UNIVERSITI PUTRA MALAYSIA

EFFECTS OF COAL MINING ON GROUNDWATER IN MUKAH, SARAWAK, MALAYSIA

JOSEPH JUBIN ANAK ARUH @ ARO

FPAS 2013 19

EFFECTS OF COAL MINING ON GROUNDWATER

IN MUKAH, SARAWAK, MALAYSIA

By

JOSEPH JUBIN ANAK ARUH @ ARO

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

June 2013

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

EFFECTS OF COAL MINING ON GROUNDWATER IN MUKAH, SARAWAK, MALAYSIA

By

JOSEPH JUBIN ANAK ARUH @ ARO

June 2013

Chairman: Associate Professor Shaharin Ibrahim, PhD

Faculty: Environmental Studies

With the present trend of increasing crude oil price globally, coal will be an attractive alternative of energy resource for electricity power generation in Malaysia. The presence of major elements such as SiO_2 Al_2O_3, Na_2O, K_2O, Fe_2O_3, MnO, MgO, P_2O_5 and SO_3 and several trace elements such as (As), Cu and Pb in the coal bodies contaminate both groundwater and surface water. The hydrocarbon waste from workshops, leaching of heavy metals from coal preparation plants, coal stockpiles, overburden dumps and refuse emplacement within coal mining area elevated further the content of contaminants. Coal mine tailings such as aggravated mud and organics substances filling oxbows contain ferric sulphides (FeS_2). The shallow and unconfined groundwater aquifers in the study area with water table ranging from 0.1m to 1.23m below vadose zone are

exposed to the influx of these contaminants. The production of acid mine drainage which contains arsenic, iron compound, nitrate and carbonate compound will pose problem to the existing biodiversity and the surrounding environment, with no exemption to surface water and groundwater to the on going coal mining area of about 192 km^2. The problem of acid drainage due to the presence of sulphur in coal bodies is a common in coal mining areas. Coal waste, which oxidized to acid residue, will eventually lead to surface water and groundwater problems. Visual features such as workshops, preparation plants, coal stockpiles, overburden dumps and refuse emplacement within vicinity of mining area can be a threat to the surrounding environment.

This research investigate the effects of opencast coal mining on the groundwater quality and the surrounding watershed including seepage of mining contaminants, transportation mechanisms of pollutants and its pathway into groundwater aquifer. The geological, stratigraphy, bore holes logging and the water quality data are analyzed and explored to the objectives of the research.

The geology of study area is simple. The Balingian Formation which is unconformable overderlain by Begrih Formation covers most of the study area. The southern part is underlain by younger Liang Formation hosted massive lignite bed. The Quaternary deposits, mudstone/shale, and sandstone with subordinate of mudstone, Begrih Conglomerate, and coal seam are common.

The primary data of groundwater is obtained by laboratory analysis of groundwater samples from the wells. The sampling of groundwater is done by storing it in polyethylene bottle and treated with bactericide to prevent contamination of the water samples. The groundwater is analyzed for major and minor elements including Cl^-, SO_4^{2-} , HCO_3, NO_3^-(anions), Ca^+, Na^+, K^+, Mg^{2+}(cations), Fe, As, Mn, Cu, Cyanide, Zn, and Pb (heavy metals). Other properties of groundwater analyzed are odour, pH, colour, turbidity, electrical conductivity (EC), total dissolved solids (TDS), hardness ($CaCO_3$, DO, COD, and BOD)

The physico-chemical data of groundwater properties, clay, and coal from the coal mining area in Mukah are explored and analyzed by using IBM Statistical Package for the Social Sciences (SPSS) version 20. The multivariate analysis of variance (MANOVA) and principal component analysis (PCA) are computed to investigate the important variables and the relationship among the variables. The Principle component analysis (PCA) explains the acidity and the presence of Fe, Mn, Ca, K, SO_4, HCO_3, CO_3, Cl and total dissolved solids in groundwater samples and to extract the important major elements such as SiO_2 , Al_2O_3, Na_2O, K_2O, TiO_2, Fe_2O_3, MnO, MgO, CaO, P_2O_5 and SO_3 in both coal ash and clay deposits.

The values of Mn, Mg and Fe are higher and slightly more acidic than groundwater outside coal mining area. The production of acidic water is due to ferric sulphide produces sulphate and free sulphuric acid under aerobic condition in the presence of water. The statistical analysis reveal that coal and clay deposits contributed to the elevated values of metals elements and production of acid mine water. The principal components of clay are TiO_2, Na_2O, K_2O, and MgO where as the principal component of coal ash are MgO, CaO, P_2O_5, SiO_2, Al_2O_3, TiO_2, Fe_2O_3, MnO and SO_3. The groundwater affected by coal mining shows relatively low the concentrations of metals (Cu, Pb, Zn, Cd, and Al) except for Fe having value of 1.4 mg/l and slightly higher than Malaysian water quality standards. Mukah groundwater is classified into SO_4 type, HCO_3 type and no dorminant type (intermediate).

The analysis lithologic data, wireline logging, resistivity imaging lines and from the Ground Penetrating Radar runs are used to interpret the hydrostratigrahic and the groundwater flow within the study area. The results of geological, geophysical, stratigraphic correlation facilitate in creating conceptual model for the intrusion of pollutant into groundwater aquifer.

The elevation and groundwater heads data were computed in surfer programme to create the 3D image by gridding method using kriging point method. The modflow vistas and MapInfo programme are used to predict the general flow direction of groundwater within Mukah coal field. The locations of the drill holes and groundwater wells are plotted on the digitized map by using Arcgis software. The elevation and groundwater heads plots indicate that groundwater flows from northeast to southwest and from central part of the mining area the direction of flow is westerly. In the central part of the Coal mining area groundwater flows radially.

The problems arise from many coal producing countries has given extra dimension in protecting groundwater from being contaminated by coal mining. The planting of trees or top soil cover plants, the construction of sediment trap or filter and settlement pond are recommended as the best practice in maintaining and protecting of the groundwater from being polluted.

Abstrak tesis dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor of Falsafah

KESAN PELOMBONGAN ARANG BATU KE ATAS AIR BAWAH TANAH DI MUKAH, SARAWAK, MALAYSIA

Oleh

JOSEPH JUBIN ANAK ARUH @ ARO

Jun 2013

Pengurusi: Associate Professor Shaharin Ibrahim, PhD

Fakulti: Pengajian Alam Sekitar

Dengan trend semasa peningkatan harga minyak mentah dunia, arang batu akan jadi satu alternatif yang menarik sebagi sumber tenaga bagi penjanaan kuasa elektrik di Malaysia. Kehadiran unsur-unsur yang utama seperti SiO_2 Al_2O_3, Na_2O, K_2O, Fe_2O_3, MnO, P_2O_5, SO_3 dan beberapa unsur surih seperti (As), Cu dan Pb dalam arang batu mercermari air permukaan dan air bawah tanah. Bahan buangan hidrokarbon dari bengkel, larut lesap logam berat dari penyediaan loji arang batu, kawasan simpanan arang batu, longgokan dan tinggalan pembuangan tanah-tanih dalam kawasan perlombongan arang batu meningkatkan lagi kandungan bahan cemar. Bahan buangan pelombongan arang batu seperti hancuran lumpur dan bahan bahan organik yang mengisi

kolam kolam lazimnya mengandungi sulphides (FeS_2). Akuifer air bawah tanah yang cetek dan terbuka di kawasan kajian dengan kedalaman paras air dari 0.1m ke 1.23m di bawah zon vadose terdedah kepada kemasukan bahan cemar ini. Penghasilan saliran lombong berasid yang mengandungi arsenik, sebatian besi, nitrat dan sebatian karbonat akan menimbulkan masalah kepada biodiversiti yang sedia ada dan persekitaran, dengan tiada pengecualian kepada air permukaan dan air bawah tanah di kawasan pelombongan arang batu seluas kira-kira 192 km^2. Masalah saliran berasid disebabkan kehadiran sulfur dalam arang batu adalah satu perkara biasa di kawasan kawasan pelombongan arang batu. Sisa arang batu yang teroksida kepada sisa asid, akhirnya akan membawa kepada masalah-masalah air permukaan dan air bawah tanah.

Kajian ini menyiasat kesan pelombongan arang batu terbuka ke atas kualiti air bawah tanah dan kawasan perairan dipersekitarannya termasuk resapan bahan cemar pelombongan, mekanisme pengangkutan bahan pencemar dan laluan ke aquifer air bawah tanah. Geologi, stratigrafi, log lubang lubang gerudi dan data kualiti air adalah dianalisis dan diterokai untuk objektif kajian ini.

Geologi kawasan kajian adalah mudah. Pembentukan pertindihan ketakselarasan formasi Balingian yang mendasari formasi Begrih meliputi kebanyakan kawasan kajian. Bahagian selatan adalah didasari oleh formasi Liang yang lebih muda dan mempunyai singkapan lignit yang massif. Enapan kuaternari, batuan lumpur/syal, dan batu pasir dengan kandungan batu lumpur yang rendah, Begrih Konglomerat dan lipit arang batu adalah biasa.

Data-data utama air bawah tanah dari telaga-telaga air diperolehi melalui analisis sampel air bawah tanah di makmal. Persampelan air bawah tanah dilakukan dengan menyimpannya dalam botol polietilena dan dirawat dengan bacterisid untuk mengelakkan pencemaran sampel air. Air bawah tanah dianalisis untuk unsur-unsur utama dan minor termasuk Cl^-, SO_4^{2-} , HCO_3, NO_3^- (anions), Ca^+, Na^+, K^+, Mg^{2+}(cations), Fe, As, Mn, Cu, Cyanide, Zn, dan Pb (logam berat). Sifat-sifat lain air bawah tanah yang dianalisis adalah bau, pH, warna, kekeruhan, pengaliran elektrik (EC), jumlah pepejal terlarut (TDS) dan kekerasan ($CaCO_3$, DO, COD dan BOD).

Data fisiko-kimia, sifat sifat air bawah tanah, tanah liat dan arang batu dari kawasan pelombongan di Mukah diterokai dan dianalisis dengan menggunakan pakej statistik IBM perisian untuk sains sosial (SPSS) versi 20. Multivariate analisis varians (MANOVA) dan analisis komponen utama (PCA) akan dikira untuk menyiasat pembolehubah penting dan hubungan antara pembolehubah. Analisis komponen utama (PCA) menerangkan keadaan berasid dan kehadiran Fe, Mn, Ca, K, SO4, HCO_3, CO_3, Cl dan jumlah pepejal terlarut dalam sampel air bawah tanah dan untuk mengeluarkan elemen utama yang penting seperti SiO_2 , Al_2O_3, Na_2O, K_2O, TiO_2, Fe_2O_3, MnO, MgO, CaO, P_2O_5 dan SO_3 dalam simpanan kedua-dua abu arang batu dan tanah liat.

Nilai-nilai Mn, Mg dan Fe adalah lebih tinggi dan lebih berasid pada air bawah tanah dalam kawasan pelombongan arang batu daripada air bawah tanah di luar kawasan pelombongan arang batu. Pengeluaran air berasid adalah kerana lazimnya sulphide menghasilkan sulfat dan asid sulfurik bebas di bawah keadaan aerobik dengan kehadiran air. Analisis statistik menyokong bahawa arang batu dan tanah liat menyumbang kepada ketinggian nilai nilai unsur logam dan penghasilan air saliran lombong berasid. Komponen komponen utama tanah liat adalah TiO_2, Na_2O, K_2O, dan MgO di mana komponen utama abu arang batu adalah MgO, CaO, P_2O_5, SiO_2, Al_2O_3, TiO_2, Fe_2O_3, MnO and SO_3. Air bawah tanah yang terjejas oleh pelombongan arang batu menunjukkan kepekatan logam (Cu, Pb, Zn, Cd dan Al) rendah kecuali Fe mempunyai nilai 1.4 mg/l dan sedikit tinggi berbanding degan piawaian kualiti air Malaysia. Air bawah tanah di Mukah dikelaskan kepada jenis SO_4, jenis HCO_3 dan tiada jenis dominan (pertengahan).

Analisis data batu batuan, pengelokkan talian wayar, pengimejan garisan resistiviti dan data dari radar menembusi tanah digunakan untuk mentafsirkan hydrostratigrafik dan aliran air bawah tanah di kawasan kajian. Keputusan korelasi geologi, geofizikal, stratigrafik membantu dalam mewujudkan model konseptual bagi pencerobohan pencemaran ke dalam aquifer air bawah tanah.

Data ketinggian dan kepala air bawah tanah diolah dengan program surfer untuk mencipta imej 3D dengan kaedah gridding dan titik kriging. Modflow Vistas dan MapInfo program digunakan untuk meramalkan arah aliran am air bawah tanah dalam lembangan arang batu di Mukah. Pendigitan lokasi-lokasi lubang-lubang gerudi dan perigi air bawah tanah di peta dilakukan dengan menggunakan perisian Arcgis. Ketinggian dan kepala air bawah tanah menunjukkan bahawa air bawah tanah mengalir dari timur laut ke barat daya dan dari bahagian tengah kawasan pelombongan, arah aliran adalah ke arah barat. Di bahagian tengah kawasan pelombongan arang batu bawah aliran air bawah tanah adalah berbentuk jejari.

Masalah masalah yang timbul dari banyak negara-negara pengeluar arang batu telah memberikan dimensi tambahan dalam melindungi air bawah tanah daripada tercemar oleh pelombongan arang batu. Penanaman pokok pokok atau tumbuh tumbuhan penutup atas tanah, pembinaan perangkap sedimen atau penapis dan kolam pemendapan yang disyorkan sebagai amalan terbaik dalam mengekalkan dan melindungi air bawah tanah daripada tercemar.

ACKNOWLEGEMENTS

This Thesis has been developed with the help of many people that have contributed many suggestions and facts from precise source of information. I would like to thank especially Assoc. Prof. Dr. Shaharin Ibrahim for his guidance, encouragement, corrections, critical comments, and suggestions, which could spend much time in writing this thesis. Also, lecturers especially Associate Professor Dr. Mohd Kamil and Associate Professor Dr. Pauziah Latif who are committee members supervising and guiding me in producing this thesis and course mates who have discussed, commented and giving suggestions to this thesis during the colloquium, their criticisms and suggestions are much appreciated.

The support is acknowledged from Director of Minerals and Geoscience Department Malaysia, Kuching for his consideration in allowing me to take this course, giving study leaves and the use of office facilities that lessen my task in this course.

I am thankful to technical staff of UPM Mr. Gafar and Mr. Zairi Ismail and Miss Asiah for their assistance in operating the resistivity imaging and ground penetrating radar equipments in the field. The assistance from fellow colleagues Mr. Robin bin Junang, Johnathan Judan Uwau, and Ambrose Edwards Kut while carried out field research and raw data acquisition are very much appreciated. The cooperation from the General Manager of Sarawak Coal Resources Berhad, Mr. Dorani Johari is indeed make my research work more easier in obtaining data both from drilling core and groundwater within the Mukah coal mining area. The attentive consent from Mr. Bakar and Mr. Lim who are both public relation officers from Sarawak Coal Resources Berhad in the time they needed are also appreciated.

The effort from Hermawati Tabeng(Geochemist) and Madam Chin(Assistant Geochemist) of Minerals and Geoscience Department Malaysia, Sarawak and Hii Lu Yong (Senior Chemist) of Chemsains Private Limited for the analysis of groundwater samples.

I certify that a Thesis Examination Committee has met on 24 June 2013 to conduct the final examination of Joseph Jubin Anak Aruh @ Aro on his thesis entitled "Effects of Coal Mining on Groundwater in Mukah, Sarawak, 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 Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Mohamad Pauzi b Zakaria, PhD
Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Wan Nor Azmin b Sulaiman, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Internal Examiner)

Mohd Rusli bin Yacob, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Internal Examiner)

Arun Kumar Saraf, PhD
Professor
Department of Earth Sciences
Indian Institute of Technology
India
(External Examiner)

NORITAH OMAR, PhD
Associate Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 20 November 2013

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:

Sahaharin Ibrahim, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Mohd Kamil Yusoff, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

Pauziah Abdul Latif, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

JOSEPH JUBIN ANAK ARUH @ ARO

Date: 24 June 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
Btg	Batang (Trunk river in Malay)
Cm	Centimeters
COD	Chemical Oxygen Demand
^{o}C	Degrees Celsius
DID	Drainage and Irrigation Department
DO	Dissolved Oxygen
DOE	Department of Environment
EIA	Environment Impact Assessment
FAU	A measure of turbidity
GPS	Global Positioning System
ha	Hectares
HEP	Hydro Electric Power
HVS	High Volume Sampler
INWQSM	Interim National Water Quality Standards of Malaysia
JKR	Jabatan kerja Raya (Department of Public Works)
Jln	Jalan (Road in Malay)
Kg	Kilograms
Km	kilometre
Kpg.	Kampung (Village in Malay)
LAT	Lowest Astronomical Tide
LANDSAT	Unmanned earth-orbiting NASA satellite
Leq	Equivalent Level
LSD	Land Survey Datum
m	Meters
meq/l	Milliequivalent per litre
mg/L	Milligrams per litre
mm	Millimetres
MPN/100ml	Most Probable Number per 100 Millilitres
MSL	Mean Sea Level
mS/cm	Millisiemens per Centimetre
NGO	Non-Governmental Organisation
NH_3-N	Ammoniacal Nitrogen
OPIC	Oversea Petroleum and Investment Corporation
PO_4^{-3}	Free Phosphate
ppm	Parts per Million
NREB	Natural Resources and Environment Board
R.Baling	Longhouse's name
Sg.	Sungai (River in Malay)
TR	Tuai Rumah (Village leader in Iban)
TSP	Total Suspended Particulates
TSS	Total Suspended Particulates
WHO	World Health Organisation
yrs	Years
μS/cm	Microsiemens per Centimetre

CHAPTER 1

INTRODUCTION

1.1 Background

Coal mining in Mukah coal field has been operating since the year 2002. As a result of the coal mining operation on area of 250 km^2 for excavation of the coal and disposal of the overburden (Figure 1.1) will be affected (Genesis Force, 1999). The areas where treated water supply were not available to the local residents, groundwater from dug out well and from the tube well developed by the government are the main sources of clean water other than rain water which is unreliable. The river water in most places within the coal mining area is intruded by seawater and not suitable for human consumption.

At present much of the coal used in electricity generation such as at Sejingkat coal power plant are imported from Indonesia. However, it is always wise for Malaysia to focus on fuel resource development within this country. A number of coals bearing formation have been identified in Sarawak, such as those in Merit-Pila, Mukah, Tutoh, and Silantek. Large area of coal reserve has also been identified in Maliau basin in Sabah, which involved an area about 23 km in diameter. The on going coal mining in Mukah is carried out by two major coal mining companies namely Genesis Force Sendirian Berhad and Sarawak Coal Resources Sendirian Berhad that covers about 250 km^2. The mining operation will pose problem on the existing biodiversity and the surrounding environment, with no exemption to surface water and groundwater. The coal mining activities provide the local people job opportunities but any mining waste leave untreated may cause pollution to the surrounding environment and possibly infiltrating into groundwater aquifer. Mukah Coalfield hosted 551.9 mt of coal reserves of a sub-bituminous B coal (Sia, et al., 2000). Coal has been one the major energy resources other than oil, gas, and hydroelectric power (HEP). Mukah coal produces an average gross calorific value of 22.21 MJ/Kg on moist mineral – matter free basis (Sia, et al., 2000). Mukah coal constituted about 33% of total Malaysia coal reserves as stated in Table 1.1. With an low angle of dipping coal seam at 10^0– 15^0 and generally low lying flat topography of Mukah coal field, opencast coal mining method had been used.

Table 1.1: Coal Reserves in Malaysia

STATE	COAL FIELD	RESERVE (in million tonnes)	SOURCE
SARAWAK	i. Selantek	50.25	Tuan Rusli bin Tuan Mohd, 2000
	ii. Merit-Pila	387.18	Laporan Tahunan, GSM 1997
	iii. Mukah	551.90	Sia et al, 2000
	iv. Balingan	203.00	Hussien Bin Mohd. Juni, et al, 2000
	v. Tutoh	203.00	Aro Jubin, Joseph, et al, 2005
	vi. Bintulu	20.00	Laporan Tahunan, GSM 1997
SABAH	i. Silimpopn	14.10	Laporan Tahunan, GSM 1997
	ii Labuan	8.90	Laporan Tahunan, GSM 1997
	iii. Meliau	215.00	Laporan Tahunan, GSM 1997
PENINSULA MALAYSIA	i. Batu Arang	17.00	Laporan Tahunan, GSM 1997
	Total Coal Reserve:	**1670.33**	

Opencast coal mining operations (Appendix I) in Mukah involves a few stages such as:

1. Clearance of vegetation and soil stripping.
2. Breakage of both overburden and coal prior to excavation. Overburden is removed by using dragline excavator (Figure 1.1).
3. Excavation of the burden and stockpiling of this material within the excavation area. Dumps can be temporary or permanent but minimum environmental damage in the long term is achieved by the progressive backfilling of worked out areas.
4. Excavation of coal (Figure1.2)
5. Dewatering or sump pumping of the excavation is carried out to maintain dry working conditions.
6. Coal preparation activities including crushing, screening and washing. Washing is done by heavy and medium separation, which, involve gravity settlement in a viscous medium. Heavy mediums used are suspensions of magnetite or ferrosilicon in water. Chemical additive such as sodium nitrite is added to the medium to reduce corrosion of the suspended particulates. The medium is generally recycled on site. Wastewater is generally slurry, which is held in lagoons.
7. Treatment of process water sump and mining wastes often involved basic settlement in large lagoons.
8. Removal of overburden and coal extraction is preceded simultaneously and mined coal is transported to stockpile site at Kampung Jebungan.

Figure 1.1. Exposing the coal seam and piled up overburden creating unstable high wall

Figure 1.2. Excavating coal and transport it to stock pile at Kampung Jebungan Mukah

1.2 Problem Statement

The production of acid mine drainage and decrease in groundwater head level affect the sustainability supply of fresh groundwater for domestic usage. The quality both groundwater and surface water affected by opencast coal mining as a result of acid drainage production is a major problem. Coal mining wastes which oxidized to acid residue eventually lead to surface water and groundwater problems. The presence of arsenic, iron compound, nitrate and carbonate compound in mine drainage water wash out into the surface water and eventually seeping into the groundwater aquifer underlying the mined coal seams.

The presence of major elements such as SiO_2, Al_2O_3, Na_2O, K_2O, Fe_2O_3, MnO, MgO, P_2O_5 and SO_3 in coal (Sia et al., 2000) could eventually be transported into groundwater and cause groundwater pollution. These elements could cause health hazard to human being through consumption of groundwater affected by coal mining activities. The released of methane gas from coal bed and excessive release of CO_2 gas from coal usage further aggravate the effect of global warming and eventually affect the groundwater table.

Visual features of coal mining such as workshops, preparation plants, coal stockpiles, overburden dumps and refuse emplacement within the vicinity of mining area can be a major threat to the environment surrounding the mining area. During coal extraction, water removal by pumping and water course diversion work may be necessary to manage mining activity. Excessive removal of water will affect groundwater and surface water movement in the surrounding area.

1.3 Need for the Study

In most cases, opencast coal mining in Sarawak as in Kapit and Mukah, the mining spoilage is dumped within the mining site. The mining contaminants seep into the porous ground and eventually enter the groundwater reservoir.

The extraction of the coal bodies involves removing of substantially thick overburden. Tropical climate brings much rainfall. Under the tropical condition the dissolution of mining spillage will occur. When surface runoff flows it will pick up a variety of loss and dissolved materials along its passage and transport it into groundwater aquifer. As the groundwater table in Mukah area is very shallow, ranging from 0.1m to 3.0m, the intrusion of coal mining contaminants into the groundwater reservoir is fast. At the moment no information available on the actual impacts of opencast coal mining activity to the surrounding watershed and the groundwater. Detail study that explains the possible pathway of these pollutants into groundwater is vital in protecting the groundwater from being contaminated from coal mining activities. Therefore the present study attempts to provide a complete understanding of the consequences of coal mining. This information could help in remediation process by preventing the possible outcome of pollution.

1.4 Hypothesis

The excessive earth works and removing of overburden during coal mining with abundant of rainfall will ease the dissolution and integration of major elements such as SiO_2 Al_2O_3, Na_2O, K_2O, Fe_2O_3, MnO, MgO, P_2O_5 and SO_3 in coal and mining waste. These elements eventually transported into groundwater and the surrounding surface water that cause pollution to any receiving surface water catchments and groundwater aquifer. A large area of opencast coal mining further induce the production of trace elements such as As, Bi, Cu, Mo, Nb, Ni, Pb, Rh, Sn, Sr, Ta, Th, U, W,Y, Zn, and Zr. These elements could cause health hazard to human being through consumption of groundwater affected by coal mining activities.

The shallow unconfined groundwater aquifer makes an easy pathway of these pollutants reaching into groundwater.

1.5 Objectives

The primary objective of this study is to investigate the effects of opencast coal mining on the groundwater quality and the surrounding watershed. This objective will lead to various objectives as follows:

I. To investigate the types of coal mining contaminants seep into the porous ground and eventually enters the groundwater reservoir due to removal of mining spoilage.

II. To investigate and create conceptual model of transportation mechanisms of coal mining wastes and its possible pathways into groundwater aquifer.

III. To identify the factors facilitate the flow of pollution due to coal mining operation.

IV. To delineate the regional aquifer–aquitard framework and evaluating the hydrostratigraphic controls and temporal patterns of groundwater flow of the study area.

1.6 Significance of the Study

The variation of chemical content, hydrostratigraphic, lithology types, and hydrochemistry are factors influenced the flow system of groundwater and its travel time. These factors will be explained in chapter 5 that includes results and discussions of the research. Therefore, a complete understanding of the consequences of coal mining could help in remediation process of preventing the possible outcome of pollution affecting groundwater aquifer. The knowledge on hydrogeology and hydrochemistry of groundwater of the study area are significant to explain the general groundwater flow. The variation of certain chemicals content of groundwater within the coal mining area is possibly influenced by hydrogeological factor. Coal mining covers large area and if there is no early preparation to prevent pollution from coal mining activities, large area will be polluted with no exemption surface water and groundwater. The visual features of coal mining such as workshops, preparation plants, coal stockpiles, overburden dumps and refuse emplacement within vicinity of mining area can be a major threat to the environment surrounding the mining area.

During the extraction of coal, the operation may require a removal of water by pumping and at the same time through diversion works. The excessive removal of water has at least some effects on the pattern of groundwater and surface water movement in the surrounding area. The coal waste which oxidized to acid residues and how its runoff could be controlled in a wet tropical country is a question that has to be answered. The understanding of subbasinal scale hydrodynamics is important for evaluating the possibility of pollution movement from contaminated shallow aquifers to the as yet uncontaminated deep aquifers and to understand the interaction between the local and regional flow systems, along with estimating and understanding the control of recharge and hydraulic parameters on the regional flow. The construction of settlement ponds in protecting of ground water from contaminated by coal mining tailings through induced infiltration of surface water will be more effective.

This research reveal geological, hydrogeological, chemistry of coal mining waste that provide database for the government, mining companies and developers in remediation process of preventing the possible outcome of pollution.

1.7 Research Framework

This Thesis is presented in six chapters namely introduction, the study area, literature review, materials and methods, results and discussions and conclusion and recommendations. Each of these chapters contains sub sections as presented in the flow chart below (Figure 1.3).

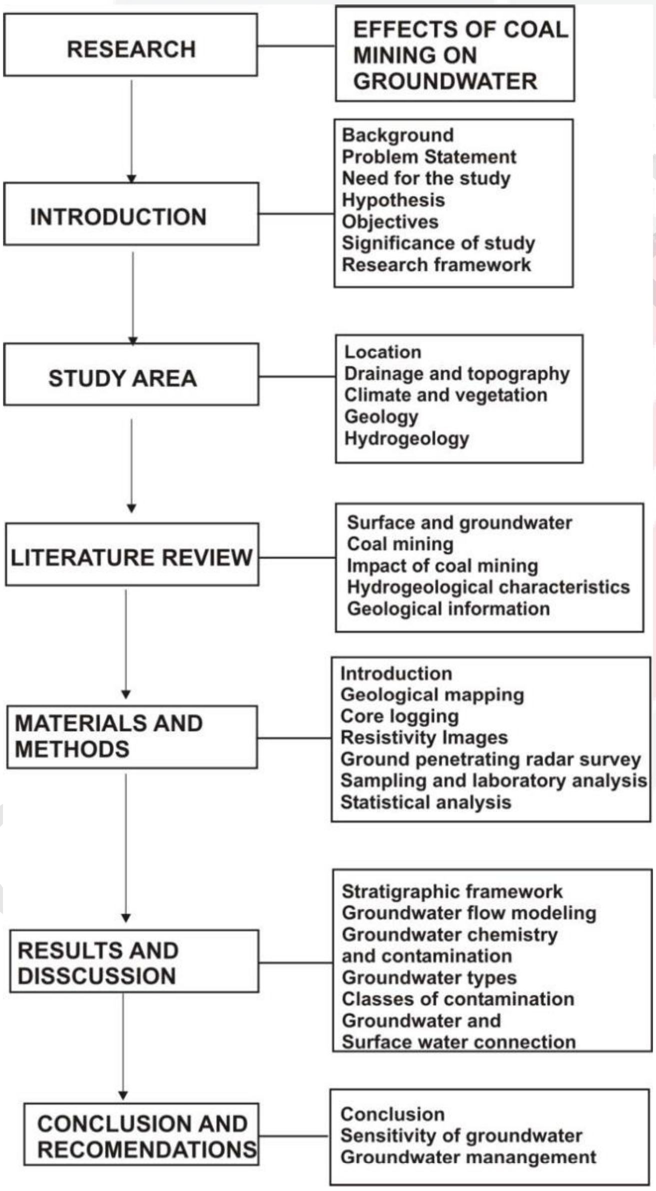

Figure 1.3. Research framework for effects of coal mining in Mukah

REFERENCES

Adams, B. and Foster, S. S.D. (1992). Land surface zoning for groundwater protection. JIWEM,6: 312-320

Alexander, S. C., and Alexander, E. C., Jr. (1989). Residence times of Minnesota ground waters: Minnesota Academy of Sciences Journal, v. 55, no. 1, p. 48-52.

Aro, Joseph Jubin,(2004). Environmental Impacts of Opencast Coal Mining in Mukah Coal field, Sarawak. MSc Thesis. University Putra Malaysia, Malaysia.

Aro, Joseph Jubin and Dorani Bin Johari(2002). The Evaluation of coal Resources of Tutoh Coalfield, Sarawak, Malaysia.

Akil, Wan Zawawie bin Wan (1985). Geophysical Logging in Kampung Teh, Mukah, Nanga Merit and Gunung Ropih area, Bau (GSKL 115/2/13). Unpublished.

Bell, F.G., Bullock, S.E.T., Halbic, T.F.J., and Lindsay, P(2001). Environmental impacts associated with an abandoned mine in the Witbank Coalfield, South Africa. International Journal of Coal Geology 45:195-216.

British Geological Survey (BGS) (2005-2010). World Minerals Statistics.

Black, A., and Craw, D (2001). Arsenic, copper and zinc occurrence at the Wangaloa coal mine, southeast Otago, Zealand. International Journal of Coal Geology 45:181-193.

Brady and Weil (1999). The Nature and Properties of Soils.

Bujang, Japri B. HJ. and Jaafar, Che Abdul Rahman (2007). Clay in The Mukah area, Sarawak. JMG. SWK (MPI) 1/2007. Minerals and Geoscience Department Malaysia.

Bujang, Yusuf B. (1986). Laporan Penyiasatan Awal Hidrogeologi di kawasan Hilir Sungai Mukah,Bahagian Sibu, Sarawak. (GSKL 435/1/(1).

Bujang, Yusuf B. (1987). Laporan Penyiasatan terperinci hidrogeologi di Kawasan Jebungan, Mukah,Bahagian Sibu, Sarawak. (GSKL 435/1/3).

Bujang, Yusuf B. (1991). Construction and Performance of Horizontal wells at Jebungan Area, Mukah District, Sibu Division, Sarawak. (GSKL 435/5).

Bujang, Yusuf B. (1995). Laporan Pembinaan Perigi Tiub di SRK Bedengan, Dearah Mukah,Bahagian Sibu, Sarawak. (GSKL 435/2/9).

Buroi Mining Sdn. Bhd (May 1996). Environmental Impact Assessment Report. Balingan Coal Mining Project.

Chuan, Goh Kim (1982). Land use and soil erosion problems in Malaysia. Development and Environmental Crisis.

Cornett, B.J., Risto, B. A., and Lee, D. R (1989). Measuring groundwater transport through lake sediments by advection and diffusion. Water Resources Research 25: 1815 – 1823.

Daro Coastal zone management study(1997)

Department of Irrigation and Drainage Sarawak(2001). Water Management Guidelines for Agriculture Development in Lowland Peat Swamps of Sarawak. 116pp.

Department of Irrigation and Drainage Sarawak, (1995-2006). Sarawak Hydrological Year Book.

Department of statistics Malaysia (2009). Year Book of Statistics, Malaysia (Sarawak), Kuching, Sarawak, Malaysia

Demirezen, D., and Aksoy, A (2006). Common hydrophytes as bioindicators of iron and manganese pollutions. Ecological Indicators 6:388-393 ELSEVIER.

Edwards, A.P. and Bremmer, J.M. (1967). Microaggregates in soils. J. Soil Science.18:64-73

Eger, P. (1994). Wetland treatment for trace metal removal from mine drainage:The importance of aerobic and anaerobic processes. Water Science and Technology 29, 249–256.

Ellis, K.V (1993). Surface Water Pollution and its Control. Antony Rowe Ltd. Reprinted.

Ezeigbo, H. I. and Ezeanyim, B. N. (1993). Environmental pollution from coal mining activities in the Enugu area, Anambka State of Nigeria.Mine Water and the Environment, Vol. 12. pp: 53-62

Fink, William B. (Jr). and Aulenbach, Donald B. (2006). Protracted recharge of treated sewage into sand part ii. Tracing the flow of contaminated ground water with a resistivity survey. Groundwater. Vol. 12, Issue 4.

Finkelman, R.B (1995). Modes of occurrence of environmentally sensitive trace elements in coal. In Swaine, D. J, Goodarzi, F (eds) Environmental Aspects of Trace Elements in Coal, Kluwer, Dordrecht, pp 24–50.

Francis, Chester W., Boegly, Jr., William J., & Turner, Ralph R. (1982). Coal Conversion Solid Waste Disposal (Electronic Version). Journal of the Environmental Engineering Division, Vol. 108, No.6, November/December 1982, pp 1301 – 1311.

Foster, S.S.D. (1998). Groundwater Recharge and Pollution Vulnerability of British Aquifers: A Critical Overview. In: Robins, N.S. (ed) Groundwater Pollution Aquifer Recharge and Vulnerability. Geological Society, London, Special Publications, 130, pp 7-22.

George, Darren and Mallery, Paul (2010). SPSS for Windows Step by Step. A simple Guide and Reference, 17.0 Update. Tenth Edition. Boston: Allyn and Bacon.

George Waterhouse Consultants Ltd. (1991). GWC Coal Handbook.

Genesis Force Sdn. Bhd. (2002). Environmental Impact Assessment. Final Report. Proposed Mukah-Balingian Coal mine near Bedengan Area, Mukah Division.

Ghazalee, Zamzuri Hj. (2001). Laporan Penyiasatan hidrogeologi bagi akuifer cetek di SK Penipah, Mukah, Bahagian Sibu, Sarawak. (GSKL 037/27/365).

Grande, J.A., Borrego, J., Morales, J.A. and De La Torre, M.L. (2003). A description of how metal pollution occurs in the Tinto-Odiel risa (Huelva-Spain) through the application of cluster analysis. Marine Pollution. Bulletin 46: 475-480.

Gray, Colin D. and Kinnear, Paul R. (2012). IBM SPSS statistics 19 made simple. Psychology Press.

Ho, Teck June (2005). Data Mining and Data Warehousing. 2nd Edition. Prentice Hall. Pearson Eduaction South Asia Pte Ltd.

Helgen, S. O. and Moore, J. N. (1996). Natural background determination and impact quantification in trace metal-contaminated river sediments. Environmental Science and Technology 30, 129-135.

Helgen, S. and Davis, A. (2000). Quantifying Metal Contributions from Multiple Sources to the Clark Fork River, Montana, USA. Journal of Environmental Forensics.

Holzer, Thomas L (1984). Ground failure induced by ground-water withdraw from unconsolidated sediments. Man-induced land subsidence. Reviews in Engineering Geology VI. The Geological society of America. Boulder, Colorado.

Hornberger, G. M., Raffensperger, J. P., and Eshleman, K. N. (1998). Elements of physical hydrogeology. Baltimore: Johns Hopkins University Press. 302pp.

Hubbert, M. K. (1956). Darcy's law and the field equations of flow of Underground fluids. Transactions, American Institute of Mining and Metallurgical Engineers 207:222-39.

Helperin, Alex N., Beckman, David S., Inwood, Dvora (2003). California's Contaminated Groundwater. Natural Resources Defense Council.

Ibrahim, Shaharin B. (1988). Application of Geophysical Technique in Hydrogeological Investigation of Southern Lincolnshire Limestone. PhD Thesis.

Juni, Hussien Bin Mohd. and Johari, Dorani Bin (2000). Evaluation of Coal Resources of the Balingian Coalfield Sarawak, Malaysia.

Katimon, Ayob and Mat Hassan, Abd Mutallib (1997). Field hydraulic conductivity of some Malaysian peat. Jurnal Kejuruteraan Awam. Jilid 10. Bil.1/1997. pp14-20.

Kim,J.G., Ko, K.S., Kim, T.H., Lee,G.H., Song, Y., Chon, C.M., and Lee, J.S (2007). Effects of mining and geology on the chemistry of stream water and sediment in a small watershed. Geosciences Journal, Vol.11, No.2, pp175-183.

Kowalski, J. and Janiak, Z (1983). Groundwater changes in the urban area of Wroclaw in the period 1874-1974. Relation of Groundwater Quantity and Quality. International Association of Hydrological Sciences. Pp 45-56. IAHS Publication No.146.

Kural, Orhan (1994). Coal Resources, Properties, Utilization, Pollution. Library of Congress Cord Number 93-79488.

Laporan Tahunan Geological Survey Malaysia(GSM) (1997)

Lapakko, K (2002). Metal mine rock and waste characterization Tools: An Overview. Minesota Department of Natural Resources, U.S.

Lee, J. Y., Choi, J. C., Yi, M. J. Kim, J. W. Cheon, J. Y., Choi, Y. K., Choi, M. J. and Lee, K. K. (2005). Potential groundwater contamination with toxic metals in and around an abandoned Zn mine, Korea.

Liaw Kim Kiat, Tan, V. and Jok, J.J(1995). Evaluation of the coal resources of the Merit block south, Merit-Pila coal field, Sarawak.

Liechti, P., Roe, F.W and N.S. Haile(1960). The Geology of Sarawak, Brunei andThe western part of North Borneo, with a chapter on the igneous rocks by H. J. C. Kirk: Brit. Borneo Geol. Survey Bull. 3, 1960, 358pp.

Linge, K.L. PhD Thesis. Assessment of contaminant availability in a shallow wetland. University of Western Australia, 2002.

Lindquist, E. (1933). On the flow of water through porous soil. Premier Congress des grands barrages (Stockholm), 81-101.

Liu, G.J., Wang, G.L., and Zhang, W (1999). Study on Environmental Geochemistry of the Trace and Minor elements in Coal. China University of Mining and Technology Press, Jiangsu.

Malaysian Health Ministry (2000). National standard for drinking water quality. Quality surveillance Unit, Engineering Services Division. Putrajaya, Malaysia.

Malim, Muhammad Rozi and Halim, Faridah Abdul (2011). Business Statistics. Oxford University Press

Marghade, Deepali, Malpe,D.B., Zade, A.B.(2010). Assessment of groundwater quality in landfill area ofNagupur city, central India. Journal of Environmental Hydrology. Volume 18

Mailvaganam, Yogeswaran (1984). Managenese 'Pollution' of the Bintulu water Water supply. GSKL422/2/(26)

Matthess, R., Oetting, R., Schiltz, M., and Werner, H(1982). Effect of coal mine wastes of Nordrhine-Westphalia on groundwater. Effect of Waste Disposal on Groundwater and Surface Water. !AHS Publ.no.139. pp 271-278.

Meyers, M. B., Swart, P.k., and Meyers, J.L(1993). Geochemical evidence for groundwater behavior in an unconfined aquifer, South Florida. *Journal of Hydrology* 148: 249 – 272.

Nash, H. and McCall, G.J.H.(1995). Groundwater Quality. 17th Special Report. Chapman and Hall.

Nugraha, C., Shimada, H., Sasaoka, T., Ichinose, M., Matsui, K., and Manege, I(2009). Waste rock characteristics at tropical coal mine area: A case study of PT.Kaltim Prima Coal, Indonesia. Department of Earth Resources Engineering, Kyushu University, Fukuoka 819-0395, Japan. Environment Department, PT. Kaltim Prima Coal, Sengata, Indonesia. International Journal of the JCRM. Volume 5, No.2

Oversea Petroleum and Investment Corporation(OPIC)(1991). Drill hole log in Mukah.

Ramli, Mohd. Zailon bin (1984). Reporrt on pumping test in the Peninpah area, 3rd Division, Sarawak. Jabatan Penyiasatan Kajibumi Malaysia Sarawak

Rattan, R.K., Datta, S.P., Chhonkar, P.K. and Singh, A.K. (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater-a case study. Agriculture, Ecosystem and Environment. Volume 109, Issues 3-4, pp310-322. Elsevier

Reddy, M. M., Reddy, M. B.,Kipp, K. L., Burman, Aaron, Schuster, Paul and Rawik, P. S (2008). Peat porewater chloride concentration profiles in the Everglades during wet/dry cycles from January 1996 to June 1998: *Hydrology Process* 22. 1713 – 1724

Romanowicz, E. A. , Siegel D. I. and Glaser, P. H (1993). Hydraulics reversals and episodic methane emission during drought cycles in mires. Geology 21: 231- 234

Rumbaugh, O.James and Rumbaugh, B.Douglas(1998). Microsoft Windows® based Groundwater Vistas® (GV) version 5. Environmental Simulations Inc., Herndon, Virgina, USA

Samuding, Kamarudin., Rahman, Mohd Tadza Abd. and Yusof(2003). Teknik nuclear dalam kajian aliran tanah. Geological Society of Malaysia Bulletin 46. pp 181-185.

Sarawak Coal Resources Sdn. Berhad(2008). Drilling data records.

Sekabira K., Oryem Origa,H., Basamba, T. A., Mutumba, G., and Kakudidi, E (2010). Assessment of heavy metal pollution in the urban stream sediments and its tributaries.

Schulz, H.D & Reardon, E.J.,(1983). A combined cell/analytical model to describe two-dimensional reactive solute transport for unidirectional groundwater flow. *Wat.Resour. Res*. 19, 493-502.

Sia, S. G., and Dorani Bin Johari(2000). Evaluation of Coal Resources of the Mukah CoalfieldSarawak, Malaysia. GSKL 002/10/148.

Singer, P.C., and Stumm, W. 1970. Acidic mine drainage. The rate determining step. Science 167, 1121-1123.

Skousen, Jeffrey G., Sexstone, Alan and Ziemkiewicz, Paul F. (2000). Reclamation of Drastically Disturbed Lands. American Society of Agronomy and American Society for Surface Mining and Reclamation. Chapter 6. Agronomy No. 41.

Stumm, W. and Morgan, J. J (1981). Aquatic chemistry, 2nd ed. Wiley & Sons, Inc., New York, 780

Swaine DJ. 2000. Why trace elements are important. Fuel Process Technol 65–66: 21–23

Enjop, Sulong (1995). Laporan Penyiasatan terperinci hidrogeologi di Kawasan Bayan, Mukah,Bahagian Sibu, Sarawak.

Tiab, D. and Donaldson, E. C. (2012). Porosity and Permeability. In Theory and Practice of Measuring Reservoir Rock and Fluid Transport Properties. Petrophysics. 3rd Edition. pp: 85-219. ELSEVIER

Tie Yiu Liong and Kueh Hong Siong(1979). A review of lowland organic soils of Sarawak. Technical Paper no.4. Research Branch, Department of Agriculture Sarawak.

Todd, D.K (1980). Groundwater Hydrology. Second Edition. John Wiley and Sons. New York Chiclester Brisbane Toronto.

Troeh, Federick R., Hobbs, J. Arthur, Donahue, Roy, L. (1980). Soil and Water Conservation. For Productivity and environmental protection.

Tuan Rusli bin Tuan Mohd(2000**)**. Evaluation of Coal Resources of the West Silantek Coalfield Sarawak,Malaysia.

Xavier, A. Gama (2006). Environmental – Biochemical aspects of heavy metals in acid mine water. Technical University of Lisbon. Mine water and the Environment. International Mine Water Association.

Yadav, S.K. (2010). Heavy metals toxicity in plants: An overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants. South African Journal of Botany 76 (2010) 167–179. ELSEVIER

Yang,J.E., Kim, H.J., Ok,Y.S., Lee,J.Y., and Park, J (2007). Treatment of abandoned coal mine discharged waters using lime wastes. Geosciences Journal, Vol.11,No.2, p.111-114.

Yin, Ee Heng., 1992. Geological map of Sarawak. 2nd Edition

Visser, W.A., Crew, W.E,(1950). *Stratigraphy of Teres-Penipah-Balingian Area, Sarawak*, Sarawak Shell Oilfield Limited, GSKL 111/5.

Walton, William C. (1985). Practical Aspects of Groundwater Modelling. Flow, Mass and Heat transport and Subsidence. Analytical and Computer Models. Second Edition.

Waygood, C.,Palmer, M.,Schwab,Rod (2006). Case study on the remediation of the defunct coal Arbor colliery, in Mpumalanga South Africa. American Society of Mining and Reclamation(ASMR), 3134 Montavesta Road, Lexington,KY 40502.

WHO (1993). Guidelines for drinking water quality. Geneva: World Health Organisation.

Wiedemeier, Todd H. et al.,(1999). Natural Attenuation of Fuels and Chlorinated Solvents in the Surface. New York: John Wiley and Sons.

Wolfenden, E.B. (1960). The Geology of and Mineral Resources of the Lower Rajang Valley and Adjoining Areas, Sarawak: British Borneo Geological Survey Memoir 11.