UNIVERSITI PUTRA MALAYSIA

EVALUATION OF SUSTAINABLE GROUNDWATER EXTRACTION FOR WATER INTAKE USING VISUAL MODFLOW AT TANJUNG MAS

MUHAMMAD AIDIL HAKIM BIN MHD RAMZAM

EVALUATION OF SUSTAINABLE GROUNDWATER EXTRACTION FOR WATER INTAKE USING VISUAL MODFLOW AT TANJUNG MAS

By

MUHAMMAD AIDIL HAKIM BIN MHD RAMZAM

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

January 2020

COPYRIGHT

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

EVALUATION OF SUSTAINABLE GROUNDWATER EXTRACTION FOR WATER INTAKE USING VISUAL MODFLOW AT TANJUNG MAS

By

MUHAMMAD AIDIL HAKIM BIN MHD RAMZAM

January 2020

Chairman : Mohamed Azwan bin Mohamed Zawawi
Faculty : Engineering

Groundwater is the largest available reservoir of freshwater in the world with a low risk of contamination and will remains available during summer. In Kelantan mainly on the northern part had taken best of this opportunity which turns this state into the largest groundwater abstraction in Malaysia. The groundwater abstraction activities started to increase when Kelantan river became high in contamination due to logging in the upper stream and uncontrolled sand mining which then forces the locals to find another alternative of freshwater sources. Subsequently, problems occur when some country in the world had suffered from land subsidence and seawater intrusion caused by over abstraction of groundwater in a particular area. To sustain the groundwater supply, understanding of the groundwater system is essential to develop proper groundwater management for future use.

This research aims to investigate the sustainability of groundwater source at Northern Kota Bharu area for portable use. In the current situation, pumping activities at Kg Puteh, Pintu Geng and Tanjung Mas wellfield are running with a capacity of 37200m3/day, 9696 m3/day and 9875 m3/day. A suggestion has been made to increase the abstraction of groundwater at Tanjung Mas wellfield to 25375 m3/day which affect the current environment. Two-dimensional Electrical Resistivity method has been used to estimate the geological structure of the study area. 3 main layers has been identified in this study; sandy silt, gravelly sand and bedrock. with aids of resistivity and geological log, a groundwater model has been developed by using Visual MODFLOW software version 4.6 to evaluate the groundwater system at the study area. The model has been calibrated with r=0.802 and the calibrated groundwater model was then applied for prediction in normal and dry season.

In this study, the prediction climate data were obtained from the Department of Irrigation and Drainage (DID). Groundwater recharge for the dry season was taking by 6% from the average annual rainfall while normal season is taking 18% of the average annual rainfall. The simulation result shows that groundwater source can be abstracted during normal condition with average recharge equal to 472.56 mm/year and total groundwater abstraction, of 9875 m3/day at Tanjung Mas wellfield without disturbing current pumping activities at Kg Puteh wellfield. In case of dry periods (recharge = 169.780mm/year), it can be seen the wide radius of influence, especially when increasing the pumping rate to 25375m3/day at Tanjung Mas wellfield. Tanjung Mas wellfield in scenario 4 has been taken to study the possibility for the subsidence to occur. Using Terzaghi's consolidation theory, the total land subsidence can occur in this site is 0.035 meter if the water table drops for a long period. The calculation for 90% final subsidence for clay layers will take place after 21.8 years and this makes the subsidence rate at Tanjung Mas wellfield 1.47 mm per year. With the combination of population growth management, conservation strategies and augmentation of existing groundwater supplies, the groundwater model will become an important tool for sustainable groundwater development.

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

PENILAIAN PENGAMBILAN AIR BAWAH TANAH YANG MAMPAN UNTUK PENGGUNA AIR MENGGUNAKAN VISUAL MODFLOW DI TANJUNG MAS

Oleh

MUHAMMAD AIDIL HAKIM BIN MHD RAMZAM

Januari 2020

Pengerusi : Mohamed Azwan bin Mohamed Zawawi
Fakulti : Kejuruteraan

Air bawah tanah adalah takungan air terbesar yang terdapat di dunia dengan risiko pencemaran yang rendah dan akan tetap ada pada musim panas. Di Kelantan terutamanya di bahagian utara telah mengambil kesempatan ini dan menjadikan negeri ini sebagai pengekstrakan air bawah tanah terbesar di Malaysia. Kegiatan pengekstrakan air bawah tanah mulai meningkat apabila sungai Kelantan menjadi pencemaran yang tinggi disebabkan oleh pembalakan di kawasan hulu dan perlombongan pasir yang tidak terkawal yang kemudian memaksa penduduk tempatan untuk mencari sumber alternative air tawar. Selepas itu, masalah berlaku apabila sesetengah negara di dunia mengalami pemendapan tanah dan pencerobohan air laut yang disebabkan oleh lebihan pengekstrakan air bawah tanah di kawasan tertentu. Untuk mengekalkan bekalan air bawah tanah, pemahaman tentang sistem air bawah tanah adalah penting untuk membangunkan pengurusan air bawah tanah yang sesuai untuk kegunaan masa depan.

Tujuan penyelidikan ini adalah untuk menyiasat kelestarian sumber air bawah tanah di kawasan Utara Kota Bharu untuk kegunaan setempat. Dalam keadaan semasa, aktiviti pengepaman di Kg Puteh, Pintu Geng dan Tanjung Mas wellfield sedang berjalan dengan kapasiti 37200m^3/hari, 9696 m^3/hari dan 9875m^3/hari. Cadangan telah dibuat untuk meningkatkan pengekstrakan air bawah tanah di Tanjung Mas wellfield kepada 25375m^3/hari yang memberi kesan kepada persekitaran semasa. Kaedah kerintangan elektrik dua dimensi telah digunakan untuk menganggarkan struktur geologi kawasan kajian. 3 lapisan utama telah dikenalpasti dalam kajian ini; lumpur berpasir, pasir berkerut dan batuan dasar. Dengan bantuan kerintangan elektrik dan log geologi, model air bawah tanah telah dibangunkan dengan menggunakan perisian Visual MODFLOW versi 4.6 untuk menilai sistem air bawah tanah di kawasan kajian. Model ini telah dikalibrasi dengan r = 0.802 dan model air

bawah tanah yang dikalibrasi kemudiannya digunakan untuk ramalan pada musim normal dan musim kering

Dalam kajian ini, data iklim ramalan diperoleh dari Jabatan Pengairan dan Saliran. cas semula air bawah tanah pada musim kering diambil sebanyak 6% daripada hujan tahunan purata manakala musim biasa diambil 18% daripada hujan tahunan purata. Hasil simulasi menunjukkan sumber air bawah tanah dapat diekstrak semasa musim normal dengan purata cas semula 472.56 mm/tahun dan jumlah pengekstrakan air bawah tanah sebanyak 9875m^3/hari di kawasan Tanjung Mas tanpa mengganggu aktiviti pengepaman semasa di Kg Puteh. Dalam kes tempoh kering (cas semula = 169.780 mm/ tahun), dapat dilihat radius luas pengaruh terutama apabila meningkatkan kadar pam hingga 25375m^3/hari di Tanjung Mas. Keadaan Tanjung Mas dalam senario 4 telah diambil untuk mengkaji kemungkinan pemendapan tanah yang akan berlaku berlaku. Dengan menggunakan teori penggabungan Terzaghi, jumlah penenggelaman tanah boleh berlaku di laman web ini adalah 0.035 meter jika jadual air jatuh dalam tempoh masa yang lama. Pengiraan untuk penebusan akhir 90% untuk lapisan tanah liat akan berlaku selepas 21.8 tahun dan ini menjadikan kadar pemendapan tanah di Tanjung Mas 1.47 mm setahun.

Dengan gabungan pengurusan pertumbuhan populasi, strategi pemuliharaan dan pembesaran bekalan air bawah tanah sedia ada, model air bawah tanah akan menjadi alat penting untuk pembangunan air bawah tanah yang mapan.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and praise to Allah SWT who has given me strength and guidance along the journey in fulfilling the requirement of this study.

Thanks to Allah for giving me such parents who always pray for my success. Not forget also to my brothers who gave me the word of light and always positive.

I wish to show greatest thanks especially want to thank my supervisor, En Mohamed Azwan Bin Mohamed Zawawi, for his important support, sharing and advice during the past three years. His experience in this field is not comparable and very useful guidance to complete this study.

Lastly, special thanks to Biological and Agricultural Engineering Department staff and friends who assist me directly or indirectly. May Allah reward for your good deeds.

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:

Mohamed Azwan bin Mohamed Zawawi
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ahmad Fikri bin Abdullah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:12 August 2021

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.: Muhammad Aidil Hakim bin Mhd Ramzam (GS48375)

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) are adhered to.

Signature:	___________________________
Name of Chairman of Supervisory Committee:	Mohamed Azwan bin Mohamed Zawawi

Signature:	___________________________
Name of Member of Supervisory Committee:	Prof. Madya Dr. Ahmad Fikri bin Abdullah

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ºC	Degree celcius
3D	Three dimensional
2D	Two dimensional
VES	Vertical electrical sounding
ERI	Electrical resistivity imaging
TDS	Total dissolve solid
MRS	Magnetic resonance sounding
TDEM	Time domain electromagnet
Ωm	Ohm-meter
CMB	Chloride mass balance
ET	Evapotraspiration
K	Hydraulic conductivity
n	Porosity
e	Void ration
w	Water content
ρ	Density
ϒ	Unit weight
E	Modulus of elasticity
AMSL	Above mean sea level

CHAPTER 1

INTRODUCTION

1.1 Background Study

Water is one of the valuable natural resources for human life and other living things. It plays a significant role in ensuring sustainable agriculture production for food security in this world. In Malaysia, there are about 97% of our surface water source supplied for domestic, agricultural and industrial needs especially river (FAO, 2016; Hock, 2008). According to Gleick (2019), there is only 1% of surface water is usable by humans and the rest of the usable quantity is situated underground. With this little amount of usable water, there will be a problem in providing adequate water sources as the population growth. The critical phase is when Malaysia experience dry season, the water demand will increase and become worse if involve with the contaminated water situation. In order to solve this issue, proper management and conveyance system becomes a key factor in contributing to the sustainable water supply.

Groundwater is the largest reservoir available of freshwater in this world. It is an alternative source that is expected with low risk of getting contaminated and the water remaining available even during summer. Estimation and understanding of groundwater recharge mechanism and capacity of an aquifer is a vital practice for preserving groundwater storage, as the abstraction rate from an aquifer should not more than the recharging rate in a long term process. Reliable estimates of groundwater recharge rates are required for effective evaluation of groundwater storage capacity. The contact between groundwater and surface water body becomes the major concern in water resources management today. Almost all surface water bodies are linked with groundwater especially in the shallow aquifer. Hence, these two sources of water must be treated as a combined system when studied regarding water quantity quality issues. Since surface water and groundwater are being one source, the possibilities for it to affect each other in term of quality is very high (Winter, 1999). The estimation of surface-groundwater interaction not only to know how much water surface recharge and discharge but also as a model to control the environmental pollution beneath the surface.

Kelantan is one of the state in Malaysia that use groundwater as a primary source for portable water supply. However, over-abstraction of groundwater can lead to harmful geomorphological effects. To determine the groundwater resources is quite challenging. It is difficult to quantify the groundwater resources as it is hidden beneath the earth's crust. Therefore, the study is needed to understand its process and this makes the required data acquisition will be extremely expensive. Groundwater exploration is similar to the exploitation of oil and gas. The investigation cost is crucial in investment for the safely exploited groundwater resources. It is important to quantify the groundwater resource accurately so that all the necessary information regarding the place can be used in the future.

Groundwater modelling is an effective tool in groundwater supervision and remediation today. A model is a simplification of the real natural phenomenon to study and predict the effect of future phenomena. The challenge is to simplify reality that does not poorly influence the accuracy and ability of the model output to meet the desired objectives by using a properly designated conceptual model. To develop a good conceptual model, all the data needed must be reliable and meet the acceptable calibration term before writing to model report.

1.2 Problem Statement

Malaysia is a blessed with an abundance of rainfall annually which average 3000 mm throughout the year and rich with water resources. Most of the surface water resources are obtained from rainfall, river, lake, and stream. Even though Malaysia rich with surface water, but it can be easily affected by extreme weather condition. In 2014, Selangor have faced extremely hot weather, which shows no time of relieved soon, was affect the water supply system and reduce the water level at Sg Selangor dam in Kuala Kubu Baru more than 50% (Ying, 2014).

Besides, surface water tends to experience pollution due to lack of control of human activities. Many types of pollution, such as sewage, detergents, oil spills, muddy stream by the floods, deforestation and quarrying, causing the treatment plant had to be closed. In the case of Kelantan, the Kelantan River's water has been turbid since the 1990s because of the high amount of suspended solids and siltation. This was caused by logging activities in the upstream area and sand mining (Yen and Rohasliney, 2013; Ambak and Zakaria, 2010). The extremely high content of total suspended solids and turbidity have caused poor and stressful condition not only for the aquatic life but also for human use.

Water consumption increases along with an increase in population, economic development and growth and accompanying increase in living standard. Urbanization, climate change, renewed emphasis on environmental water needs and the need for the life millions of people offer great challenges to the agriculture sector. In 1987, there are 18 water supply systems in Northern Kelantan. They can be categorised as groundwater supply system and river abstraction supply system. As groundwater constitutes the largest source of supply in the study area, a total of 9 groundwater supply has been developed in and around the town of Kota Bharu. Most of the groundwater is abstracted from the first aquifer which generally lies between 5 to 15 meters depth below ground surface (Heng and Singh, 1989). It also states that the groundwater contained beyond this depth is called deep groundwater and three main aquifers have been recognized named 2nd, 3rd and 4th aquifers. Water in 2nd aquifer is brackish whereas it is saline in the 4th aquifer.

Kota Bharu area is located near the coastal area which is underlain by Quaternary alluvium. This area has good groundwater potential because located near the Kelantan river and the elevation is less than 20 meters. Even though it has good groundwater potential, but does mean that it can be extracted blindly without proper management. The common problems occur when over-abstraction of groundwater near coastal area due to water demand by the growing population is seawater intrusion. In the 1970s, 11 tubewell belongs to water companies at England have been closed due to saltwater intrusion problem and 50 sites belong to industry and private abstractors. Thus, this reminds us that Malaysia needs to have enough understanding of the movement of the groundwater system.

Furthermore, even the groundwater consumption is still low in Malaysia but we need to consider the impact of over-abstraction for a certain place. Over abstraction means that the usage rate of groundwater is greater than the rate at which it is replaced by natural processes. According to FOMCA (2009), over-abstraction groundwater can lead to the social, economic and environmental consequences including land subsidence and damage to surface infrastructure, saltwater intrusion, declination of surface water bodies and critical changes in patterns of groundwater flow to and from adjacent systems is also recorded.

Past problem due to over-abstraction at the United States of America reported that more than 17,000 square miles in 45 states were having land subsidence problems. Approximately 83% of the problem took place due to groundwater abstraction (National Research Council, 1991). At China, the maximum depth of land subsidence was recorded at 2.63 meters in shanghai City from 1921 to 1965 and in Tianjin City, it was recorded at 2.46 meters from 1959 to 1985 (Ruilin, 2006). Also, a research has been conducted by Din. M et al. (2015) using Persistent Scattered (PS) InSAR and focused on three prominent well field which is Pintu Geng, Tanjung Mas and Tumpat. This method uses an image from satellite to processes and extracts the deformation signal with time period. The deformation rate was verified by correlated with GPS time series and supported with a hydrogeological map. It was found that the deformation rate at Tanjung Mas, Pintu Geng and Tumpat was 2.39 mm/yr, 1.78 mm/yr and 1.87 mm/yr. This small amount of subsidence is relatively small compared with time period.

Sustainable groundwater abstraction is very important to prevent any undesirable incident as discussed before. Northern Kelantan is where most of the entire population are depending on groundwater whether through state government nor individual itself. But the main concern for this problem is the abstraction of groundwater from the state government that more than 50 MLD from different wellfield. This amount is large enough to pull seawater of its located near to the coastal area. Even though until now there is no sign of environmental effect like other countries, it is good to take precaution step to prevent before it happens.

1.3 Objectives

The main objective of this research is to evaluate the sustainable abstraction of groundwater at Tanjung Mas as a water intake for portable use. The specific objectives of this research are:

i. To characterize the potential aquifer of using electrical resistivity tomography and well log.

ii. To develop a hydrogeological model using Visual MODFLOW software.

iii. To evaluate the predicted groundwater abstraction from Tanjung Mas wellfield to avoid environmental effect at the surrounding area.

1.4 Scope of Work

This research is divided into three phases i.e. development of a conceptual hydrogeological model, calibration of the hydrogeological model and application of the hydrogeological model for prediction under different climate condition. The evaluation of land subsidence focused at Tanjung Mas wellfields because the increase in groundwater abstraction only recommended in Tanjung Mas area. The calibration part is crucial as it leads to the proper conceptual model and also determines whether the model is acceptable or vice versa. To achieve these objectives, the following step must be done:

i. The preliminary investigation involves searching the secondary data from internet, journals, reports and agencies involved regarding the data needed for this research.

ii. Site survey has been conducted to develop a better understanding regarding the condition of land use and environment around the study area.

iii. Conducting electrical resistivity survey using ABEM Terrameter with electrode selector and other accessories

iv. Develop a hydrogeological conceptual model using Visual MODFLOW software.

v. Calibration of the hydrogeological model.

vi. Conducting Simulation of groundwater abstraction on a different scenario for prediction.

1.5 Limitation

i. The default value was used for aquifer properties in groundwater simulation as there are limited data of pumping test to estimate these parameters. Resistivity survey has been conducted to determine the potential aquifer layer in the study area.

ii. The river information provided by DID only available at Sungai Kelantan. Several assumptions have been made at Pengkalan Chepa River, Baung river and Pengkalan Datu River.

iii. Groundwater head measurement is based on secondary data taken only in the year 2002. Thus the gap period of groundwater head and boundary condition will affect the model accuracy and groundwater flow modelling prediction

iv. As the data available are limited, only steady-state was considered in this research.

v. This research only focused on groundwater quantitative measurement. Groundwater quality is excluded from this study.

vi. The sustainability of groundwater was evaluated in terms of the environmental impact of land subsidence only in Tanjung Mas wellfield. Kg Puteh and Pintu Geng wellfield are excluded in this section.

REFERENCES

Abdullah, N. I. (2015). Malaysians need to reduce water consumption. Selangor: Malaysiakini.

Abdullahi, Musa Garba et al. (1997). "Assessment of Natural Groundwater Recharge in Terengganu, Malaysia Assessment of Natural Groundwater Recharge in Terengganu, Malaysia." Annual Geological Conference (November).

Adeoti, L., O. M. Alile, and O. Uchegbulam. (2010). "Geophysical Investigation of Saline Water Intrusion into Freshwater Aquifers: A Case Study of Oniru, Lagos State." Scientific Research and Essays 5(3): 248–59.

Ahmed Amara Konaté, H. P. (2015). Machine Learning Interpretation of Conventional. Advances in Swarm and Computational Intelligence (pp. 360-370). Switzerland: Springer

Aktürk, Ö., & Doyuran, V. (2012). Soil Profile Identification Around Necatibey Subway Station (Ankara, Turkey), Using Electrical Resistivity Imaging (ERI) Özgür Aktürk,1 and Vedat Doyuran 2 1. International Journal of Engineering & Applied Sciences, 4(4), 1–14.

Alley, W. M., Reilly, T. E., & Franke, O. L. (1999). Sustainability of Ground-Water Resources, U.S. Geological Survey Circular 1186. U.S. Geological Survey Circular 1186, 79.

Ambak M. A. and Zakaria M. Z. (2010). *Freshwater fish diversity in Sungai Kelantan.* Journal of Sustainability Science and Management 5(1): 13-20. (1):13-20

Anderson, M. P., & Woessner, W. W. (1992). Applied ground water modeling: Simulation of flow and advective transport. Academic Press. Inc., New York, NY.

Anderson M P and Woessner W. W. (2002) Applied groundwater modeling – Simulation of flow and advective transport

Anderson, M. P., Woessner, W. W., & Hunt, R. J. (2015). Applied groundwater modeling: simulation of flow and advective transport. Academic press.

Ashrafianfar, N., Busch, W., Dehghani, M., and Haghighatmehr, P. (2009), Differential SAR Interferometric Technique for Land Subsidence Monitoring Due To Groundwater Over-Exploitation in the Hashtgerd, Proc. 'Fringe 2009 Workshop', Frascati, Italy, ESA SP-677.

Barlow, Paul M., and Eric G. Reichard. (2010). "Saltwater Intrusion in Coastal Regions of North America." Hydrogeology Journal 18(1): 247–60.

Bear, J., & Cheng, A. H. D. (2010). Modeling groundwater flow and contaminant transport (Vol. 23). Springer Science & Business Media.

Berhane, G. (2010). Geological geophysical and engineering geological investigation of a leaky Micro-dam in the Northern Ethiopia. Agricultural Engineering International, XII(1346).

Bouwer, H. (1978). Groundwater hydrology (No. 04; GB1003. 2, B6.).

Braadbaart, O., & Braadbaart, F. (1997). Policing the urban pumping race: industrial groundwater overexploitation in Indonesia. World Development, 25(2), 199-210.

Chandler, V. M. (1994). Gravity investigation for potential ground-water resources in Rock County, Minnesota. Minnesota Geological Survey, Report 44. ISSN 0076-9177

Chen, H., Wang, S., Gao, Z., & Hu, Y. (2010). Artificial Neural Network Approach for Quantifying Climate Change and Human Activities Impacts on Shallow Groundwater Level -A Case Study of Wuqiao in North China Plain.

Chilton, J., & Seiler, K. (2006). Groundwater occurrence and hydrogeological environments. In Protecting Groundwater for Health: Managing the Quality of Drinking-water Sources. London: IWA Publishing.

Domenico, P. A., & Mifflin, M. D. (1965). Water from low-permeability sediments and land subsidence. Water Resources Research, 1(4), 563-576.

Domenico, P. A., & Schwartz, F. W. (1998). Physical and chemical hydrogeology (Vol. 506). New York: Wiley.

FAO. (2016). AQUASTAT website. Food and Agriculture Organization of the United Nations (FAO). Website accessed on 2019/08/15.

Federation of Malaysian Consumers Associations (FOMCA). (2009). A Study Report on Groundwater - a Reminder To Malaysia. eds. Federation of Malaysian Consumers Associations, Water and Energy Consumer Association of Malaysia, and Forum Air Malaysia. Selangor: Federation of Malaysian Consumers Associations (FOMCA).

Fuhrer, G. J., R. J. Gilliom, P. A. Hamilton, J. L. Morace, L. H. Nowell, J. F. Rinella, J. D. Stoner, and D. A. Wentz. (1999). The Quality of Our Nation's Waters -- Nutrients and Pesticides. U.S. Geological Survey Circular 1225, Reston, Virginia, 82 p.

Fourie, F. (2009). The influence of curved and angled survey lines on 2D resistivity surveys employing the Wenner (α) geometry. 11th SAGA Biennial Technical Meeting and Exhibition, (January 2009).

Gleeson, T., Moosdorf, N., Hartmann, J., & Van Beek, L. P. H. (2014). A glimpse beneath earth's surface: GLobal HYdrogeology MaPS (GLHYMPS) of permeability and porosity. Geophysical Research Letters, 41(11), 3891-3898.

Gleick, P. H. (1996): Water resources. In Encyclopedia of Climate and Weather, ed. by S. H. Schneider, Oxford University Press, New York, vol. 2, pp.817-823

Gorokhovski, Vincent, and Donald, N. (1996). “Validation of Hydrogeological Models Is Impossible : What ' s Next ?” In Calibration and Reliability in Groundwater Modelling, , 417–24.

Gun, Jac Van Der, and Annukka Lipponen. (2010). “Reconciling Groundwater Storage Depletion Due to Pumping with Sustainability.” Sustainability (2): 3418–35.

Hagen, G. (1839). On the motion of water in narrow cylindrical tubes. Pogg. Ann, 46(423-440), 2-4.

Haque’, S. A. (2006). “SALINITY PROBLEMS AND CROP PRODUCTION IN COASTAL REGIONS OF BANGLADESH.” Pakistan Journal of Botany 38(5): 1359–65.

Hartmann, J., & Moosdorf, N. (2012). The new global lithological map database GLiM: A representation of rock properties at the Earth surface. Geochemistry, Geophysics, Geosystems, 13(12).

Heath, R.C. (1983). Basic ground-water hydrology, U.S. Geological Survey Water-Supply Paper 2220, 86p.

Heng, T. E., & Singh, M. (1989). Groundwater supply studies in Northern Kelantan. Bulletin of the Geological Society of Malaysia, 23(October), 13–26.

Hiscock, K. M., M. O. Rivett, and R. M. Davison. (2002). “Sustainable Groundwater Development.” The Geological Society of London 193: 1–14.

Hock, L. C. (2008). State of Water Resources in Malaysia. Dialogue on Water Environment Partnership in Asia (WEPA).

Ibuot, J. C., G. T. Akpabio, and N. J. George. (2013). “A Survey of the Repository of Groundwater Potential and Distribution Using Geoelectrical Resistivity Method in Itu Local Government Area (L.G.A), Akwa Ibom State,Southern Nigeria.” Central European Journal of Geosciences 5(4): 538–47.

Iglesias, A., Garrote, L., Flores, F., & Moneo, M. (2007). Challenges to manage the risk of water scarcity and climate change in the Mediterranean. Water resources management, 21(5), 775-788.

Jumikis, A. R. (1984). *Soil mechanics.* R.E. Krieger Pub. Co.

Kaponda, A. (2012). Introduction to Groundwater Occurrence, Water Well Construction and Development with Emphasis on Quality and Effective Methods and Materials. In Waterutilities East Africa. Tanzania.

Keller G.V. and Frischknecht F.C., (1996), Electrical methods in geophysical prospecting. Pergamon Press Inc., Oxford.

Kellett, J. (1974). *Terzaghe's Theory of One Dimensional Primary Consolidation of Soils and its Application.* Department of Mineral and Energy. Canberra: Bureau of Mineral Resources, Geology and Geophysics.

Khadri, S. F. R., and Chaitanya Pande. (2016). “Ground Water Flow Modeling for Calibrating Steady State Using MODFLOW Software: A Case Study of Mahesh River Basin, India.” Modeling Earth Systems and Environment 2(1): 1–17.

Kim, Gyoo-bum. (2010). “Application of Analytical Solution for Stream Depletion Due to Groundwater Pumping in Gapcheon Watershed, South Korea.” HYDROLOGICAL PROCESSES 3546(July): 3535–46.

Konikow, Leonard F., and John D. Bredehoeft. (1992). “Ground-Water Models Cannot Be Validated.” Advances in Water Resources 15: 75–83.

Marker, P. A. et al. (2015). “Performance Evaluation of Groundwater Model Hydrostratigraphy from Airborne Electromagnetic Data and Lithological Borehole Logs.” Hydrology and Earth System Sciences 19(9): 3875–90.

Md Din, A. H., Md Reba, M. N., Mohd Omar, K., Bin Md Razli, M. R., & Rusli, N. (2015). Land subsidence monitoring using persistent scatterer InSAR (PSInSAR) in Kelantan Catchment. ACRS 2015 - 36th Asian Conference on Remote Sensing: Fostering Resilient Growth in Asia, Proceedings.

M.H.Loke. (2004). Tutorial : 2-D and 3-D electrical imaging surveys, (July).

Mohamed, A. F., Yaacob, W. Z., Taha, M. R., & Samsudin, A. R. (2009). Groundwater and Soil Vulnerability in the Langat Basin Malaysia. Journal of Scientific Research, 27(January), 628–635.

National Research Council, (1991), Mitigating losses from land subsidence in the United States: Washington, D. C., National Academy Press, 58 p.

Noor, I. B. M. (1980). Prefeasibility Study of Potential Groundwater Development in Kelantan, Malaysia. Ph.D. Thesis. University of Birmingham, United Kingdom. (unpublished). 427p

Olasehinde, P. I., & Raji, W. O. (2007). Geophysical Studies of Fractures of Basement Rocks at University of Ilorin, Southwestern Nigeria: An Application to Groundwater Exploration. Water Resources, 17, 3-10.

O'Riordan, Timothy. (2000). 112 The British Journal of Psychiatry Environmental Science for Environmental Management. Second Edi. New York: Routledge.

Pfeiffer, D., & Chong, F. (1974). Groundwater exploration in Kota Bharu—Report No. 1. Unpublished report Geological Survey of Malaysia.

Poiseuille, J. (1840). Experimental research on the movement of liquids in capillary of very small diameters. Weekly reports of Academy of Science sessions, 11, 1041-1048.

RES2DINV Version 3.4. (2000). Rapid 2-D Resistivity & IP Inversion Using the Least-Squares Method. Geotomo Software.

Ruilin, H. U. (2006). Urban land subsidence in China. *The Geological Society of London*, (786), 1–8.

Saad, Rosli, M.N.M. Nawawi, and Edy Tonnizam Mohamad. (2012). "Groundwater Detection in Alluvium Using 2-D Electrical Resistivity Tomography Groundwater Detection in Alluvium Using 2-D Electrical Resistivity Tomography (ERT)." Journal of Geotechnical Engineering 17(February 2018).

Saimy, I. S., & Raji, F. (2015). Jurnal Teknologi Applications and Sustainability in Groundwater Abstraction in Malaysia. Jurnal Teknologi, 2050(Figure 1), 39–45.

Seifert, Dorte et al. 2012. "Assessment of Hydrological Model Predictive Ability given Multiple Conceptual Geological Models." Water Resources Research 48(6): 1–16.

Shin, C.F. (1977). Hydrogeological report of Kota Bharu, Kelantan.

Shirazi, S. M., Hosen, I., Akib, S., & Yusop, Z. (2013). Groundwater vulnerability assessment in the Melaka State of Malaysia using DRASTIC and GIS techniques Groundwater vulnerability assessment in the Melaka State of Malaysia using DRASTIC and GIS techniques. Environmental Earth Sciences, 70(April), 2293–2304.

Sidiropoulos, E., & Tolikas, P. (2008). Genetic algorithms and cellular automata in aquifer management. Applied Mathematical Modelling, 32(4), 617-640.

Sophocleous, M. (2000). From safe yield to sustainable development of water resources - The Kansas experience. Journal of Hydrology, Volume 235, Issues 1-2, August, 27-43.

Sophocleous, Marios. 2002. “Interactions between Groundwater and Surface Water : The State of the Science.” Hydrogeology Journal 10: 52–67.

Stephens, J. C., Allen Jr, L. H., & Chen, E. (1984). Organic soil subsidence. Reviews in Engineering Geology, 6, 107-122.

Stollar, R. L., & Roux, P. (1975). Earth Resistivity Surveys—A Method for Defining Ground-Water Contamination. Groundwater, 13(2), 145-150.

Suratman, S. (1997). Groundwater protection in North Kelantan, Malaysia: an integrated mapping approach using modelling and GIS (Doctoral dissertation, University of Newcastle upon Tyne).

Tahir, W. Z. W. M., Hussin, N. H., Yusof, I., Mamat, K., Latif, J. A., & Demanah, R. (2014). Integrated Assessment of Groundwater Recharge in the North. Environmental Science, 46(33), 1–15.

Tan, Y., Shi, Y., Buarque, F., Gelbukh, A., Das, S., & Engelbrecht, A. (2015). Advances in Swarm and Computational. In D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, G. Weikum (Eds.). Beijing: Springer International Publishing Switzerland.

Terzaghi, K., Peck, R. B., & Mesri, G. (1996). Soil mechanics in engineering practice. John Wiley & Sons.

Theis, C. V. (1940). The source of water derived from wells. Civil Engineering, 10(5), 277-280.

Tool, Community-based Risk Screening. (2006). “User’s Manual.” (October): 1–47.

UNESCO. (2009). Third United Nations World Water Development Report: Water in the changing World. World Water Assessment Program.

Wallace, D. E. (1970). *Some Limitations of Seismic Refraction Methods in Geohydrological Surveys of Deep Alluvial Basinsa. Ground Water, 8(6), 8–13.*

Wanjohi, A. W. (2012). Intergrated Geophysical Methods Used To Site High Producer Geothermal Wells. *Short Course VII on Exploration for Geothermal Resources*, 1–9.

Van Dam, J. C. (1976). Possibilities and limitations of the resistivity method of geoelectrical prospecting in the solution of geo-hydrological problems. Geoexploration, 14(3-4), 179-193.

Vouillamoz, Jean Michel et al. (2002). “Application of Integrated Magnetic Resonance Sounding and Resistivity Methods for Borehole Implementation. A Case Study in Cambodia.” Journal of Applied Geophysics 50(1–2): 67–81.

Yen, T. P., & Rohasliney H. (2013). Status of Water Quality Subject to Sand Mining in the Kelantan River, Kelantan. *Tropical Life Sciences Research*, *24*(1), 19–34.

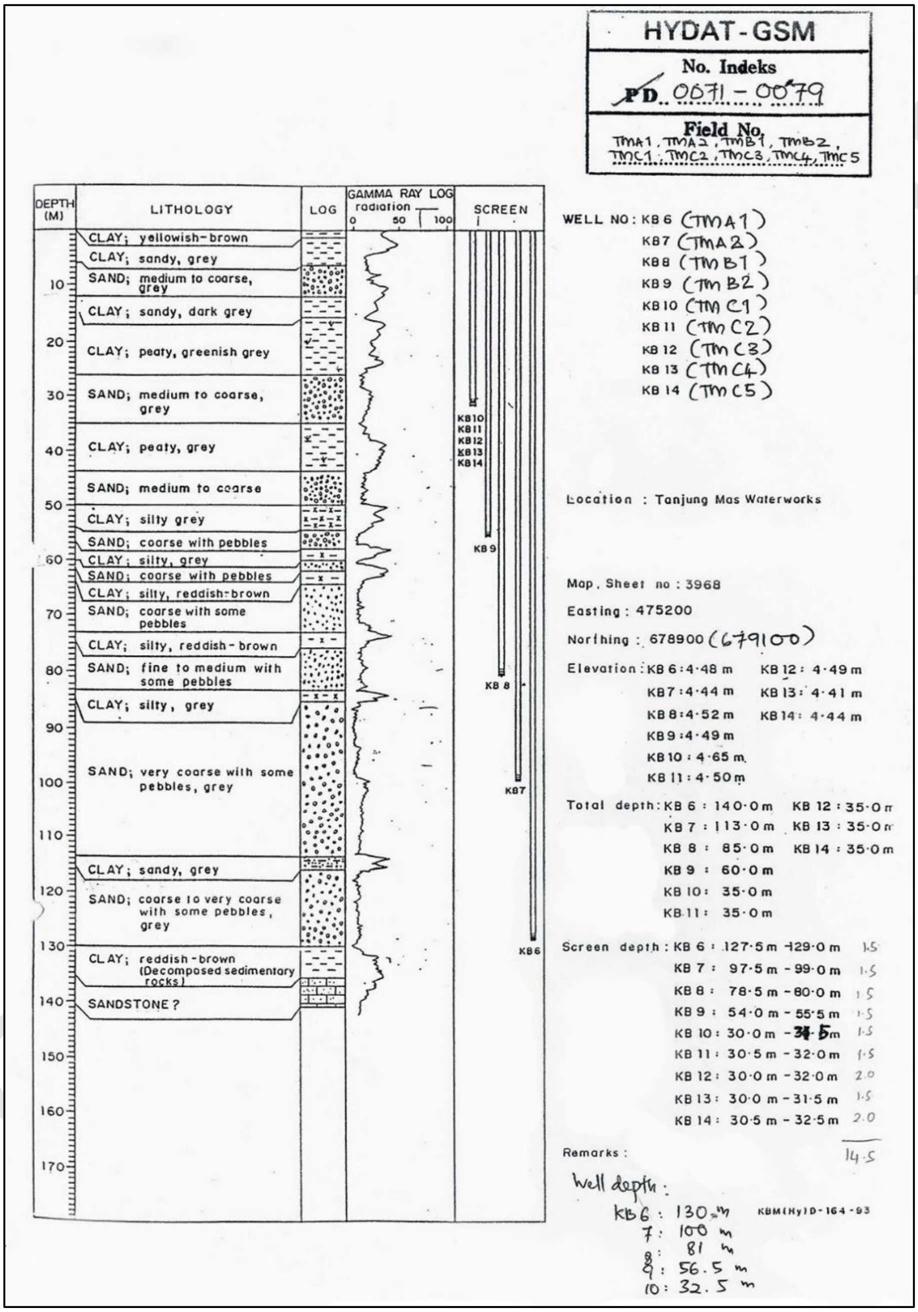
Ying, L. C. (3 March, 2014). *In search of water.* Selangor: The Star Online

Zhou, Haiyan, J. Jaime Gómez-Hernández, and Liangping Li. (2014). “Inverse Methods in Hydrogeology: Evolution and Recent Trends.” Advances in Water Resources 63: 22–37.

Zohdy, A. A., Eaton, G. P., & Mabey, D. R. (1974). Application of surface geophysics to ground-water investigations.

APPENDICES

Appendix A: Well lithology at Tanjung Mas Wellfield



BIODATA OF STUDENT

The student was born on 21th November 1993 in HUSM Kubang Kerian, Kelantan. He started his education in primary school from Sekolah Kebangsaan Kijal, Kemaman, and Sekolah Kebangsaan Deshon, Sibu from years 1999 to 2005. He then attended Sekolan Menengah Kebangsaan Sibu, Sibu and Sekolah Menengah Kebangsaan Dato' Ismail, Pasir Puteh from 2006 to 2010. He entered Selangor Matriculation College before pursuing his degree in Bachelor of Agricultural and Biological Engineering at Universiti Putra Malaysia. He took four years to complete and was awarded the degree in the year 2016. He started working as a research assistant at Faculty of Engineering for 6 months before he pursued a degree of master in Water Resources Engineering.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : Second Semester 2020/2021

TITLE OF THESIS / PROJECT REPORT :

EVALUATION OF SUSTAINABLE GROUNDWATER EXTRACTION FOR WATER INTAKE USING VISUAL MODFLOW AT TANJUNG MAS

NAME OF STUDENT: MUHAMMAD AIDIL HAKIM BIN MHD RAMZAM

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☐	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐	**PATENT**	Embargo from____________ (date) until ____________ (date)

Approved by:

(Signature of Student)
New IC No/ Passport No.:

Date :

(Signature of Chairman of Supervisory Committee)
Name:

Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]