methods and are inadequate and lacking the ability to assess the accuracy. Develop new techniques has overcome this weakness and currently used around the world. The first time to be applied in Malaysia, this study aim to assess the capability of data-driven Geographical Information System (GIS) modelling technique for mapping gold potential areas of Kelantan, Malaysia. The study area is located at the south of Kelantan state, Malaysia borders Pahang state. The study area covers about 593 km^2 and is situated approximately 186 km from Kota Bharu, Kelantan. In this study, six gold deposit controlling factors that influence the gold deposit occurrences were extracted from available maps and spatial databases. These controlling factors are: lithology, fault, geochemical data of Copper (Cu), Lead (Pb) and Tungsten (W) and geophysical data of Potassium (K). In the GIS environment, all six controlling factors were integrated and modelled based on data-driven technique. The generation of the gold potential map was carried out using two different types of GIS modelling techniques. The models applied are evidential belief functions (EBF) and logistic regression (LR). The spatial relationship between gold deposit and its controlling parameters was assessed. The predicted gold potential map was classified into four distinct zones based on the classification scheme from the literatures. The analysis and comparison of these results indicate that: (1) The gold potential map generated by EBF model is considered as the best results with prediction accuracy of 81%, (2) The gold potential map generated using LR model has low prediction accuracy of 62.67% and (3) The most influential controlling factors for gold deposit occurrences is lithology, followed by Cu, W, fault, K and Pb. The predicted gold potential map of the study area generated using EBF technique indicated that about 4.8% or 28.49 km^2 are in the very high potential zone, with about 10.9% or 65.22 km^2 in high potential zone, with about 38.7% or 229.6 km^2 fall in the moderate potential zone, and about 45.6% or 269.69 km^2 constituting the low potential zone. The results indicate that it can be used for future planning of gold exploration by providing a rapid reproduction approach with reduce

time and cost. The results also demonstrate that this modelling technique may also apply to other area with similar parameters.

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

PEMETAAN POTENSI EMAS MENGGUNAKAN MODEL STATISTIK BIVARIAT DAN MULTIVARIAT DALAM GIS DI GUA MUSANG, MALAYSIA

Oleh

SUHAIMIZI BIN YUSOFF

Januari 2015

Pengerusi: Biswajeet Pradhan, PhD

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Sepanjang sejarah manusia, emas kekal sebagai logam yang paling dikehendaki. Disebabkan kewujudan kecil dalam kerak bumi, pemerolehan logam berharga ini adalah sangat sukar. Di Malaysia, peta potensi emas telah dihasilkan menggunakan kaedah konvensional yang selalunya tidak memadai dan tidak mempunyai keupayaan untuk dinilai ketepatannya. Penghasilan teknik-teknik baru telah mengatasi kelemahan ini dan pada masa ini sedang digunakan di seluruh dunia. Kali pertama untuk digunakan di Malaysia, kajian ini bertujuan untuk menilai keupayaan teknik pemodelan panduan data Sistem Maklumat Geografi (GIS) untuk pemetaan kawasan potensi emas di Kelantan. Kawasan kajian terletak di selatan negeri Kelantan, Malaysia bersempadan dengan negeri Pahang. Kawasan kajian meliputi kira-kira 593 km^2 dan terletak kira-kira 186 km dari Kota Bharu, Kelantan. Dalam kajian ini, enam faktor yang mempengaruhi kewujudan deposit emas diekstrak daripada peta-peta dan pangkalan data spatial yang ada. Faktor-faktor yang mempengaruhi adalah: litologi, sesar, data geokimia tembaga (Cu), Plumbum (Pb) dan Tungsten (W) dan data geofizik kalium (K). Kesemua enam faktor pengawal disepadukan dan dimodelkan berdasarkan teknik panduan data di dalam persekitaran GIS. Penghasilan peta potensi emas dilakukan dengan menggunakan dua teknik pemodelan GIS yang berbeza. Model-model yang digunakan adalah *evidential belief functions* (*EBF*) dan *logistic regression* (*LR*). Hubungan spatial antara deposit emas dengan parameter-parameter yang mengawalnya dinilai. Peta ramalan potensi emas diklasifikasikan kepada empat zon berbeza berdasarkan skema klasifikasi dari literasi. Analisis dan perbandingan keputusan menunjukkan bahawa: (1) Peta potensi emas yang dihasilkan menggunakan model *EBF* dianggap sebagai hasil yang terbaik dengan ketepatan ramalan sebanyak 81%, (2) Peta potensi emas yang dijana menggunakan model *LR* mempunyai ketepatan ramalan yang rendah iaitu 62.67% dan (3) Factor yang paling berpengaruh untuk kehadiran deposit emas adalah litologi, diikuti dengan Cu, W, sesar, K dan Pb. Peta ramalan potensi emas kawasan kajian menggunakan teknik *EBF* menunjukkan kira-kira 4.8% atau 28.49 km^2 berada di dalam zon potensi sangat tinggi, kira-kira 10.9% atau 65.22 km^2 di zon berpotensi tinggi, kira-kira 38.7% atau berjumlah 229.6 km^2 di zon potensi sederhana, dan kira-kira 45.6% atau 269,69 km^2 membentuk zon potensi rendah. Keputusan menunjukkan bahawa ia boleh digunakan untuk perancangan masa depan penerokaan

emas dengan menyediakan pendekatan penghasilan semula peta ramalan yang pantas dengan pengurangan masa dan kos. Keputusan ini juga menunjukkan bahawa teknik pemodelan ini juga boleh digunakan di kawasan lain dengan parameter yang sama.

ACKNOWLEDGEMENTS

First of all praise to Allah the Almighty for His blessings that gives me strength which enable me to complete this MSc thesis. Honestly, I face many obstacles to complete this study within the time period given of two years by the financial sponsor. So I would like to take the opportunity to thank my supervisor, Associate Prof. Habil Dr. Biswajeet Pradhan for checking and editing the draft of my thesis. He also gives many valuable suggestions as well as continuous encouragement during the preparation of this thesis.

I also want to thank other members of supervisor committee Associate Prof. Dr. Helmi Zulhaidi Mohd. Shafri who have helped and give me a lot of invaluable advices. Thousands of thanks to Prof Dr. Wan Fuad Wan Hassan, Dr. Mohamad Abdul Manap, Dr. Nuraini Surip, Wan Mohd Razi Idris, Mohd Zukeri Ab Ghani, Mustafa Hamzah, Abdul Halim Hamzah, Abdul Hadi Abdul Rahman, Zulkiflee Che Soh, John Joseph Jinap, Mohd Anuar Ishak, Mohamed Hizam Abdul Kadir, Mohamed Asri Omar, and Zaki Alias who give cooperation and suggestion.

Besides that, I would like to express my gratitude to my current employer the Department of Minerals and Geoscience (JMG) and Department of National Mapping and Survey (JUPEM) for providing the necessary data and information to undertake during this study.

I also want to express my appreciation to JMG for selecting me to pursue my study at the MSc level. I would like to express my gratitude to the Government of Malaysia through the Public Services Department (JPA) for providing the financial support.

To my colleagues and friends particularly in the JMG Terengganu, JMG headquarters in Kuala Lumpur, JMG state office, Universiti Putra Malaysia (UPM) and Universiti Kebangsaan Malaysia (UKM), many thanks to all of you for your supports and assistances.

Last but not least, my warmest thanks to my family members especially my beloved wife Seri Hayati Annuar, my three charming prince and princesses namely Nur Husna, Mohamad Haris and Nur Hazirah, my parent Hajjah Karimah Abdullah and Haji Yusoff Ali, my wife parent Che Mahani Tengku Ibrahim and Annuar Yahya, my siblings as well as my wife siblings who have been very supportive and faithfully praying all the time for my success.

I certify that a Thesis Examination Committee has met on 30 January 2015 to conduct the final examination of Suhaimizi bin Yusoff on his thesis entitled "Gold potential mapping using bivariate and multivariate statistical models in GIS at Gua Musang, Malaysia" 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 Master of Science.

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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 Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by graduate student

I hereby confirm that:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
cps	Counts per Second
EBF	Evidential Belief Functions
ETM+	Enhanced Thematic Mapper Plus
FR	Frequency Ratio
GDP	Gross Domestic Product
GIS	Geographical Information Systems
JMG	Minerals and Geoscience Department
LR	Logistic Regression
MINGEOSIS	Minerals and Geoscience Information System
PALSAR	Phased Array type L-band Synthetic Aperture Radar
SPOT	Satellite Pour l'Observation de la Terre
UKM	National University of Malaysia
UM	University of Malaya
WoE	Weights-of-Evidence
WGS84	World Geodetic System 1984

CHAPTER 1

INTRODUCTION

1.1 Background to the research

For centuries mankind has been captivated by the absolute beauty of gold and its many unique properties. In recent years, the price of gold has raisen sharply due to an ever increasing demand for gold that is always exceeding supply. World gold supply in 2013 mainly comes from China, Australia, Russia, United States of America, Peru, South Africa and other countries (Australian Gold, 2013). Throughout the history, foreign traders have acknowledged the Malay Peninsula as a gold producing country or Aurum Khersonese as written by Claudius Ptolemy in the second century AD (Wheatley, 1961).

Gold abundance in the earth's crust is very rare, making the metal acquisition very difficult. The abundances of gold in igneous rock and sediment earth's crust are very small between 4-6ppb (Turekian and Wedepohl, 1961), like 4 peas in 1,000 tonnes of sand. In Malaysia, the figure is also quite similar with granite rocks having 1.0 ppb (Hassan et al., 1997). This small abundance contributes to the low content of gold in earth. As a reference, a total of 174,100 tonnes of gold have been extracted until 2012 (World Gold Council, 2013a). This is roughly equivalent to about 9,261 m^3.

Approximately 50% of the world's gold has been used as jewelry, 40% in finance, and 10% in manufacturing. The price of gold as of 2013 was RM159 per gram and nearly 60% of the gold's price goes to the extraction process (World Gold Council, 2013b).

Currently, gold occurrences in Peninsular Malaysia are predominantly found in the Central Belt, stretching from Batu Melintang in Kelantan in the North and southwards through Sokor, Pulai, Selinsing, Raub, Chenderas to Gunung Ledang in Johor (Chu, 2000). Although seemingly random, gold distribution is actually controlled by geological processes, mostly by the Permian-Triassic volcanic arc of Peninsular Malaysia. Types of gold mineralization in Peninsular are quartz vein, massive sulphide, skarn type and intrusion-related gold.

According to MacDonald (1967), gold production in Kelantan started from Pulai through Galas and Pergau until the border of Thailand. At that time, the most important area for gold production was Pulai (Middlebrook, 1933). Kelantan produced a great deal of gold in early 19th century that Dodge (1977) assumed Kelantan was the main gold producer in Peninsular Malaysia. In Kelantan, gold exploration by the Europeans was pioneered by Duff Company in 1903 using dredge for placer gold in Sungai Galas and adit for primer gold in Sokor. However, due to lack of profit, the works stopped in 1907 (Low, 1921).

1.2 Problem statement

In Malaysia, less effort is made on gold potential mapping using Geographic Information System (GIS) and Remote Sensing (RS). Only Surip et al., (2007) presented some case studies in Penjom-Merapoh, Pahang using knowledge- driven modeling techniques. This present study is the first attempt to utilize data-driven techniques in GIS environment. GIS is used in the integration and analyzing of a selection of Geoscience information, namely geological, geochemical and geophysical factors. The spatial relationships between geochemical, geological and geophysical factors with gold deposits occurrences are unknown. No gold potential map has been generated from multiple controlling factors such as geochemical, geological and geophysical data. The existing published gold potential map by JMG in the year of 1987 is based only on the conventional approach of overlaying factors without qualitative analysis with the gold deposits and this can be further improved using new techniques.

1.3 Goal of study

The goal of this study is to evaluate the capability of data-driven GIS modelling techniques for mapping gold potential areas at Gua Musang, Kelantan, Malaysia.

1.4 Objectives

There are four main objectives of this study as follows:

i. To identify the spatial relationship between geochemical, geological and geophysical factors with the occurrence of gold;

ii. To apply bivariate and multivariate prediction models (evidential belief functions and logistic regression) for finding the best prediction approach for gold potential mapping in Malaysia;

iii. To generate gold potential maps using a quantitative gold potential index;

iv. To compare the predicted gold potential map with the existing published gold potential map by JMG;

1.5 Research questions

This study will try to answer four research questions, which are:

i. What are the factors that control the occurrences of gold in the study area?

ii. Which controlling factors have significant association with occurrences of gold in the study area?

iii. Which data-driven GIS modeling technique is the most suitable for delineation of the gold potential map in the study area?

iv. Are the generated gold potential maps from GIS performing better than the currently published gold potential map?

1.6 Scope and limitation of the study

The list below contains the scope of the study:

i. Gold deposit.

There are eight known gold deposits in the study area. This research is to assess and understand the spatial correlation with features controlling its occurrences.

ii. Gold deposit occurrences controlling factors.

Six gold deposit controlling factors were used in this study i.e. lithology, fault, geochemical data of Copper (Cu), Lead (Pb) and Tungsten (W) and geophysical data of Potassium (K).

iii. Generation of predicted gold potential map by using two different types of data-driven GIS modeling techniques.

The models are evidential belief functions (EBF) and logistic regression (LR).

iv. Model validation using area under the curve (AUC) and the existing gold deposit.

An available gold deposits was used for model validation.

v. Map comparison for the best data-driven GIS modelling technique.

Comparison between predicted gold potential maps generated from evidential belief functions and logistic regression.

This study is limited by two factors, namely:

i. The type of gold deposit.

Due to lack of information, it is unknown whether gold deposits used are primary or secondary. Knowing the type will provide a more focused study.

ii. Limitation of gold potential map produced.

Gold potential in this study is rather estimated. The economic value is not considered as the size and grade of deposit cannot be determined.

1.7 The structure of the thesis

This thesis is split into five chapters. The summary of each chapter is:

i. **CHAPTER 1: INTRODUCTION**. This chapter briefly discusses the problem statement of the study, its goal, objectives and the scope of the study. Also included in this chapter are research questions and the overall structure of the thesis.

ii. **CHAPTER 2: LITERATURE REVIEW**. This chapter provides an overview of the gold status and previous works on gold potential mapping based on GIS and RS in Malaysia. It also presents the gold controlling factors that influence the gold occurrences and a discussion describing the GIS modeling techniques applied to delineate the gold potential areas. Lastly, the validation approaches were used to evaluate the accuracy of the prediction maps.

iii. **CHAPTER 3: METHODOLOGY.** This chapter briefly describes the characteristic of the study area. It then focuses on methodology, the sources of all the data, the GIS model used and their validation approach for gold potential mapping of the study area.

iv. **CHAPTER 4: RESULTS AND DISCUSSION.** This chapter shows the findings of the two different types of data-driven GIS modelling techniques supported by diagrams and tables, followed by a comparison between the two data-driven GIS modelling technique in gold potential mapping and a comparison of the best predicted gold potential map with the existing gold prospective map of JMG. Finally, a selection of the best prediction gold potential maps and the significant relationship between gold controlling factors with gold occurrences in the study area will be discussed.

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

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